A SIMULATION MODEL FOR MANAGEMENT OF BLACK BEAR PROBLEMS IN SEQUOIA NATIONAL PARK

Michael E. Walraven
Dept. of Forestry and Conservation
University of California
Berkeley, CA 94720

Abstract.

Property damage associated with black bears searching for and procuring foods intended for visitor consumption within developed campground areas has been a continuing management problem within Sequoia National Park. A computer model was developed to examine the relationship between seasonal changes in the quantity and quality of bear foods and the magnitude of the bear-visitor problems by simulating seasonal changes in bear distributions within major habitat types. Five habitat types were differentiated on the basis of the relative abundance of seasonally important black bear foods: manzanita berries, acorns, yellow jackets, wet meadow grasses and forbs, and visitors' food. Location of a bear in a particular habitat type was theorized to be a function of both relative abundance of all available foods and the food qualities as measured by digestable energy. Bears were assumed to maximize their net energy input by minimizing energy expended while searching and maximizing the quality of the foods ingested. Values reported in the literature were used to estimate digestability. Seasonal abundance of the different foods was estimated from 1974 and 1975 field data. Actual bear density data showed trends similar to the simulated bear distributions. Simulated bear management strategies employing relocation or permanent removal were generally ineffective as long as only poor quality natural foods were available. Reduction in campground food availability significantly reduced simulated bear numbers in the campground areas.

INTRODUCTION

The black bear (Ursus americanus) is one of the animals most often associated with national parks, evoking varying images for different people throughout North America. For some people, the black bear is a playful clown, a "Yogi Bear," providing entertainment for children and adults alike. For others, the bear symbolizes wilderness. For still others, the bear represents the unpredictable and uncontrollable danger which lurks within our national parks. The great range in visitors' feelings toward black bears, as well as a general lack of knowledge of bear behavior, leaves many National Park visitors unguarded and susceptible to property damage or personal injury resulting from black bears foraging through campgrounds in search of food. The negative interactions between black bears and human visitors within North American National Parks continues today to be a problem of major concern for the National Park Service.

Although property damage due to black bears is more common than physical injury, the latter is a tragic ending to a visitor's Park experience. Even when damages are minimal, continual exposure to black bears in the developed areas of the Parks at best leads to a decline in visitor respect for the bear as a powerful and dangerous animal and increases the probability of future injury.

While the National Park Service is charged with the goal of maintaining black bear populations in conditions that would have existed in more primeval times (Leopold 1963), it is also responsible for creating settings where the probability of visitor property damage and personal injury is minimized, thereby ensuring visitor safety and enhancing the visitors' Park experience.

Because variables in the bears' environment like food quality and quantity, are continually changing both seasonally and annually, it is difficult to evaluate the effectiveness of different types of management on black bears. To provide information that will aid in management of black bears consistent with Park Service goals, a model was developed to simulate the distribution of a bear population throughout the different seasons of the year. Data collected in Sequoia National Park during 1975 was used to initialize the model parameters. Important environmental variables could then be controlled in different simulation runs so that the effects of different bear management strategies on a bear population could be examined.

METHODS

A computer model was developed to simulate a distribution of black bears' feeding on different foods in different habitat types. Digestable energy as a measure of both food quantity and quality was used as a basis for determining how the bears apportion their feeding time. The model simulates one year at a time beginning with bear emergence from denning and ending in denning. For this reason, bear mortality could be used as a parameter in the simulations while reproduction could not. Model parameters are set with habitat data for any animal in which pursuit and capture times are negligible. These parameters can be changed to simulate different years or different locales within a region, or different regions such as different National Parks or Forests. For the purposes of this paper, the model parameters were set using data collected from Sequoia National Park with reference to black bears.

Description of the Study Area

Sequoia National Park is a 1565.59 square kilometer area located in the southern portion of the Sierra Nevada Mountains in California. The area of the Park from which the data for the model parameters was collected included Merriam's Transition and Canadian Life Zones (Ingles 1965:33-34), between 1220 and 2743 meters in elevation, and the following plant communities recognized by Munz and Keck (1959:15): yellow pine forest, red fir forest, and lodgepole pine forest. This area was considered to have the characteristics of prime year round habitat for black bears.

Data was collected between June and October during 1974 and 1975. In 1974, six different foods were identified as major constituents of the black bears diet in the Park: grass-like vegetation, forb vegetation, yellowjackets or vespids (*vespidae*), manzanita berries (*Arctostaphylos patula*), acorns (*Quercus kelloggii*), and food from campgrounds and other developed areas originally intended for visitor consumption. These foods differentiated five broad habitat types which could be recognized on the basis of life form and the degree of human development: wet mountain meadows, coniferous forest, mountain shrub, mixed conifer with oak, and campground and developed areas (Table 1).

Model Components

Rate and period of increasing or decreasing abundance for each food type, as well as changes in the energy assimilated per gram ingested, the digestable energy (DE) for each food type are, parameters set using the 1975 Park data. Food quantity (grams/-hectare) and quality (DE in kcal/hectare) are calculated at each time step. Biomass consumed by bears during each time step is subtracted from food available at the beginning of the time step, then new food inputs are added. Competition for food from other animals is handled implicitly in the simulations by maintaining each food quantity close to the values observed in the field during 1975.

For the simulations, grasses and forbes are the first foods grown, and are available during the spring and early summer. Vespids are made available in mid-July. Manzanita berries and acorns are made edible in mid-August and late September respectively. Unusual weather conditions existed in 1975 with snow still covering the meadows in June, delaying plant phenology for all bear foods by at least four weeks from what it would have been in a more normal year. This factor is taken into account in the parameters. Campground foods remain at low levels until late June, at which time they are maximized within a couple of weeks and remain at a constant high level throughout the summer until the second week in September, one week after Labor Day.

Digestability of food items (DE) was estimated from literature values (Barrett 1971, Mealey 1975) and the highest and lowest values used in the simulation are reported in Table 2. Digestability of the plant foods was changed throughout each simulation run, reflecting actual lignification of herbaceous material and ripening of mast. Campground food digestability remained constant throughout the simulation and the values used reflect consumed but undigestable wrappings and garbage.

For an animal like a black bear, which is primarily a searcher, foods should be consumed in the proportion in which they are located (MacArthur and Pianka 1966). This maximizes the amount of food ingested relative to energy expended in searching. In this model, digestable energy per hectare was calculated for each food type to estimate its occurrence or density.

Quality as well as quantity was theorized to be important in determining which foods a bear eats. In repeated feeding trials conducted with two captive black bears, the bears chose foods with a higher DE more often than foods with a lower DE (Bacon 1973). In this model, a ration between the maximum DE possible (5.0 kcal/gram) and the estimated DE for each food at each time step was used as an index of food quality.

The preference for a food type (Pref) was calculated by multiplying the digestable energy per hectare by the food quality index. The proportion of time spent on a food type was calculated as the ratio between the food preference for each type and the sum of all six of the food preferences ($PREF(I)/\Sigma PREF(I)$).

The size of the smaller habitat types, like the campgrounds, makes it difficult for all of the Park bears to utilize the foods available in these habitats given the spatial distribution of bears. In addition each habitat has a different density of the different food types. Each major habitat type has only one dominant food type except for the meadows which have both grasses and forbs. To simplify the interpretation of the model results, the proportions of a bears' feeding on different food types were multiplied

Table 1. Black bear habitats, dominant foods and area sizes used in the simulation model.

Habitat Type	Dominant Bear Food	Area (km.)
Wet Mountain Meadow	Grass-like Vegetation	8.09
	Forb Vegetation	8.09
Coniferous Forest	Vespids	121.41
Mountain Shrub	Manzanita Berries	16.19
Mixed Conifer with Oak	Acorns	16.19
Campground (and Developed Areas)	Campground Food	0.12

Table 2. Digestability of the 6 food types used in the simulations in kcal per gram.

FOOD TYPE	LOWEST VALUE	HIGHEST VALUE
Grass-like vegetation	.66	2.0
Forb vegetation	.66	1.7
Yellowjackets	4.5	4.5
Manzanita berries	.5	1.3
Acorns	.8	3.6
Campground foods	3.5	3.5

by the total number of bears used in the model (100), and used as the number of bears in that habitat for that time period. Thus, if 20 percent of the diet was campground foods, then 20 of the 100 bears were assumed to be feeding in the campground. The others would be assumed to be feeding exclusively on the other food types and in the other habitat types.

A limit on the total amount of food which could be consumed from any one habitat type at a particular time step was set at 90 percent of the total available. This acted as a carrying capacity for bears in each habitat where either food or habitat area was small, which was important in limiting the numbers of bears feeding in the campgrounds. If a limit was reached, the maximum number of bears capable of being sustained on the amount of food available in that habitat type was subtracted from the total number of bears used in the simulation. The food preference of that food type was then set to zero, and new proportions of bears in the remaining habitat types were calculated based on food preferences. This kept the model from unrealistically placing all the bears in the campgrounds when the total food in that habitat type could not supply their energetic requirements.

Simulation Runs

A time step of one day was used to keep the simulations sensitive to subtle changes in food status. The model was run for the period represented by April 1 to November 15, a total of 231 days. Field data from 1975 was used to initialize the food parameters in the model and four different simulations were run.

The first run simulated the conditions in the Giant Forest developed area during 1975. All food types were available at some point during the year. The second run simulated the 1975 conditions in Lodgepole Campground area where no manzanita berries were available during the year. Run 3 simulated 1975 Lodgepole conditions under the first management strategy; if the number of bears in the campground reached ten, then one bear a day would be permanently removed from the campground until the number of bears in the campground dropped below ten again. This strategy was to simulate successful relocation procedures as well as killing bears known to have returned to the campground following relocation. Run 4 simulated 1975 Lodgepole conditions under a second management strategy; if the number of bears in the campground exceeded ten, then the amount of food available to the bears in the form of campground food would be halved for the remainder of the year. This latter strategy was to simulate ranger patrols which warned campers of bear dangers and instructed them on how to store their food properly so that it was unavailable to the bears.

Population Estimates

In order to validate the model, estimates of bear numbers in the developed areas were made using the Jolly-Seber method (Seber 1973) on the 1975 multiple mark-release-recapture data collected from the Giant Forest developed area. Initial captures were made using a culvert trap or capture gun during 1974 and 1975. Captured bears were tagged in both ears with individual identifying markings. To overcome the problem of trap shyness which plagues most bear mark-recapture studies, visual observations were used in addition to physical recaptures. Each one week period from Sunday through Saturday, was used as a capture period. Known bear relocations were treated as captures, but not releases. If the bear returned to the area following relocation, it was considered to be a new animal in the population.

Scat Analysis

All black bear scats encountered throughout the Park between June 1 and October 26, 1975, which could be accurately dated to within one week of deposition were collected. In addition to collecting scats found accidently, scats were systematically collected every two weeks from permanent transects established in the coniferous forest habitat, mountain brush habitat, mixed conifer with oak habitat, around meadows, and around and through campgrounds. An occular estimate was used to estimate percent content of the different food types. Food content was recorded as actual volume, and summed over weekly periods. Percent volume of each food type for each week was then calculated.

RESULTS

The results of the first simulation run for the Giant Forest area are graphically displayed in Figure 1, as the average number of bears associated with each food type for each one week period. Between the weeks of June 1-7 and July 6-12, there is a decrease in feeding on grasses and an increase in bear feeding on campground foods. This corresponds with an increase in the availability of camper foods and a decrease in the digestability of grass-like vegetation due to lignification.

Forbs remain more succulent and digestable than the grasses as the summer progresses and feeding on forbs remains high until the week of July 19-26, when vespid nests begin to become available. The results show vespids to be the dominant food during the late July and August period.

Ripe manzanita berries become readily available during the week of August 24-30. The simulation results show feeding on manzanita berries increasing during the week of September 1-6 while feeeding on vespids and campground foods decreases. By September 7-13, human visitation in the Park begins to decrease, decreasing the density of campground foods. At the same time, manzanita berry availability and digestability peaks and feeding on manzanita berries reaches its highest level. Feeding in campground areas continues to decrease until the end of September at which time the campgrounds are virtually empty again. By late September, the acorn crop has begun to ripen and bear feeding shifts from berries and vespids to acorns.

Figure 2 shows the results of the scat analysis for the 411 dated scats. The vertical axis represents the percent volume of each of the six main food types. Note the similarity in the general trend of the curves in Figures 1 and 2.

Figure 3 shows the results of the Jolly-Seber population estimate for the Giant Forest developed area for 1975, compared with the average number of bears feeding in campground areas from the first simulation run (Figure 1). The number of hectares used for the developed areas in the simulation was approximately three times the actual hectares in the Giant Forest Developed area.

Management Options

The weekly averages of the numbers of bears feeding on campground foods resulting from Simulation Runs 2, 3, and 4 are shown in Figure 4. Simulation Run 2, in which no bear management was used, is in fact quite similar to Simulation Run 1 (Figure 1) for the developed areas, except that no manzanita berries were available in Run 2. Consequently, the decrease in bear numbers feeding in the campground areas is delayed by one week which corresponds to the emptying of the campgrounds during the week of September 7-13. Note that in Run 2, an increase in the availability of yellow

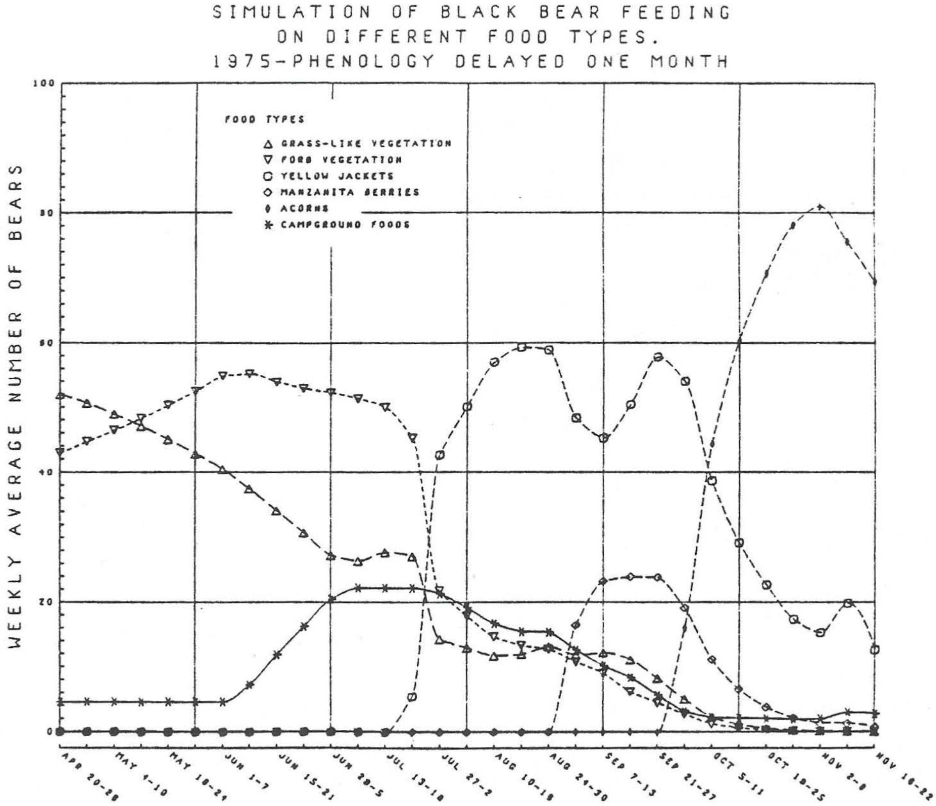

FIGURE 1. Simulation of black bear feeding distributions on different food types for Giant Forest area 1975.

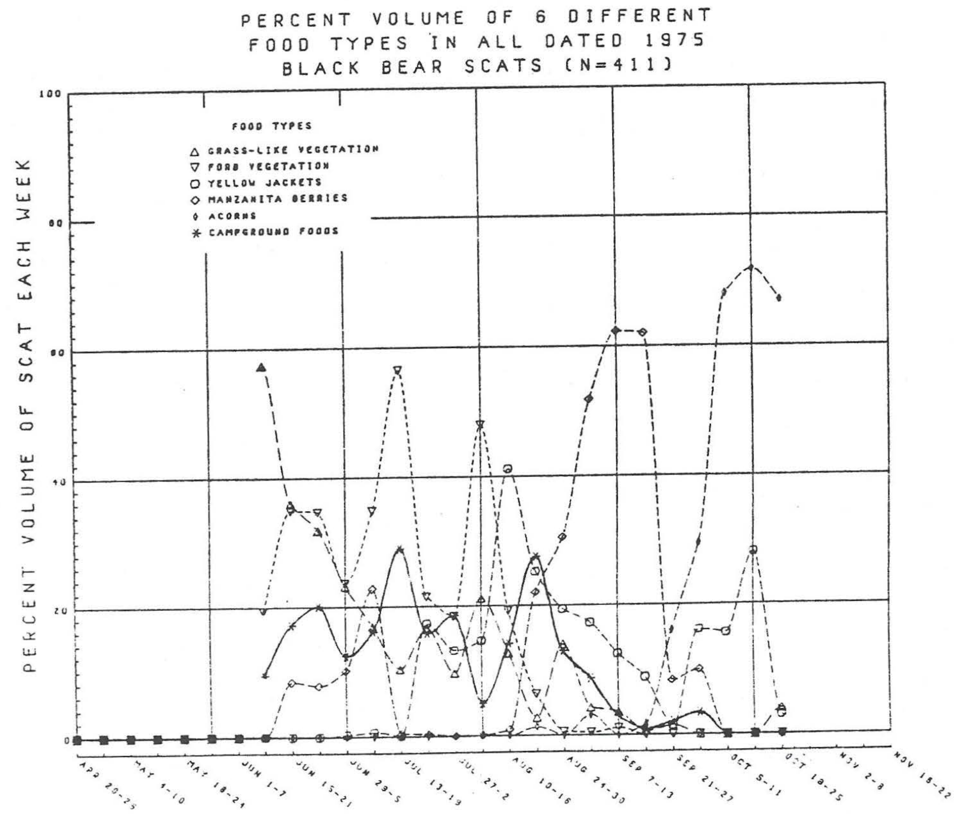

FIGURE 2. Percent volume of the 6 major bear food types in all dated black bear scats collected during 1975 broked down by weeks.

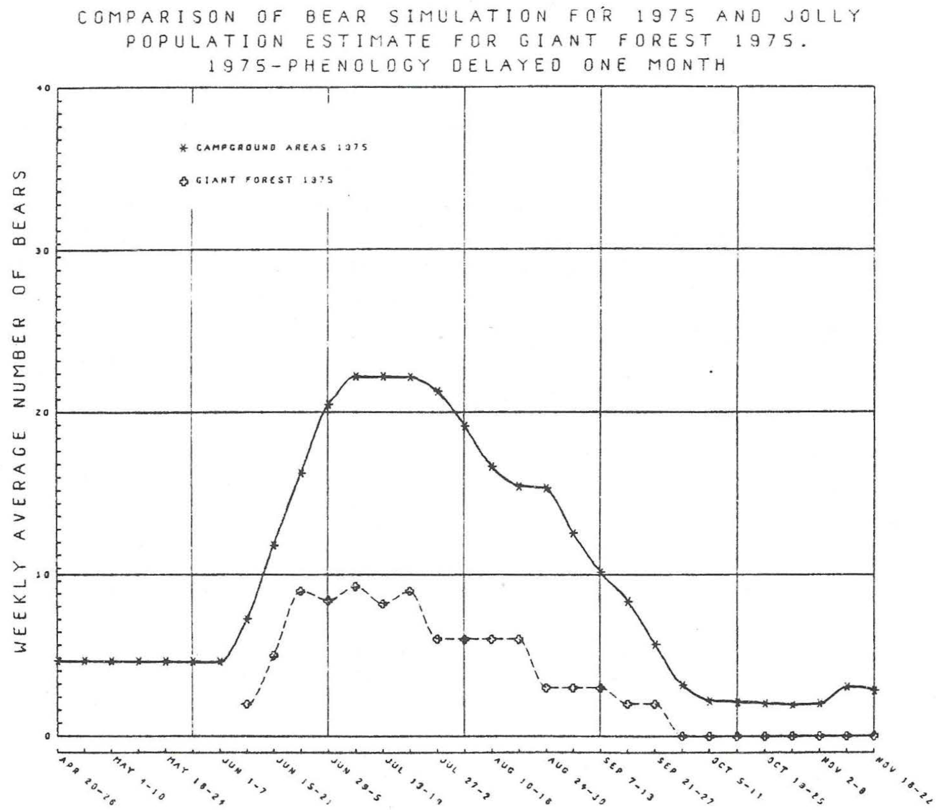

FIGURE 3. Comparison of the bear simulation for campground areas using Giant Forest area conditions in 1975 with the Jolly-Seber population estimates of the bears in the Giant Forest developed area for 1975.

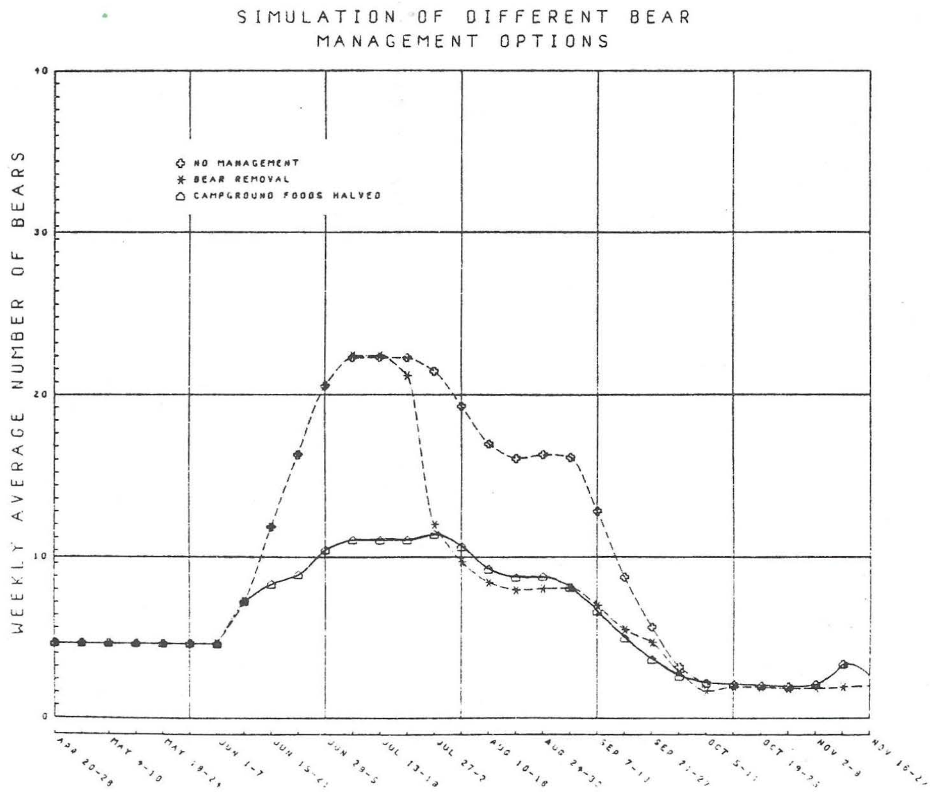

FIGURE 4. Comparison of the 3 simulated management strategies for the developed areas using the 1975 Lodgepole area conditions.

jackets decreases the number of bears feeding in the campground areas from 22 to 16 without the use of any bear management.

The results of Simulation Run 3, which permanently removes one bear from the population each day the number of bears in the campground areas is greater than ten, show bears numbers increasing over the threshold of ten during the week of June 15-21. An actual decrease in the number of bears feeding in the campgrounds does not occur until the week of July 20-26, when vespids become available. At this time, 40 bears had been removed from the bear population which initially numbered 100. Removal of bears continues for an additional ten days before bear numbers in the campground drops below ten again, leaving only 50 bears or half the intital population.

The final simulation, Run 4, in which the campground food available to bears is halved when bear numbers exceed the threshold of 10, shows that during the period prior to the increase in vespid abundance (June 15-July 27), reducing the campground food source is a more effective method of reducing the number of bears in the campground than permanent removal. During the remainder of the season, the management option in which campground food is halved results in a reduction in the number of bears in the campground similar to the permanent removal of 50 bears. However, using the former option, 100 bears remain in the population at the end of summer.

DISCUSSION

Because the black bear relies on stored energy through the winter months while denning, year-to-year survival depends heavily on adequate fat deposition during the late summer and fall months, as well as adequate food supplies when the bear emerges from denning in the spring. The black bear is a generalist feeder, consuming all palatable foods locally available (Hatler 1967, Murie 1937, Tisch 1961), seasonally switching from one food source to another (Beeman 1971), and from one habitat to another (Beechum 1976, Jonkel and Cowan 1971). The relationship of bears to their food is fundamental to understanding black bear behavior and ecology and is a key factor for any future attempt to manage bears in National Parks.

MacArthur and Pianka (1966) theorized that an animal primarily adapted to searching for foods which required little pursuit, should consume the different food types in proportion to the rate in which they are encountered. In this model, the density of assimilatable energy of each food weighted by a quality factor was used as the basis for distributing bear feeding on the different food types. To simplify the model, it was assumed that the bears environment was homogeneous or random with respect to food distribution. However, Sequoia National Park is characterized by extreme patchiness of habitat types and associated food types. Grass-like vegetation and forbs may be relatively homogeneous or random in distribution within a mounatin meadow, but a mountain meadow and manzanita patch may be separated by a kilometer or more of coniferous forest containing little or no grass-like vegetation, forbs, or manzanita berries.

Whereas, density of food is the major criteria for searchers in a homogeneous or random environment, MacArthur and Pianka (1966) suggest that the strategy for searching patchy environments should be based not only on the food density in the different patch types, but the travel time required to move from one patch to another. Because each food type except for the grasses and forbs occur in different habitat types, food density for each patch type (or in this case habitat type) is the density of the food type used in the model. Even though travel time between patches was not considered, there appears to be a good fit between the model and the 1975 data.

The results of Simulation Run 1 (Figure 1) show the same general trend as the results obtained from the scat analysis (Figure 2). Manzanita berries appear to be more important in the analysis than in the simulation while vespids appear to be more important in the simulation. However, vespids contain approximately three times the quantity of digestable energy per gram as manzanita berries; thus the energy assimilated from the manzanita berries found in the scats, relative to the vespids in the scats would be as shown in Figure 1. Adjusting the percent volumes in the scat analysis for manzanita by dividing by a factor of 3 and for vespids by multiplying by a factor of 3, the Pearson-correlation-coefficient between the weekly average number of bears for the six food types in Simulation Run 1 and the weekly percent volume of the food types in the scats is r =.73.

The correlation between the number of bears in the campground areas from Simulation Run 1 and the Jolly-Seber population estimates for the Giant Forest developed area is r =.925, indicating that the model is a good fit of the bear population estimates calculated from the 1975 data. Further examination of the 1975 conditions will be necessary to understand why the model predictions are so close to the 1975 data, even though the model uses no data on travel times between habitat patches.

In the early summer, due to low visitation rates, campground foods are in low densities, supporting a few bears, but non adequately. Thus, for most bears, only the meadows have available food, while a few bears' search must include campgrounds and meadows. Many bears appear to spend the entire spring and early summer at a single meadow. The meadows contain a mixture of grass-like vegetation and forbs, so that the calculated preferences used in the model, with no travel time considered, are good predictors of the actual condition. Even when the campground foods increase in availability, they are still limited, so that alternative food sources like meadows must be searched regardless of travel time.

By late July, vespids occurring predominantly in the coniferous forest, are the preferred food. The other habitats, mountain meadows, mountain shrub, and campgrounds, are relatively small patches in size in comparison to the forest. Time required to search each of the non-forest areas is relatively small. Because these patches are distributed throughout the coniferous forest, it may take less time to continue searching through them than to go around them. This is not true of the meadows which by late summer have very poor quality food. It may be more efficient energetically to go around the meadows. During this period, the bear may be acting as if there is little or no habitat structure, and the food types are randomly distributed throughout the forest in general. In addition, the model is based solely on energetic principles, not nutritional needs. Need for a balanced diet may necessitate searching multiple habitat types. The model appears to fit this late summer data well, indicating that one or several of the above hypotheses are acting.

By fall, bear interest has shifted primarily to the oaks, which are a considerable distance from some of the developed areas (2-3 kilometers). In this case, travel time from the coniferous forest patches which have abundances of oak to the camping areas may be significant in determining which habitat a bear will search, making this model inappropriate. However, for 1975, the acorn crop did not mature until the campgrounds had emptied of visitors. There was therefore no reason for the bears to travel between the two habitat types. In contrast to 1975, and 1974 acorn crop ripened before Labor Day. Bears were not observed in the Lodgepole campground for the entire week before Labor Day, even though the campground was packed and food readily available.

It appears likely that under certain conditions like early acorn ripening, when different habitat types are widely spaced, this model may be incomplete.

Future bear research and model development should examine the effect of habitat size and travel time between habitats on bear feeding behavior. With large scale habitat manipulation now taking place in the form of logging and timber regeneration on National Forests as well as prescribed burning and let-burn policies in the National Parks, research on habitat size and distribution is vitally important. It is conceivable that negative changes in habitat size, quality and distribution could affect not only National Park black bears, but all black bear populations, further aggravating current bear problems.

Although this model may be incomplete for certain situations, management problems with bears are least when the acorns are available. It is in the summer, when the bear model and data are relatively isomophic, that examination of the simulation management strategies may prove insightful for future bear management. The results of the management option simulations for the Lodgepole campground (Figure 4) lead to a conclusion that reduction of food available to bears in the campgrounds is a more effective means of reducing bear numbers in that habitat type as long as only forbs and grass-like vegetation are the only naturally occurring bear foods available. During the period when other foods are available, limiting campground food availability is at least as effective a management technique as permanent bear removal. Decreasing the food supply in the campground areas has intuitive appeal as well; it is merely a reduction in the campground carrying capacity for bears.

The original numbers of bears in the Sequoia National Park area is unknown. Outside the Park boundaries, the density of black bears has been greatly reduced by hunting, making the Park population in many respects an island population. Although this Park has never killed large enough numbers of bears so as to endanger the populations' ability to recover, it is not impossible to envision the negative effects which a misguided bear management effort could have on the population in the course of several years. If there were successive years of failures of important natural bear foods, which led to many bears foraging in the campgrounds, coupled with bears leaving the Park and foraging on privately owned lands outside the Park where they would be subject to heavy hunting pressure, a permanent bear removal management strategy could have severe effects on the Park bear population by reducing it to dangerously low levels.

Regardless of the method used to physically remove bears from the campgrounds, "consumer demand" among bears for campground foods will remain high as long as the only available alternative foods are of poor quality. Removal of each bear from the campground leaves a space for another to enter. Figure 4 indicates that the permanent removal strategy will not work until there is a shift in food availability.

Although the numbers of bears in and around a campground is not apriori correlated with amounts of damage, there does appear to be a relationship between numbers of bears in the campground areas and the numbers of visitor complaints of bear damage. A decrease in the number of bears feeding on campground foods should decrease damage and improve visitor safety.

This model does not differentiate between each individual bear's potential for causing damage, therefore interpretation of these management simulation should be tempered. Some bears may cause more damage than others. Identification and removal of these animals may result in less overall damage if less damaging bears replace the relocated bears in the campgrounds. However, the reverse is also possible. The bear that is removed may have been specializing by breaking into only those cars containing food. The replacement bear may be more of a generalist and break into all cars regardless of whether they contain food or not, resulting in an increase in damage.

How can relocation be used in a positive manner? This model assumes that all bears have perfect knowledge; it assumes that the bears always know the availability and location of all foods in the Park. If a previously unavailable food ripens or becomes available, but is locally absent from the area around the campground, there may be a delay in bears switching to the new food. During this time, relocation could expose the bears to the new food source and accelerate the switch from the campground foods. This would be especially important in cases when the new food occurs in habitats which are not within or adjacent to the current home range of the bears.

CONCLUSIONS

In the past century, solutions to wildlife management problems have often required the management of habitats. The black bear problems in the National Parks should now be added to the list. Creation of new habitat types in the form of campgrounds, has resulted in increased contact between humans and bears. Increased visitor safety and maintenance of bears in pristine conditions consistent with park Service goals requires the active management of these habitats containing significant densities of visitors. Decreasing the quantity of foods originally intended for visitor consumption and now available to black bears is fundamental to a reduction in the bear problem.

LITERATURE CITED

Amstrup, S.C. and J. Beecham. 1976. Activity patterns of radio-collared black bears in Idaho. J. Wildl. Manage. 40(2):340-348.

Bacon, E.S. 1973. Investigation of perception and behavior of the American black bear (Ursus americanus). PhD. Dissertation. Univ. of Tennessee, Knoxville. 161 pp.

Barrett, R.H. 1971. Ecology of the feral hog in Tehama County, California. PhD. Dissertation. Univ. of California., Berkeley. 367 pp.

Beeman, L.E. 1971. Seasonal food habits of the black bear (Ursus americanus) in the Smokey Mountains of Tennessee and North Carolina. M.S. Thesis. Univ. of Tennessee, Knoxville. 58 pp.

Hatler, D.F. 1967. Some aspects in the ecology of the black bear (Ursus americanus) in interior Alaska. M.S. Thesis. Univ. of Alaska, College. 111 pp.

Ingles, L.G. 1965. Mammals of the pacific states. Stanford Univ. Press, Stanford, California. 506 pp.

Jonkel, C.J. and I. Mct. Cowan. 1971. The black bear in the spruce-fir forest. Wildl. Monogr. 27:1-57.

Leopold, A.S. et. al. 1963. Wildlife management in the National Parks. Trans. N. Amer. Wild. and Nat. Res. 28:29-42.

MacArthur, R.H. and E. Pianka. 1966. Optimal use of a patchy environment. Amer. Natur. 100:603-610.

Mealey, S.P. 1975. The natural food habits of free ranging grizzley bears in Yellowstone National Park, 1973-1974. M.S. Thesis. Montana State Univ., Bozeman. 158 pp.

Munz, P.A. and D.D. Keck. 1968. A California flora. Univ. of Calif. Press, Berkeley. 1681 pp.

Murie, A. 1937. Some food habits of the black bear. J. Mammal. 18(2):238-240.

Seber, G.A.F. 1973. The estimation of animal abundance. Griffin, London. 506 pp.

Tisch, E.L. 1961. Seasonal food habits of the black bear in the Whitefish Range of northwestern Montana. M.S. Thesis. Montana State Univ., Missoula. 108 pp.