How Many Top Carnivores Can Black Rock Forest Support?

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ABSTRACT

The purpose of this exercise was to quantify the potential amount of usable energy available to the top carnivores in the Black Rock Forest. In determining this result, the estimates of potential energy amounts available at lower trophic levels were established. This data is important for educational purposes. This knowledge can be applied in other areas of research aside from the ones made by ecologists. One can apply a similar exercise in order to calculate typical human energy uses, such as quantifying how much energy an apartment building in Manhattan uses over a similar period. The following data stream was taken from the "Data Harvester" at http://ingrid.ldgo.columbia.edu/SOURCES/.BRF/.Weather. The PAR (amount of radiation that plants can readily use for photosynthesis) values for May through September in 1998 was used. The influx of solar energy is utilized by primary producers to create biomass and is also used to determine the potential amounts of energy available to support various trophic levels. However, quantifying the amounts required unit conversions. A multiplier was used to convert the units that the PAR values were recorded in for determining biomass production. Results from this exercise showed that the potential amount of energy for green biomass production at Black Rock Forest is 6.07973E+11 Joules/year. At the herbivore trophic level, this amount was determined to be 6.07973E+10 Joules/year. In the primary and secondary (top) carnivore levels, the estimates were 6.07973E+9 Joules/year and 6.07973E+8 Joules/year, respectively. The results for potential secondary carnivore production enabled the feeding need of a secondary (top) carnivore to be established. This amount was 14530562.6 calories/year, which is approximately

398098 calories/day. With this figure and the daily caloric intake of a top carnivore, it was determined that approximately 361 top carnivores can be supported at the Black Rock Forest. In

an acre of forest land at Black Rock Forest, the number of top carnivores that can be sustained is approximated 10.5.

INTRODUCTION

"Just like an economy runs out of money, so does an ecosystem runs on energy, all which comes initially from the sun" (Gosz et al. 1978). Ecology has a concern for valuable commodities through a network of producers and consumers. An ecosystem is a basic fundamental unit of nature and is comprised of a group of living organisms and the physical and chemical world in which they live. In this study, it can be thought of as being made up of plants and animals, all linked by food webs and flows of energy.

Even though the world receives an enormous amount of solar energy, its energy budget is actually pretty small. Organisms do not utilize energy directly. There is only a small portion of it that is converted by the green plants through the process of photosynthesis. This small portion of energy that is converted is known as the Photosynthetically Active Radiation. The wavelengths measured for PAR must be within 400-700 nm, which is the optimal amount that chloroplasts can convert (not all) into energy in plant cells. There are several ways to study the flow of energy in nature (Gosz et al. 1978). The method that was chosen in this exercise was similar to the broadcast approach conducted by Gosz et al., however, this exercise does not go into as great a depth of investigation as the one conducted at the Hubbard Brooks Forest. We have the data already recorded at the "Data Harvester," a web site for the Black Rock Forest that contains many data streams of different variables. The different data streams can provide plenty of information for research, unfortunately, since the data collection began in 1996, there has yet to be an analysis made with what data is available. The data stream chosen for this exercise was the Photosynthetically Active Radiation (PAR) amounts. PAR values would be able to provide some basic but vital information about a forest ecosystem such as the one at Black Rock Forest. This was a good way to begin research on the forest and to eventually determine what the ecological requirements are in order to sustain a healthy forest ecosystem. Some practical applications can be made for example, such as to assess how much hot water a collector can yield on an average day. Solar radiation is not sunlight coming directly from the sun. It comes from many directions. Some is scattered in the atmosphere, some is reflected off the ground. The combination of these two forms is called "global solar radiation." By using the average amount of global solar radiation, as seen in the box for example, we can assess how much hot water a 40-square-foot collector can make on an average day. Based on the example given, a solar collector can provide about 55% of hot water needed in a home in Los Angeles. The approach is similar to some of the approaches that will be made on this study.

The approach to this exercise is a logical one. The PAR values were recorded at various times during the day and in units of μmoles/m^2/day at Black Rock Forest. In order to quantify the amount of energy potentially available for biomass production though, there is a need to convert these units into units that are functional or practical in order for these estimations to be made. The desired units of measure are in W/m^2. A multiplier that has these desirable units must be established in order to produce fundamental estimates that are to be determined in this exercise. Some of these estimates include determining how much energy is available for total biomass production in a growing season to asses the energy potentially available for a group of top carnivores limited by a 10% ecological efficiency rate at each trophic level. The PAR data for the months of May through September (the growing season) is used because there is greatest influx of solar energy for photosynthesis during these months and it is also when climate conditions are most optimal for production (Appendices A, B, C, D, E).

With the aid of the unit converting multiplier to determine energy available for biomass production, the ultimate goal here is to establish the feeding need of a top carnivore at Black Rock Forest. If this can be determined, future management plans can be more efficient to sustain the many different organisms in this forest ecosystem.

General characteristics of food chains

All ecologists understand that all of these areas of study are interrelated. With the study of ecological food webs, the dynamics of population interactions and the patterns of trophic connections (who eats whom) among species can be made. All the animals and plants of a place are linked together with ties of eating and being eaten, what fishery biologists came to call food chains (Colivaux 16). Figure 1 shows a food chain, a chain of eating and what's being eaten that connects large and carnivorous animals to their plant food. A likely food chain might be pine trees→aphids→spiders→titmice→hawks. Organisms living in a natural ecosystem are involved in a complex network of many interconnected food chains, called a food web.

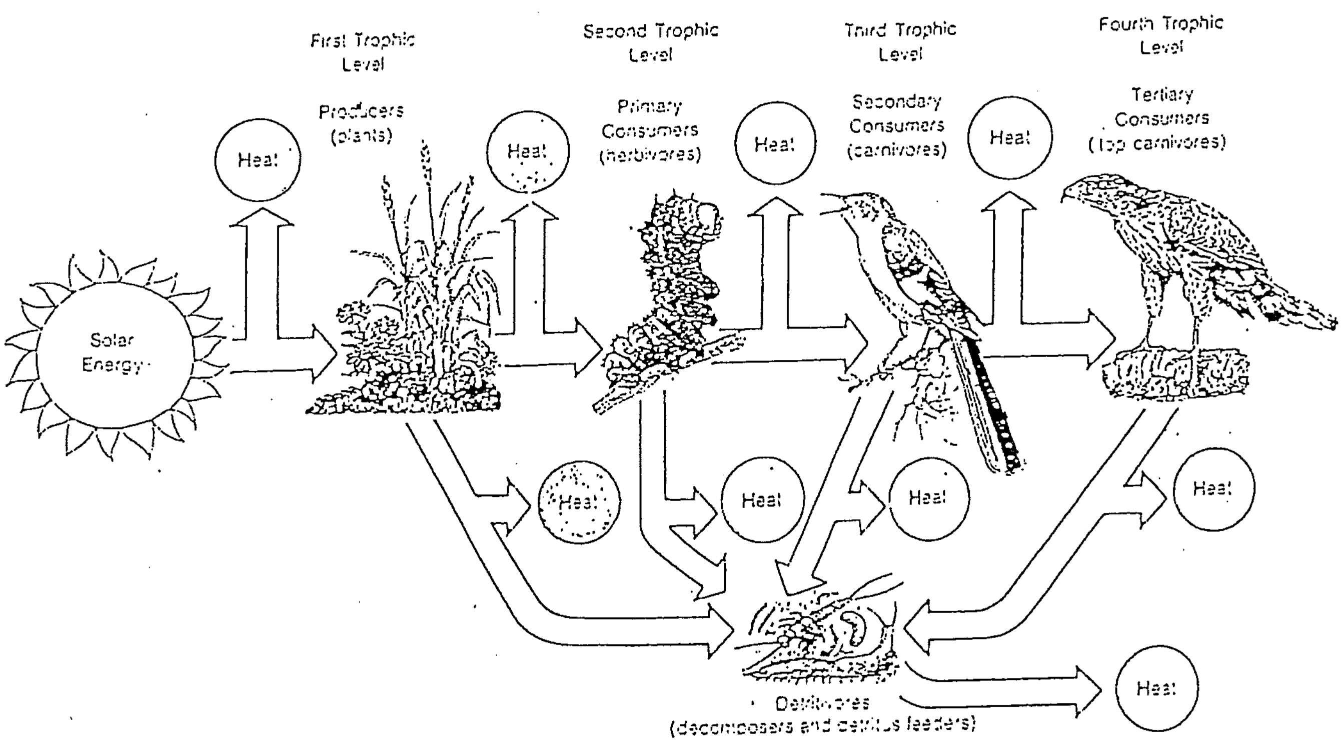


Figure 1: A food chain. The arrows show how chemical energy in food flows through various trophic levels, with most of the high-quality chemical energy being degraded to low-quality heat in accordance with the second law of energy.

Energy Flow

During each transfer from one trophic level to another in a food chain or web, work is done. An average of 10% of high quality chemical energy level available at one trophic level is transferred. Then, it is stored in usable form as chemical energy in the bodies of the organisms at the next level. See figure 2. The rest of the energy is used to keep the organism alive, and most is eventually degraded and lost to the environment. The loss of usable energy at each step in a simple food chain shows that the greater the number of trophic levels in a food chain or web, the

Figure 2:
Lindeman Efficiencies Calculated from Standing Crops ar Turnover
These estimates are in error, being too high. They are often coted, however, and they lead to the ecological rule of thumb that energy is usually transferred between tropic levels with an efficiency of about 10%. Real ecological (Lindeman) efficiencies may usually be significany lower than 10%. (From Lindeman, 1942, and H. T. Odum, 1957.)

	Cedar Bog Lake (%)	Lake Mendota (%)	Silver Springs, Florida (%)
Primary consumers (herbivores)	13.3	8.7	16
Secondary consumers (1° carnivores)	22.3	5.5	11
Tertiary consumers (2° carnivores)	No data	13.0	6

greater the cumulative loss of usable high quality energy. The rate at which plants in an ecosystem produce usable chemical energy or biomass is the net primary productivity. It equals the rate at which plants use photosynthesis to store chemical energy in biomass minus the rate at which they use some of this chemical energy in aerobic cellular respiration to live, grow, and reproduce. The net primary productivity is the amount of energy produced by the plant material in a particular area of land over a given time. It can be thought of as the basic food source of animals. Thus, green plants (the producer level) occupy the first trophic level. Plant-eaters (herbivores), make up the second level (the primary consumer level). Carnivores, which eat herbivores, make up the third level (the secondary consumer level). Finally, the secondary carnivores comprise the fourth level (the tertiary consumer level). In sum, the 10% rule means that fewer organisms can be supported at each higher trophic level, thus setting an upper limit to the length of food chains, e.g. that is why top carnivores are rare and often endangered.

Solar energy Flow

The flow of radiant energy is controlled by reflection, heat loss, evaporation, and photosynthetic use. In the Northern Hemisphere, An ecosystem has its greatest impact on energy flow during the months of June through September, or depending on how far the distance is from the equator, otherwise known as the growing season. Solar energy fixed in photosynthesis provides most of the energy necessary to drive biological functions of an ecosystem and it is also stored within the ecosystem in the form of the carbon compounds that make up ecosystem structure.

Solar radiation for photosynthesis

The plant trophic level is fueled from the sun. "Efficiency with which the plants of a community harvest energy is the efficiency with which energy is transferred into the 6-carbon sugar glucose, by photosynthesis" (Colinvaux 32). The chemical processes of photosynthesis are basically the same in all green plants and have been for over a thousand million years. Plants utilize light directly in biomass production. Through photosynthesis, light constitutes the primary source of most forms of biological energy. The sun is by far the most important source of biologically significant natural energy. The sun emits a large spectrum of radiant energies. See figure 3. About half of these are prevented from reaching the surface of the Earth by atmospheric effects, and only the radiant energies with wavelengths between 400-1000nm, the so-called "biological window," influence life processes. The energy of radiation is inversely proportional to its wavelength. Radiation of wavelength greater than 1000nm has too little energy to cause photochemical change in any available molecules; thus, no biological work can be obtained from this region of the spectrum. Conversely, radiation of wavelengths less than

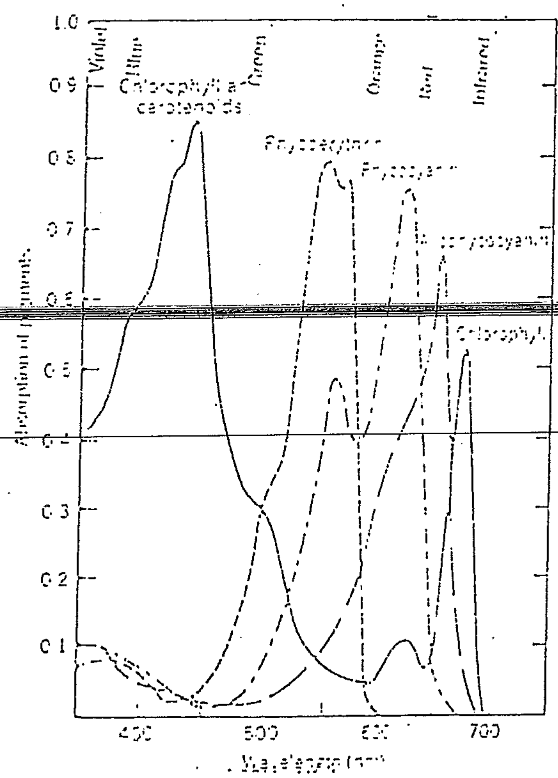


Figure 3:
Light absorption by accessory pigments of seaweeds.
The chlorophyll a and carotenoid system absorb the blue and red ends of the visible spectrum as in land plants, but brown and red algae also possess pigments that absorb light in the wavelengths reflected by chlorophyll a. Energy is passed to chlorophyll a from these pigments by resonance. (Modified from Gantt, 1975.)

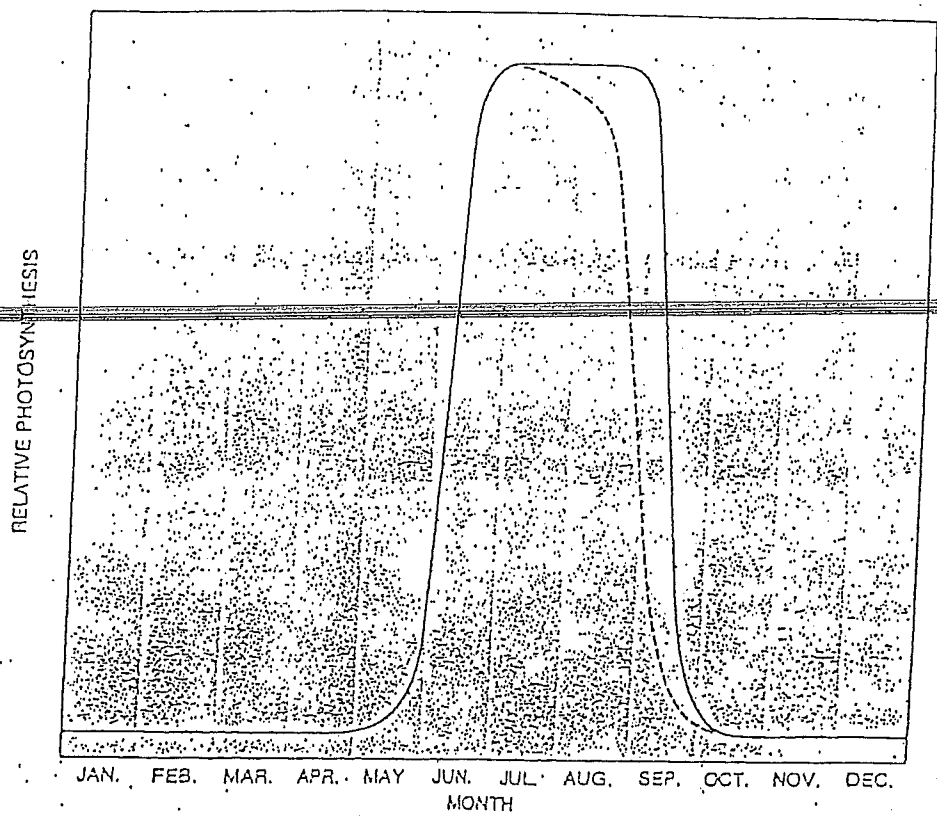
unreadable

300nm is energetic enough to break chemical bonds, and therefore highly destructive to "putative biological photoreceptors" (Hart 4). Within the optimal wavelength range, life processes are able to take place and organisms are able to survive.

Comparison with other studies

Bormann and Likens further examined the Hubbard Brook ecosystem Study. Some of their methods of obtaining data were taken into consideration while performing the Black Rock Forest exercise. As a result, it was established that this study was essential in getting a better idea of what steps can be taken to obtain the desired results and also provided more information on forest ecosystems that may be useful for further research. Bormann and Likens used this information to present data and propose hypotheses that characterize structural, functional, and dynamic aspects of the aggradation and reorganization phases. Brooks studies were made predominantly in the Hubbard Brook Experimental Forest which was a basal area of study approximately 24-m^2/ha, while in northeastern forests, 28-m^2/ha is representative of second-growth (after clear cutting). Experimental Forest the studies made by Bormann were made over a 15 year period on hydrology, biochemistry, and ecology of six small watershed-ecosystems covered with second growth forest. The forest at Hubbard Brook is similar to other hardwood forests found throughout Northern New England. This study was further examined by Gosz, et al. and found that total solar radiation during the months of June-September was 480,000 kilocalories per square meter, about 1 percent of the solar energy input. This total is was not accurate however, because it included all the wavelengths of electromagnetic radiation that reached the earth from the sun. The actual should only be about .4 %. The total living plant-biomass of the Hubbard Brook forest contained 71,420 kilocalories per square meter in 1970. Leaf-eating insects, primarily caterpillars, were consuming the living plant tissues. Although other small animals such as the chipmunk or deer consumed some of the leaf tissue at or near the ground, the wide variation in the amounts consumed in different years is related mainly to fluctuations in the caterpillar population. Of the 1,485 kilocalories per square meter per year net production of foliage, the animals consume amounts mostly less than 1 percent. In most years, about 75% of the net annual production is not consumed by animals in the grazing food web or accumulated in living-plant biomass. Instead, it falls to the forest floor and enters the detritus energy pathway. The average amount entering this pathway is about 3,505 kilocalories per square meter. The route of energy transfer is mainly through the fall of leaves, branches and trunks. The organic matter falling to the forest floor is utilized by consumers in the detritus food web, including bacteria, millipedes, and certain insect larvae. In turn, these consumers serve as prey for carnivorous invertebrates such as spiders and certain

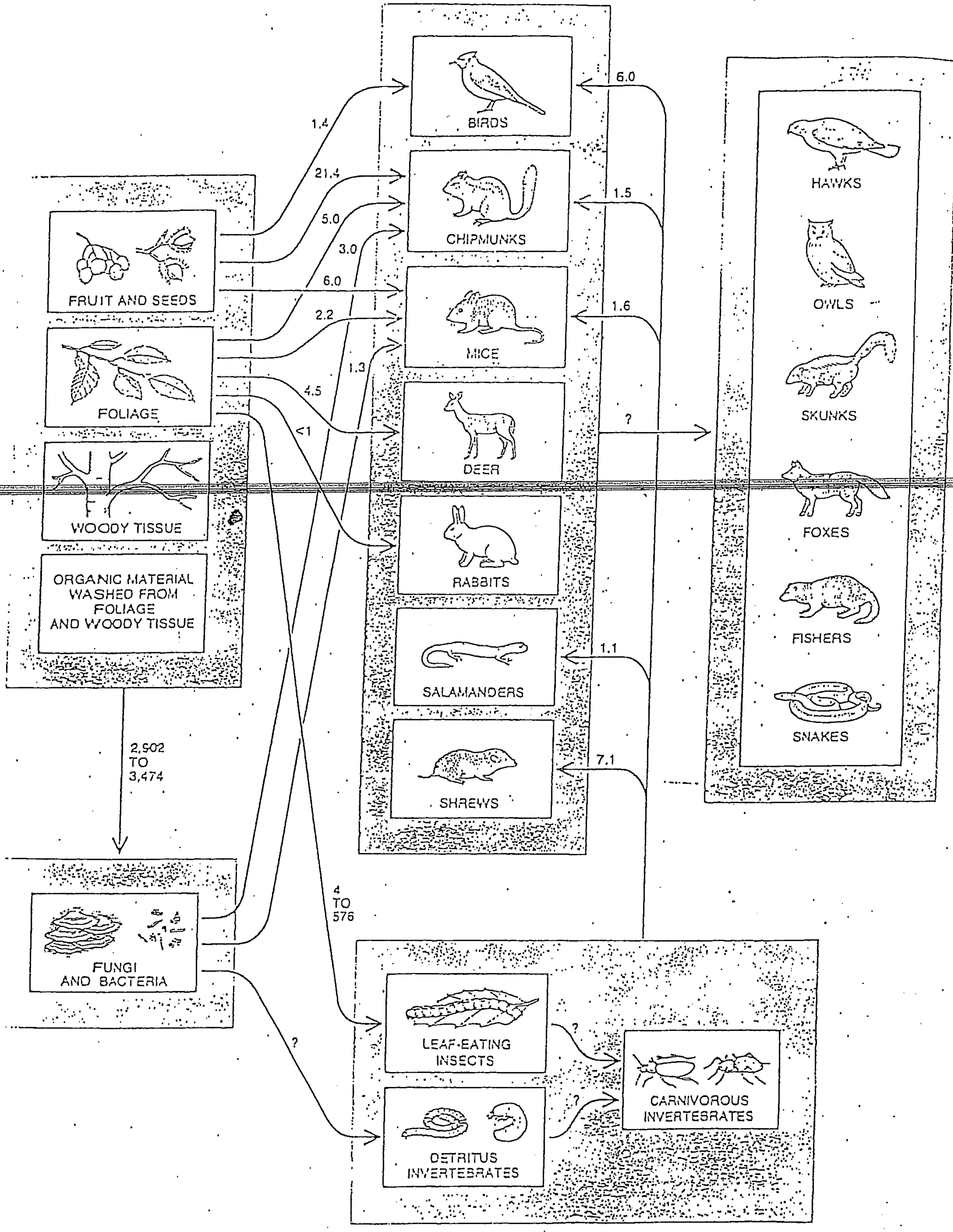
Figure 4:



PHOTOSYNTHETIC PRODUCTION by plants is not uniform throughout the year but is largely concentrated in the four-month period from June through September; during the other eight months most of the trees in northern forests are in a leafless or dormant state. The solid curve shows the relative photosynthesis in the ecosystem under favorable summer conditions; the broken curve shows it under stressed conditions, such as low moisture.

vertebrates such as rodents and salamanders. The food webs of consumers in the Hubbard Brook forest is diagrammed with the consumption rate of organisms in each population. The data in the Hubbard Brook study can be used as a guideline for the estimates to be determined at Black Rock Forest.

In another study made by Gosz et al., an analysis of energy budget of a forest ecosystem was made. Again, they have made their study at the Hubbard Brook Experimental Forest, which is operated by the U.S. Forest Service in the White Mountain National Forest of New



FOOD WEBS of consumers in the Hubbard Brook ecosystem are diagrammed, together with the consumption rate of organisms in each population. All numerical values are in units of kilocalories per square meter per year. The consumption of leaf tissue by herbivorous insects varies greatly from year to year and may have widespread effects on the utilization of energy by other consumers. In most years a large amount of organic material falls to the forest floor and enters the detritus food web, where it is utilized by fungi, bacteria and certain invertebrates. These organisms serve as food for carnivorous invertebrates, salamanders, shrews and some animals primarily associated with the grazing food web. Birds participate in the grazing food web by eating berries and caterpillars, but they also are able to tap the large detritus energy pool characteristic of northern hardwood-forest ecosystems by feeding on insects whose larvae feed on detritus.

Hampshire. Three general ways are used to look at the way energy circulates in nature. The most specific one is population analysis, which estimates a particular population in the wild. This method is very time consuming for the data is compared with demographic surveys of the population in its natural habitat to estimate how much energy the population utilizes. The second approach is a food-chain analysis. "This method can yield detailed information about how species interact to partition available energy resources, "but it provides little information about the partitioning of energy within the complex food webs of an ecosystem"(Gosz et al. 1978). Finally, the third and broadest approach is ecosystem analysis. It determines the amount of energy transferred between the different trophic levels. This approach makes it possible to draw up a balance sheet for energy flow. They determined values such as the total amount of solar radiation reached to the watershed (their test site). It was estimated that the amount was 1,254,000 kilocalories per square meter. The plants in this forest fix 55% of the energy for their own maintenance. As a result, the Net Primary Productivity (NPP) estimated for that year was about 4,680 kilocalories per square meter, or some. ?? They also determined some of the caloric needs of various organisms in the forest. Their study included more organisms than the study conducted at Black Rock Forest. The approach to much estimation in the Gosz study was much more identifiable ? to the study at Black Rock Forest.

Highlands between Newburgh and Peekskill (Appendix A). It can rise more than 180m above the adjacent lowlands and reach 400m for a maximum elevation. Forests of this region are part of the Quercus-Castanea region of the eastern deciduous forest (Maenza-Gmelch, 1). The region's climate is characterized by cold and dry air from the northern continental interior, humid and warm air from the Gulf of Mexico and subtropical waters, and maritime air originating over the North Atlantic Ocean (Maenza-Gmelch). Precambrian gneiss and granite are the two rock types that make up the bedrock geology. An environmental monitory station located in an open area near the northern edge of the forest (the Open Lowland Station) can be used to obtain the necessary information such as the amount of solar radiation received in the forest (Appendix B). Upon completing these more useful and similar conversions, total daily budgets will be obtained and this data will be used to determine how much potential energy is available at the Black Rock Forest for top carnivore consumption.

RESULTS

The multiplier was applied to the sum of the PAR daily total values, which produced a New PAR total. That total was determined to be 1102.000313 W/m^2. This value, the raw PAR values, as well as the sum of the raw PAR values can be seen on Table 1. The New PAR value can be useful in determining the total potential energy available for biomass production.

time	Photosynthetically-Active Radiation
day	µmole/m2/day
5/1/98	1161949
5/2/98	1705006
5/3/98	2215416
5/4/98	1431735
5/5/98	1454619
5/6/98	1441053
5/7/98	1623223
5/8/98	589214.7
5/9/98	160127.1
5/10/98	360817.2
5/11/98	651963.8
5/12/98	2894709
5/13/98	4326975
5/14/98	4317471
5/15/98	4176035
5/16/98	3995172
5/17/98	2504305
5/18/98	3915508
5/19/98	3634959
5/20/98	3932616
5/21/98	3212634
5/22/98	4008012
5/23/98	4664208
5/24/98	4609929
5/25/98	1649731
5/26/98	3765938
5/27/98	3672906
5/28/98	4365062
5/29/98	3508390
5/30/98	4377594
5/31/98	3413269

Table 1 (continued)

time	Photosynthetically Active Radiation
day	umole/m2/day
6/1/98	4188580
6/2/98	3733143
6/3/98	3817770
6/4/98	4215717
6/5/98	3955591
6/6/98	4426954
6/7/98	2403374
6/8/98	1977236
6/9/98	4561766
6/10/98	4599823
6/11/98	1690738
6/12/98	982939.7
6/13/98	764697.9
6/14/98	1000863
6/15/98	1342148
6/16/98	2859843
6/17/98	3065703
6/18/98	3412268
6/19/98	4270547
6/20/98	3864998
6/21/98	4121689
6/22/98	2834337
6/23/98	1320908
6/24/98	3609252
6/25/98	3438058
6/26/98	3344744
6/27/98	2205632
6/28/98	4497475
6/29/98	1904603
6/30/98	2290707
7/1/98	2854364
7/2/98	4216919
7/3/98	4166514
7/4/98	2804210
7/5/98	3524020
7/6/98	3855839
7/7/98	1878714
7/8/98	513216.3
7/9/98	3197862
7/10/98	3735635
7/11/98	3937700

Table 1 (continued)

time	Photosynthetically Active Radiation
day	umole/m2/day
7/12/98	3743663
7/13/98	4283779
7/14/98	3493605
7/15/98	2496424
7/16/98	2577954
7/17/98	2723062
7/18/98	4265692
7/19/98	3176401
7/20/98	1987472
7/21/98	3300322
7/22/98	3292876
7/23/98	2542427
7/24/98	3705880
7/25/98	2998534
7/26/98	4465059
7/27/98	3360490
7/28/98	3119732
7/29/98	2812913
7/30/98	3778980
7/31/98	3122754
8/1/98	4427032
8/2/98	4362054
8/3/98	4210006
8/4/98	3162070
8/5/98	2460512
8/6/98	3328056
8/7/98	3752808
8/8/98	4102461
8/9/98	2601818
8/10/98	1726759
8/11/98	2721285
8/12/98	3386481
8/13/98	3086696
8/14/98	1282755
8/15/98	2198652
8/16/98	2547976
8/17/98	689995
8/18/98	2050672
8/19/98	3319853
8/20/98	3190277
8/21/98	2833165
8/22/98	2632724

Table 1 (continued)

time	Photosynthetically Active Radiation
day	umole/m2/day
8/23/98	2015340
8/24/98	2789507
8/25/98	2153762
8/26/98	1884819
8/27/98	3326687
8/28/98	2871834
8/29/98	2116197
8/30/98	2949597
8/31/98	3100891
9/1/98	2986343
9/2/98	981870.7
9/3/98	2317048
9/4/98	2338023
9/5/98	2764549
9/6/98	2916018
9/7/98	872005.1
9/8/98	1871657
9/9/98	1214975
9/10/98	2204876
9/11/98	2556548
9/12/98	2208638
9/13/98	2878003
9/14/98	1316614
9/15/98	1317368
9/16/98	1156091
9/17/98	2893631
9/18/98	2846429
9/19/98	2070958
9/20/98	2267749
9/21/98	2040223
9/22/98	554523.5
9/23/98	2650146
9/24/98	2602719
9/25/98	831411.4
9/26/98	2049249
9/27/98	2328563
9/28/98	2412046
9/29/98	2565940
9/30/98	1194561

Table 1 (continued) Significant figures??

TOTAL SUM of PAR	426867180.4
NEW PAR (with multiplier)	1102.000313

Table 1. The raw PAR values for the months of May through September, which are the months in a growing season. The sum of raw PAR daily totals are determined and used to quantify the New PAR value using the multiplier. The multiplier converts the raw PAR units into desired units of W/m^2 when estimating the potential energy budgets, which are measured in Joules/year.

Table 2 reveals the amount of energy potentially available at the first, secondary, and tertiary trophic levels with the limitation of an ecological efficiency rate of 10% at each trophic level.

Trophic Level	Energy potentially available
primary producer	6.07973E+11 J/y
Herbivore	6.07973E+10 J/y
primary carnivore	6.07973E+9 J/y
Secondary carnivore	6.07973E+8 J/y

Table 2. Shows the amount of potential amount of energy available within each trophic level.

Table 3 is the estimated feeding need for a top carnivore at Black Rock Forest. Based on assumed calorie intake of a top carnivore to be approximately 1100, units?? it was determined that this forest can sustain approximately 361 top carnivores.

Secondary (top) Carnivores	No. of individual top carnivores BRF can support
*assumiption intake of 1100 calories/day	361

No. of carnivore/acre	10.48

Table 3. The number of top carnivores that Black Rock Forest can support is based on the assumption that a top carnivore consumes has a daily intake requirement of 1100 calories.

CONCLUSION

This exercise was conducted to quantify how many top carnivores can be supported at Black Rock Forest. This was determined by assessing the potential amount of energy available for biomass production. With the limit of an ecological efficiency rate of 10% in mind, the potential amount of energy at the, secondary and tertiary trophic levels can be estimated as well. In reaching the results, the multiplier that was determined to convert the PAR (Photosynthetically Active Radiation) values into units that are more "practical" and facilitate mathematical applications was applied. The New PAR total (using the multiplier) that was used to calculate the total sustainable amount of biomass was1102.000313 m^2/day. The total amount of NPP (Net Primary Productivity) or "green" biomass" that could be sustained in Black Rock Forest was calculated to be 6.07973E+11 J/y. This amount can be seen in table 1. This table also shows that the potential amount of energy available to sustain the herbivores is 6.07973E+10 J/y and the amounts of energy to sustain the primary and secondary carnivores are 6.07973E+9 J/y and 6.07973E+8J/y respectively. Table 2 indicates the amount calories that are made available to the top carnivores in Black Rock Forest. The amount was converted into units of calories from the original unit of Joules in order to work with a unit of measure that would enable the nutritional need (calorie intake) to be determined. In table 3, having assumed that there are 365 days per year and the average top consumer at Black Rock Forest consumes about 1100 calories, the total number of secondary carnivores can be determined. That number was estimated to be approximately 361, which means that per acre available at Black Rock Forest (out of a total of 3,785 acres), approximately 10.5 top carnivores can be supported.

This exercise was filled with many trials and errors in computation. Determination of the multiplier required consideration of many factors and the final results obtained are still uncertain. There are other methods to determine the multiplier and to quantify energy budgets to determine feeding needs of a group of carnivores. The methods used in this particular exercise were just a few of many methods that can be used. This exercise mostly required computations. It is possible that there was error in calculating.

DISCUSSION

The results from this exercise have shown what the amounts of biomass production were for the year of 1998 at Black Rock Forest. The New PAR value made all the calculations possible. The total amount of biomass produced at Black Rock Forest was established, which determined what the potential amounts of energy are available in the secondary and tertiary trophic levels. Each trophic level relies on 10% of energy produced by the previous level in order to survive. The amounts of biomass available could then be converted into units of calories to quantify the feeding need of a secondary (top) carnivore at Black Rock Forest. The study conducted by Gosz et al. (1978) was a similar study where the strategies of this exercise was obtained from. The energy budget in the primary producer level was obtained in a similar fashion to the total potential energy budgets of this exercise. The knowledge gained from analysis of the data can be very vital to an environmentalist. This can facilitate their research and proposals for new and improved management programs each year if the feeding needs can be determined on a yearly or daily basis. The proposals and actual implementations will be more effective and the various organisms and species needs can be tended to.

The exercise carried out here has the potential to be a guideline for future research on managing forest ecosystems similar to the one at Black Rock Forest. The "Daily Harvester" provides several types of data streams, all of which are very applicable and necessary for various areas of study, especially for modifying management plans. For example, the determination of precipitation amounts, wind speed and wind direction can be estimated for certain areas over a certain amount of time. Having this information can establish the most optimal conditions for organism and plant survival; tree pruning methods can be enhanced and introducing a new species into the forest, the information would be valuable in determining which species are best suited for a forest ecosystem similar to Black Rock Forest.

By following similar steps in the exercise just completed, further information on carnivore feeding requirements can be determined as well. This exercise lay the guidelines for future research and provided several examples of what could be determined such as what was already determined from the values that the PAR data stream. This exercise was only the beginning to what further research and knowledge acquired on this type of data and others can offer.

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APPENDIX

Appendix A: Map of Black Rock Forest

Appendix B: Trail Legend of Black Rock Forest

Appendix C: Table for Solar radiation budgets for solar water heating

Appendix D: Graph of PAR vs. Time for May

Appendix E: Graph of PAR vs. Time for June

Appendix F: Graph of PAR vs. Time for July

Appendix G: Graph of PAR vs. Time for August

Appendix H: Graph of PAR vs. Time for September

Appendix I: Total forest area

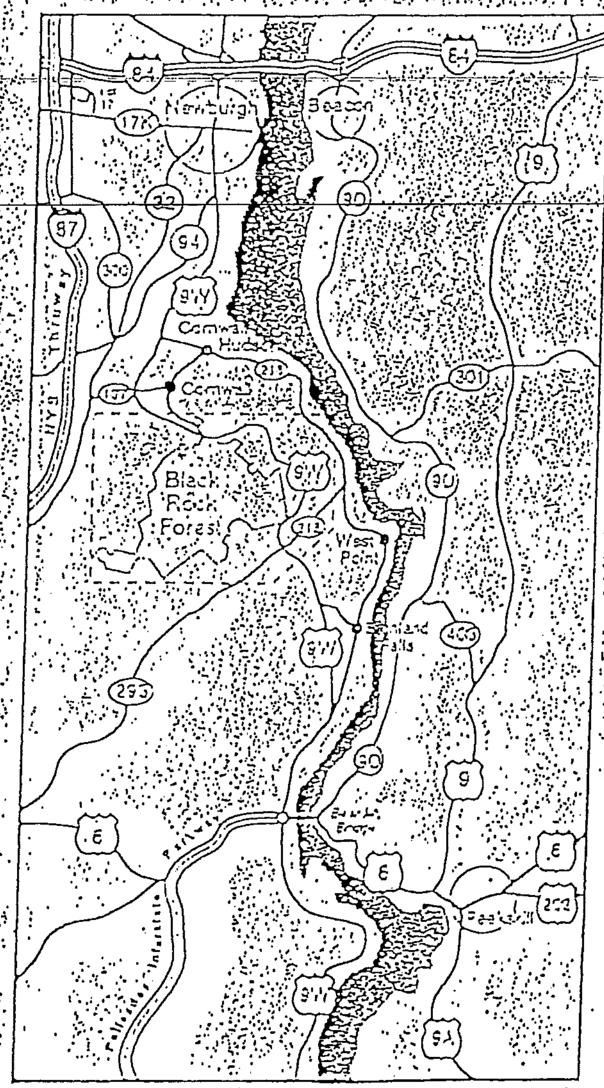
Appendix J: Multiplier for PAR values

Appendix K: Biomass production at each trophic level

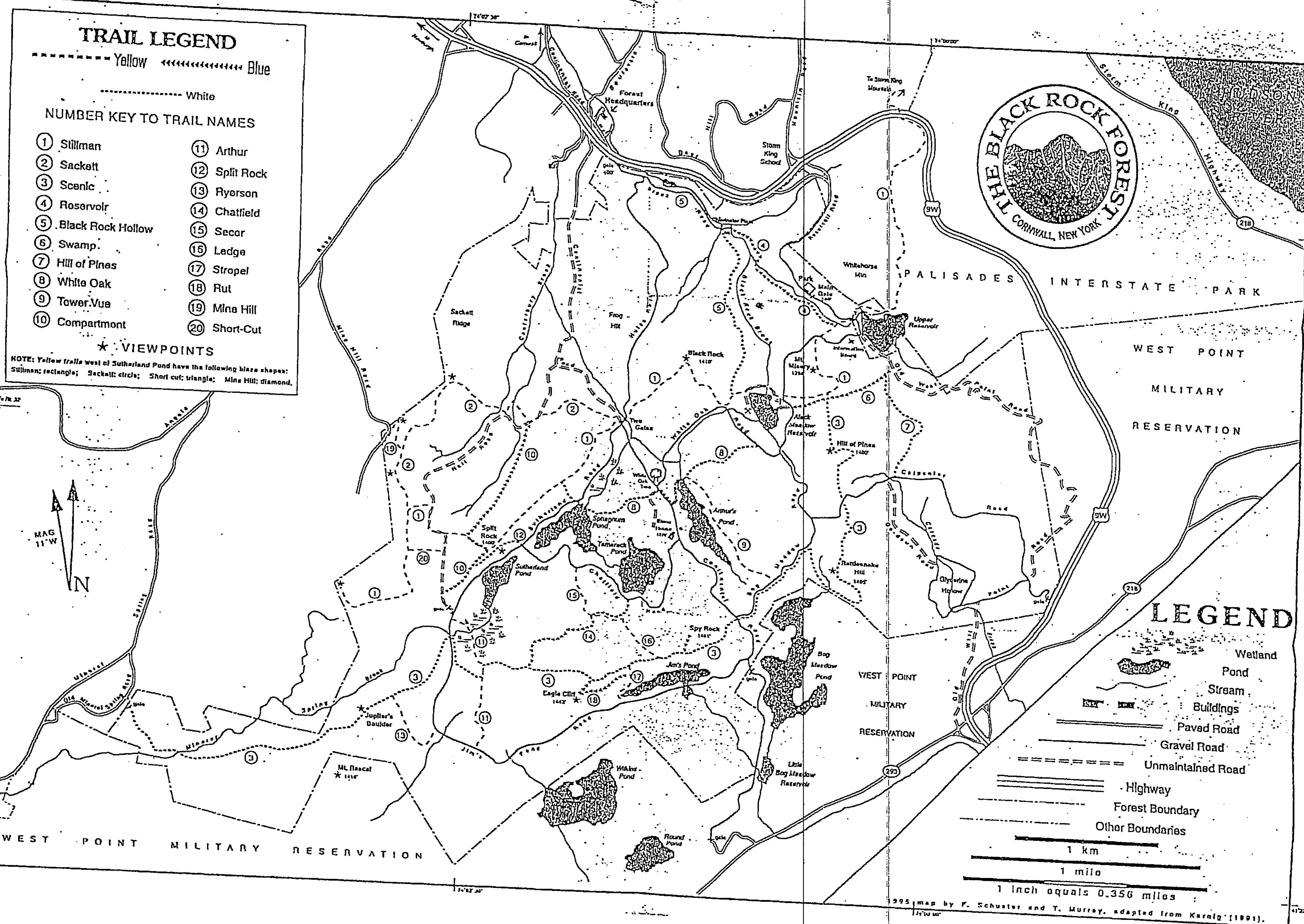
Appendix L: Feeding need of a top carnivore

Appendix A

Black Rock Forest
Index Map



Appendix B


THE BLACK ROCK FOREST
CORNWALL, NEW YORK
TRAIL LEGEND
Yellow
Blue
White
NUMBER KEY TO TRAIL NAMES
1 Stillman
2 Sackett
3 Scenic
4 Reservoir
5 Black Rock Hollow
6 Swamp
7 Hill of Pines
8 White Oak
9 Tower Vue
10 Compartment
11 Arthur
12 Split Rock
13 Ryerson
14 Chatfield
15 Secor
16 Ledge
17 Stropel
18 Rut
19 Mine Hill
20 Short-Cut
★ VIEWPOINTS
NOTE: Yellow trails west of Sutherland Pond have the following blaze shapes: Stillman: rectangle; Sackett: circle; Short cut: triangle; Mine Hill: diamond.
MAG 11°W
N
LEGEND
Wetland
Pond
Stream
Buildings
Paved Road
Gravel Road
Unmaintained Road
Highway
Forest Boundary
Other Boundaries
1 km
1 mile
1 inch equals 0.356 miles
1995 map by F. Schuster and T. Murray, adapted from Karnig (1991).
HUDSON RIVER
Storm King Highway
PALISADES INTERSTATE PARK
WEST POINT MILITARY RESERVATION
Forest Headquarters
Storm King School
Whitehorse Hill
Upper Reservoir
Sackett Ridge
Frog Hill
Black Rock
Two Gates
Black Meadow Reservoir
Hill of Pines
Carpenter Road
Split Rock
Sphagnum Pond
Tamarack Pond
Arthur's Pond
Sutherland Pond
Rattlesnake Hill
Glycerine Hollow
Spy Rock
Jim's Pond
Eagle Cliff
Bog Meadow Pond
Jupiter's Boulder
Mt. Rascal
Wilkins Pond
Round Pond
Little Bog Meadow Reservoir
Mine Hill Road
Jim's Pond Road
9W
218
293

Appendix C

Average Global Solar Radiation (for hot water panels installed at an angle equal to the latitude minus 15 degrees in U.S. cities)	
City	Daily Average Solar Radiation (kilowatt-hours per square meter per day)
Anchorage, Alaska	3.1
Phoenix, Arizona	6.4
Los Angeles, California	5.5
San Francisco, California	5.3
Colorado Springs, Colorado	5.5
Miami, Florida	5.1
Honolulu, Hawaii	5.5
Chicago, Illinois	4.4
New Orleans, Louisiana	4.9
Boston, Massachusetts	4.5
Minneapolis, Minnesota	4.6
Kansas City, Missouri	4.9
Helena, Montana	4.7
Albuquerque, New Mexico	6.3
New York City, New York	4.5
Bismarck, North Dakota	4.9
Cleveland, Ohio	4.2
Oklahoma City, Oklahoma	5.3
Nashville, Tennessee	4.8
San Antonio, Texas	5.3
Salt Lake City, Utah	5.2
Richmond, Virginia	4.7
Seattle, Washington	3.8

A typical size for a flat-plate solar collector is 40 square feet (4 feet by 10 feet), which is equal to 3.72 square meters. For a house in Los Angeles on an average day, a collector that size would receive about 20.5 kilowatt-hours of solar energy:

3.72 square meters × 5.5 kilowatts-hours per square meter per day (on average)
= 20.5 kilowatt-hours per day

Because flat-plate solar collectors are only about 35 percent efficient, the collector would produce 7.2 kilowatt-hours of heat on an average day:

20.5 kilowatt-hours per day × 0.35 = 7.2 kilowatt-hours per day

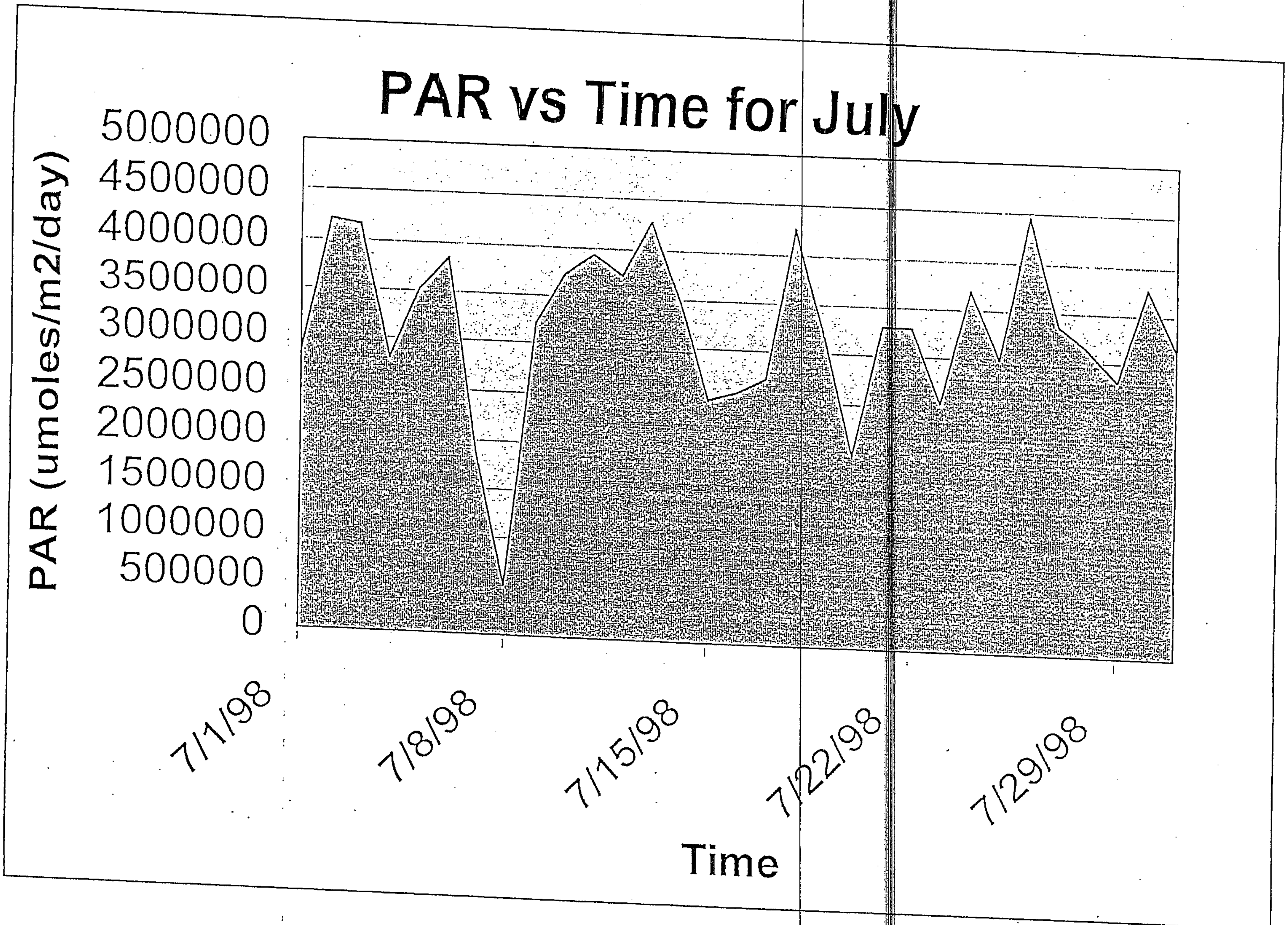
This is the equivalent of 24,500 Btu. To find out what that means, it's important to know that the average water heater starts with cold water at about 50EF (10EC) and heats it to 130EF (54EC). To do that for 1 gallon (3.8 liters) of water takes about 667 Btu, which is equal to 0.2 kilowatt-hours of heat. So in Los Angeles, a 40-square-foot solar collector (which collects 7.2 kilowatt-hours per day) could produce roughly 36 gallons (137 liters) of hot water each day:

7.2 kilowatt-hours per day ÷ 0.2 kilowatt-hours per gallon = 36 gallons per day

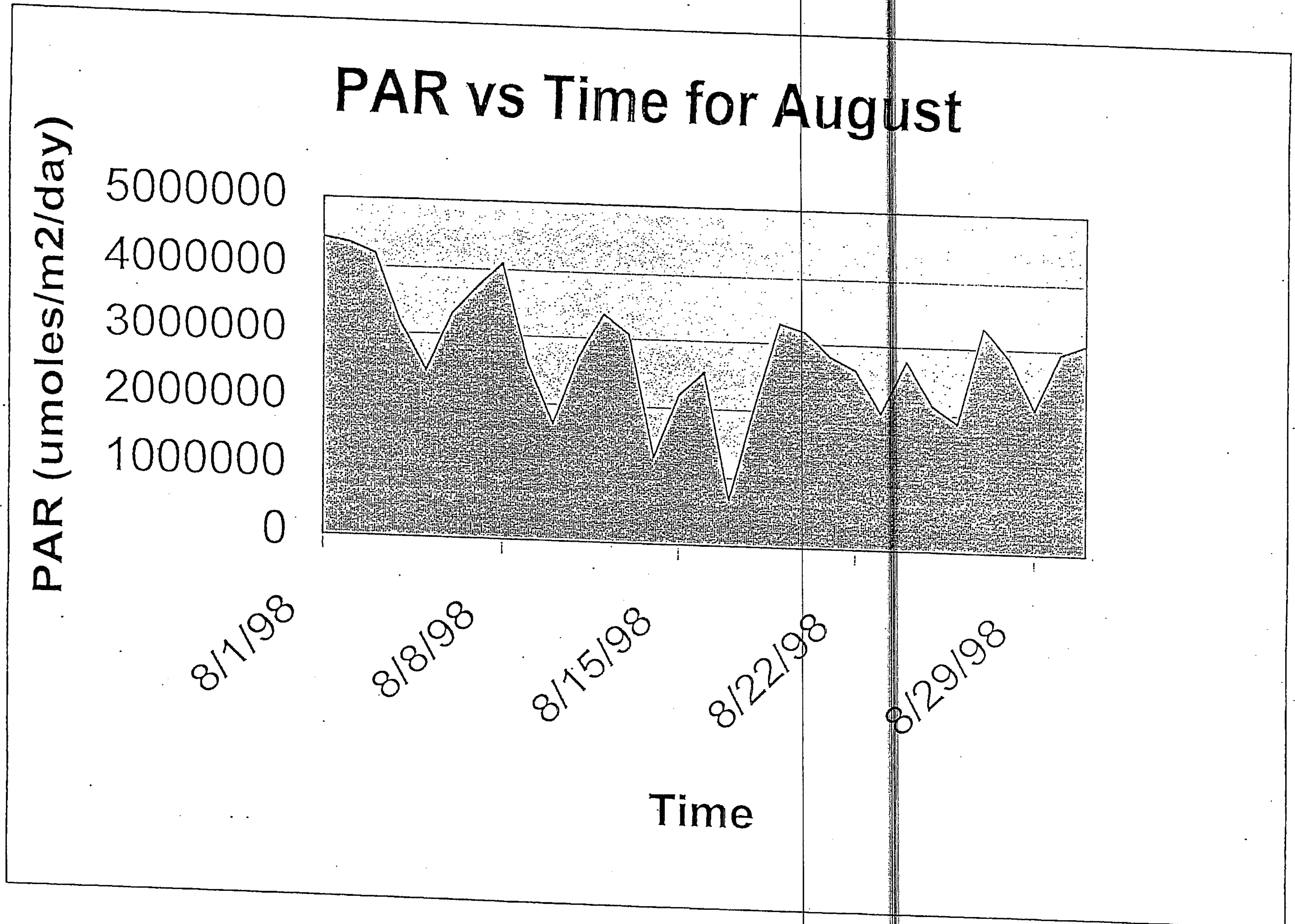
Because the average household uses about 65 gallons (247 liters) of hot water each day, one 40-square-foot solar collector in Los Angeles could provide about 55 percent of the hot water needs:

36 gallons ÷ 65 gallons = 0.55 = 55 percent

Appendix F

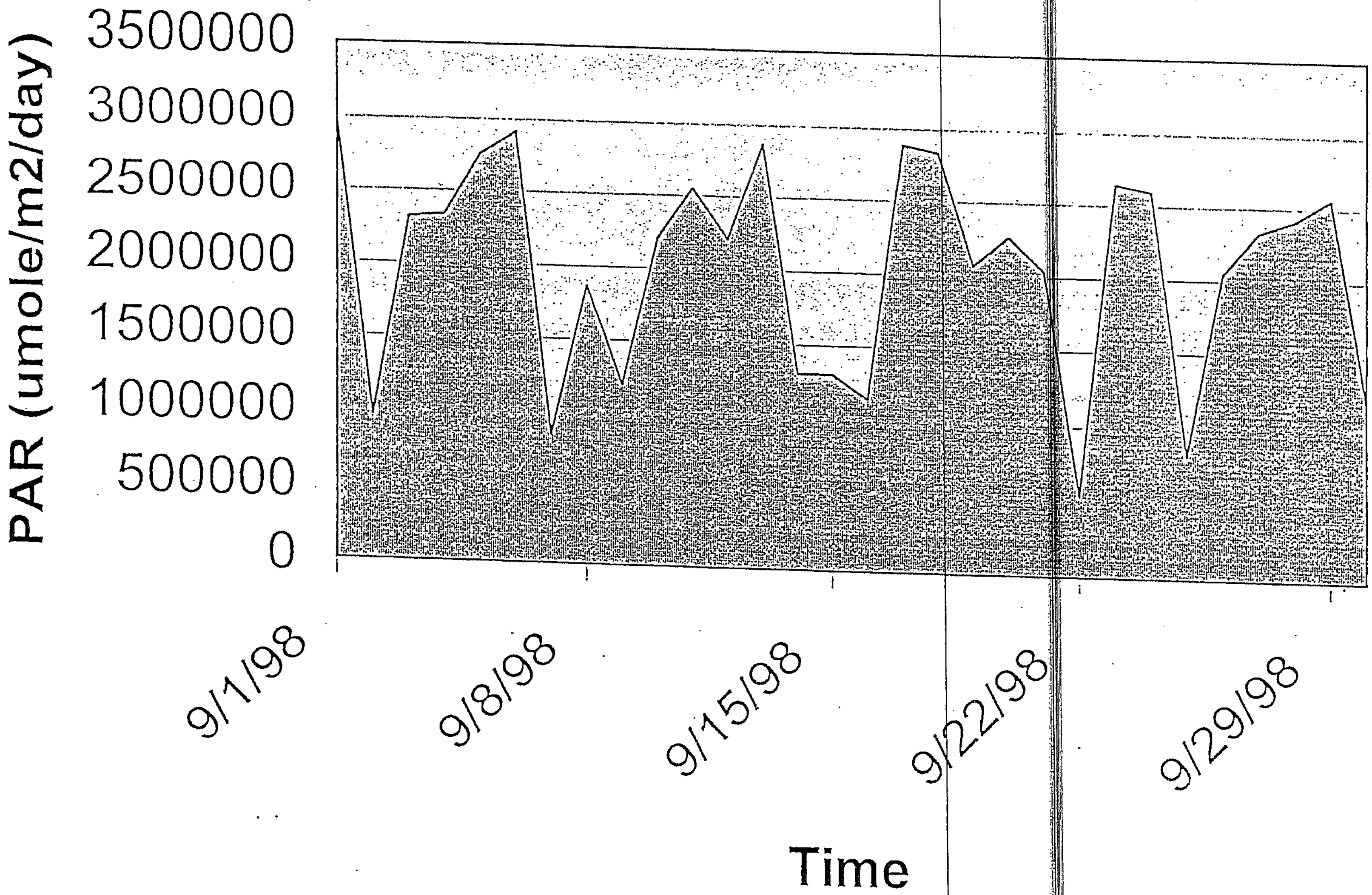

PAR vs Time for July
PAR (umoles/m2/day)
5000000
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
7/1/98
7/8/98
7/15/98
7/22/98
7/29/98
Time

Appendix G


PAR vs Time for August
PAR (umoles/m2/day)
5000000
4000000
3000000
2000000
1000000
0
8/1/98
8/8/98
8/15/98
8/22/98
8/29/98
Time

Appendix H

PAR vs Time for September



Appendix I

Total forest area:

(3,785 acre) x (43,560 ft^2/acre) = 164,874,600 ft^2

1 m^2 = 3.28 ft x 3.28 ft = (10.7584 m^2)

(164,874,600 ft^2) / (10.7584 m^2) = 15,325,197.06 m^2 ≈ 15,325,197 m^2

Appendix J

Multiplier for PAR values:

$$\frac{\mu moles}{m^2 \cdot day} = \frac{E\text{-}6\ moles}{m^2 \cdot 86400\ s} = 1.157E\text{-}11\ moles = 6.967E{+}12\ \frac{particles}{m^2 \cdot day}$$

Energy of particle:

$$E = h\upsilon = \frac{hc}{Y} \qquad h = 6.626E\text{-}34\ \frac{Joules}{sec}$$

$$c = 3E{+}8\ \frac{m}{s}$$

$$[<1/\lambda> = \frac{1}{(700\text{-}400)^*\ E-9\ m} \int_{400E\text{-}9}^{700E\text{-}9} \frac{1}{\lambda}\, d\lambda = \frac{1}{300E\text{-}9\ m}\ lu\ \lambda]_{400}^{700}$$

$$= \frac{1}{300E\text{-}9m}\ lu\ \frac{7}{4}$$

$<1/\lambda> = 1.865E6\ m^{-1}$

use 550 nm: $1.8181E{+}6\ m^{-1}$

$$<E> = \frac{hc}{\lambda} = 3.7055E\text{-}19\ Joules$$

$1\ \frac{\mu mole}{m^2 \cdot day}$ equivalent to $2.5816E\text{-}6\ \frac{W}{m^2}$

$$[W] = \frac{[Energy]}{[time]} = \frac{Joules}{s}$$

Multiplier: $2.5816E\text{-}6\ \frac{W}{m^2}$

Appendix K

New PAR total (with new multiplier):

Sum of PAR values = 42687180.4 μmoles/m^2/day

PAR total with multiplier = (42687180.4 μmoles/m^2/day) x (2.5816E-6 W/m^2)

New PAR total = 1102.000313 Joules/sec

Amount of potential energy available for each trophic level:

Primary producers:

(1102.000313 Joules/sec) x (3600 s/growing year) x (15325197 m$^{2)}$ x (0.01) = 6.07973E+11 Joules/year

Herbivores:

(6.07973E+11 Joules/year) x (0.1) = 6.07973E+10 Joules/year

Primary Carnivores:

(6.07973E+11 Joules/year) x (0.1) = 6.07973E+9 Joules/year

Secondary (Top) Carnivores:

(6.07973E+9 Joules/year) x (0.1) = 6.07973E+8 Joules/year

* Primary producers can only fix 1% of incident solar radiation
* W/ m2 = J/s
* There are 3600 seconds in the 123 days of the "growing season"
* 10% energy loss in each trophic level from producers up to top carnivore level

Appendix L

Number of calories available for consumption:

Top Carnivores (per year):

(6.07973E+8 Joules/year) x (0.239) = 14530562.6 calories/year

Top Carnivores (per day):

(14530562.6 calories/year) / (365 days) = 398097.651 calories/day

Number of individual top carnivores that calories can support:

(398097.651 calories/day) / (1100 calories) = 361.9069554
≈ 361 top carnivores

(3,785 acre of forest) / (361 top carnivores) = 10.48
≈ 10.5 top carnivores/acre