HIBERNATION ADAPTATION IN THE BLACK BEAR: IMPLICATIONS FOR MANAGEMENT

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Abstract: Bears are exceptional mammals in responding to prolonged periods of no food and water. Black bears may go without food or water for 5-9 months while maintaining near-normal body temperatures. Heart, breathing, and metabolic rates are depressed during hibernation yet the bear can quickly arouse and achieve somnolent mobility. Urination and defecation do not occur during hibernation. Urea is recycled by 2 pathways, preventing protein catabolism. Protein turnover is accelerated during hibernation. Adipose tissue is the source for both energy and water. The biochemical state of hibernation is attained several weeks prior to denning and does not appear to vary annually with food abundance. Hibernation likely continues for a short period after den emergence. Studies of bear hibernation led to development of a diet for anephylic humans which could prolong hibernation for up to 10 days. Better understanding of the biochemistry of bear hibernation may lead to improved treatment for severe burns, obesity, and metabolic disorders in humans. The presence of elevated blood calcium and muscle atrophy in denning bears merits more intensive examination. The period of hyperphagia and onset of hibernation, rather than denning, should be considered in any bear transplant program. Impact of hibernation on the physiology of bears should be considered in any bear management program. Impact of hibernation on the physiology of bears should be considered in any bear management program.

Most mammals respond to stress of no food or water by utilizing fat rather than carbohydrate to meet energy requirements, decreasing use of protein stores, and reducing urea formation while developing ketosis. Despite these similarities, some mammals are more resistant to the pathologic effects of no food or water than others. In fact, there appears to be a continuum of responses from mammals which are exceptionally good (the bear) to those which are exceptionally poor (human beings). Bears can be independent of need for food and water for 9 months. At the end of this time they are in excellent clinical condition. On the other hand, the lifetime in humans is measured in days when denied food and water. The independence of the bear from seeking food or water can only be described as a metabolic marvel because throughout the period of hibernation its body temperature is within a normal range. Thus, the bear burns a calculated 4000 kcal/day while not eating, drinking, urinating or defecating (Nelson 1980).

Considering this spectrum of responses to no food or water, a continuum of mammalian species can be listed. Many liberties were taken to construct Table 1. At its head are 3 species of bear (Ursus maritimus, U. arctos, U. americanus) who have the best adaptation to no food or water. The northern elephant seal (Mirounga angustirostris), a non-hibernator, is considered fourth because it subsists at normal body temperature without food or water for 12 weeks after weaning. However, the animal does lose small amounts of urine which must represent nitrogen losses (Perkins et al. 1972). The woodchuck (Marmota monax) goes through winter alternating bouts of deep hibernation with arousal, yet does not eat or drink. However, its low body temperature greatly lowers energy requirements (Folk 1974). Hedgehogs (Erinaceus europaeus) and marmots (Marmota flaviventris), although similar to the woodchuck, show urea and ketosis respectively (Kristoffersen 1963, Baumber et al. 1971). The ground squirrel (Spermophilus spp.) is listed below these hibernators because it is capable of hibernating with cyclic periods of arousal. Every 9-11 days it eats and drinks (Folk 1974). The bat, although a hibernator, must have water, and therefore is listed below the others (Kallen and Kantor 1967).

Several choices are possibilities for the remainder of the list. The prairie dog (Cynomys ludovicianus) is a non-hibernator, was chosen because of its remarkable ability to conserve nitrogenous substances under conditions of no food or water (Pfeiffer et al. 1979). However, because of small urine volumes, quantities of nitrogen are lost. The deer (Odocoileus virginianus) is listed above the human being (Homo sapiens), because of its adaptive annual changes, which are voluntary hypophagia and loss of body weight under severe cold ambient temperatures (McMillin et al. 1980). The human is last. Although some humans can starve for 6 months, they must have water daily to survive.

Table 2 compares blood findings from the starving bear with those from the starving human being. Important differences between these 2 species are that after long starvation lean body mass does not change in the male bear, whereas, a 20% reduction occurs in human beings. Plasma proteins increase in the bear but decrease in the human. In hibernating bears, plasma urea decreases, creatinine increases and the urea/creatinine ratio decreases from 90 to less than 10. In the human, no change in urea, creatinine or their ratio is observed. The low urea/creatinine ratio has been shown to be a biossay for hibernation in bears (Nelson et al. 1983a). Concentrations of essential and

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Table 2—Comparison between hibernating black bears and starting human beings.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Units</th>
<th>Bears* Before</th>
<th>During</th>
<th>Human Before</th>
<th>During</th>
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<tr>
<td>Lean body mass</td>
<td>Kg</td>
<td>80</td>
<td>82</td>
<td>10</td>
<td>32</td>
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<tr>
<td>Plasma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Proteins</td>
<td>mg/dL</td>
<td>2.63</td>
<td>8.27</td>
<td>6.57</td>
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<tr>
<td>Urea</td>
<td>mg/dL</td>
<td>34</td>
<td>20</td>
<td>20</td>
<td>31</td>
</tr>
<tr>
<td>Creatinine</td>
<td>mg/dL</td>
<td>1.15</td>
<td>2.29</td>
<td>1.22</td>
<td>1.28</td>
</tr>
<tr>
<td>Urea/creatinine ratio</td>
<td></td>
<td>30</td>
<td>6</td>
<td>25</td>
<td>26</td>
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<tr>
<td>Total Amino Acids</td>
<td>µM</td>
<td>2869</td>
<td>5966</td>
<td>4290</td>
<td>3850</td>
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<tr>
<td>Alanine</td>
<td>µM</td>
<td>355</td>
<td>355</td>
<td>310</td>
<td>116</td>
</tr>
<tr>
<td>Lysine</td>
<td>µM</td>
<td>188</td>
<td>184</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Glucose</td>
<td>mg/dL</td>
<td>83</td>
<td>75</td>
<td>82</td>
<td>61</td>
</tr>
<tr>
<td>Ketones</td>
<td>µM</td>
<td>29</td>
<td>244</td>
<td>90</td>
<td>1190</td>
</tr>
</tbody>
</table>

*Data from Nelson et al. 1973; Nelson et al. 1975; Lumberg et al. 1976; Ahlquist et al., in press.

Human data from Keys et al. 1950; Cabill et al. 1966; Owen et al. 1969.

Non-essential amino acids remain unchanged in bears, while in humans, some show sharp decreases. Finally, although plasma ketones increase 10-fold in bears, they rise 50-fold in humans (diagnostic of ketosis).

Since the human and the bear show similar types of metabolic reactions to starvation, it is unreasonable that the mechanisms utilized by the bear might well be induced in the human being, under specific experimental situations.

Hibernation in the Bear

General Responses

Body temperature of the bear decreases from 37°C to 35°C. It can be considered within normal limits for an active bear. Heart rate decreases from a summer sleeping rate of between 40-50 beats per minute to 8-10 beats per minute at the end of December (Folk 1974), and the basal metabolic rate decreases (Nelson 1980). Bears assume a dormancy position of small hibernators and appear to enter a light sleep (Folk 1974). However, the bears can be active in winter and arouse quickly. They can defend themselves and, thus, maintain their position in the predator sequence (Nelson 1980). Anorexia develops; the bear does not eat or drink and urination and defecation do not occur (Nelson 1980).

There is a change in hypothalamic reactivity. Hypothalamic hyperthermia occurs (Adin et al. 1979). The hypothalamus shows a delayed response to injection of glucagon and insulin. Stimulation of corticosteroid release by the hypothalamic-pituitary axis is delayed (Palumbo et al. 1983).

Organ Responses

Liver—Liver control of urea metabolism appears to be the most important factor in permitting the bear to be resistant to no food or water at normal body temperatures for 9 months. Bears who become uremic cannot hibernate and will die (Nelson 1980). If urea is injected into bears, urine output increases and dehydration occurs (Nelson et al. 1978).

In hibernation, a gradual decline occurs in blood urea, thus preventing uremia. Urea production from amino acids is slowed (Nelson et al. 1973). However, that which is formed is degraded by 2 mechanisms. One appears to be by diffusion of urea into the intestinal lumen where it is hydrolyzed to produce ammonia and carbon dioxide (Nelson et al. 1973). After reabsorption, ammonia reacts with glyceraldehyde (released from triglyceride hydrolysis from adipose tissue) to form alanine and serine (Ahlquist et al., in press).

These amino acids are then incorporated into plasma proteins (Lundberg et al. 1976; Ahlquist et al., in press).

A second mechanism by which the urea molecule is degraded was suggested by preliminary studies of the metabolism of doubly labeled 15N urea in hibernating bears. Within hours, labeled nitrogen derived from urea appeared most quickly as single labeled urea, in plasma proteins, and in the amino acids ornithine, arginine, glycine, tyrosine, phenylalanine, and threonine (Wolfe et al. 1982a, Wolfe et al. 1982b). Four days later, 15N nitrogen also was detected in ammonia. To our knowledge, the pathway of urea nitrogen into these amino acids shown in these pilot studies has not been defined for mammals. Nitrogen was added to both essential (phenylalanine, threonine) and non-essential amino acids. However, it is not known if there are such things as essential amino acids for the bear. In hibernation, therefore, the bear prevents uremia by at least 2 mechanisms which appear to recycle urea nitrogen with amino acids. Protein synthesis and formation of neurotransmitters such as catecholamines and glycine are then possible.

An accompanying prerequisite for successful hibernation appears to be an increase in protein turnover, both synthesis and catabolism, incorporation of amino acids into proteins and breakdown of plasma protein increase approximately 5-fold (Lundberg et al. 1976; Ahlquist et al., in press). However, anabolism exceeds catabolism. About 3 grams of nitrogen, obtained from urea, are incorporated into plasma proteins. Thus, the male bear is pregnant in a sense, since there is an increase of approximately 21 grams of plasma proteins by the end of hibernation. Thus, under the umbrella of starvation, there is an anabolic pathway in which urea nitrogen is converted into plasma proteins (Nelson et al. 1983a).

The increase in protein turnover may help to slow urea synthesis. It has been shown that when amino acids enter into protein formation at increased rates, their entry into the urea cycle is inhibited (Mutu 1976). Also, increased protein turnover may be responsible, in part, for maintaining body temperature within normal limits. The liver also forms carbohydrates such as glucose, pyruvate, and lactate from glycerol, alanine, and serine (Ahlquist et al., in press).

Adipose Tissue—Stored triglycerides furnish the energy for hibernation and, by production of metabolic water, maintain normal hydration (Nelson et al. 1973; Ahlquist et al., in press). Glycerol released from triglyceride hydrolysis furnishes carbon skeletons for
formation of imessential amino acids such as alanine and serine (Ahituv et al., in press).

There is lipid anabolism as shown by formation of pyruvate, lactate, glucose, and lipid esters of triglycerides, phosphoglycerides, and sphingomyelin from glycerol and other lipids (Ahituv et al., in press). A peculiarity of lipid metabolism in hibernation is the lack of ketosis. It is speculated that glycerol may recombine with free fatty acids to form triglycerides and help prevent excess ketone body formation. Also, acetyl Coenzyme A may be limiting so that ketone production does not occur.

Kidney—The glomerular filtration rate decreases in hibernation from approximately 100 ml/min to 30 ml/min (Brown et al. 1971). Urine is constantly formed and enters the urinary bladder (Nelson et al. 1973, Nelson et al. 1975). However, the bladder wall reabsorbs urea, water and other constituents at a rate equal to that of urine formation (Nelson et al. 1975). Thus, kidney function persists and that urine formed is reabsorbed back into circulating plasma. Bladder distention and urination do not occur.

Induction of Hibernation

It has been shown that many black bears develop signs of biochemical adaptation of hibernation in late August and September, weeks prior to entering their den. These animals show a urea/creatinine ratio of 10 or less (Nelson et al. 1988a). Other animals show declination of the ratio towards 10. This phenomenon is not related to food availability or type of food eaten and appears to develop gradually (Nelson et al., in press).

Other studies support the concept of gradual induction of the hibernation state in bears. For instance, denning bears show a gradual decline in pulse rates reaching lowest levels at the end of December (Folk 1974). Serum thyroxin and triiodothyronine gradually decrease throughout hibernation (Azizi et al. 1979). In the male bear, testosterone level is lowest in October but during hibernation, gradually increases to levels approaching those found in the mating season (McMillan et al. 1976). In the female bear the fertilized ovum begins to divide, pregnancy develops to term with delivery between 1 to 5 cubs weighing 0.5 kg which are nursed to weights of 5 kg before mother and cubs leave their den in the springtime (Folk 1974). Thus, the bear appears to be in the metabolic state of hibernation before denning and this state continues to develop throughout denning.

There are data which also support the contention that the biochemical adaptation persists into springtime, after the bear has left its den. Bears studied in captivity in the wild demonstrate continued anorexia for both food and water after leaving dens. The period lasts for approximately 3 weeks. Despite ad lib food and water, a grizzly bear studied 3 weeks after denning ate no food and drank minimal water. Daily urine output was 140 ml/day (Folk and Nelson 1981). These data suggest that the hibernation adaptation was persistent, but waning. Urination occurred but was negligibly small compared to the size of the animal. Thus, the umbrella of hibernation, which permits independence from need of food and water, begins prior to denning and persists after the bear leaves the den (Nelson et al. 1988a).

The Bear as an Animal Model to Better Understand and Treat Human Disorders

Data from studies on bears were instrumental in defining a diet program to reduce the frequency of dialysis for anephric human beings awaiting kidney transplantation. The diet successfully controlled both water and protein metabolism to such a degree that hemodialysis could be postponed for 10 days. This was equivalent to urinating only once every 10 days. During the study, the patients remained ambulatory, had no water except for medications, were not thirsty, and were in good clinical condition (Nelson et al. 1979). The diet later proved successful for people on hemodialysis who wished to dialyze less often (Dyck et al. 1975).

There are other possibilities that further research in bears may well improve lifestyles of human beings. Examples are:

1. Reversing the excessive catabolic state of protein in severe burns.
2. Treatment of anorexia nervosa.
3. Treatment of obesity.

Finally, control of lipid and protein metabolism in normal human beings to the extent evidenced by the bear have great implications for space flight. If the necessary energy could be stored as adipose tissue and the need for drinking water eliminated, the length of space flights could be increased substantially. However, by merely creating an obese state and drinking only required amount of fluid to maintain normal kidney function, obese astronauts (with 18 kg of adipose tissue) could prolong any space flight by 100 days (Nelson 1973, Nelson 1980).

Implications for the Future

Besides the possibilities of improving the fate of human beings who have suffered chronic renal disease, extensive burns, anorexia nervosa, and obesity, there are implications from research in bears for other human problems as well. For instance, the bear remains in a stationary position for months in hibernation. Despite the high metabolic rate and active metabolic processes, these animals demonstrate no obvious problems with calcium metabolism. In the human being, going to bed for a week will induce extensive loss of calcium from bone and precipitate hypercalcemia and hypercalcuria.

Inactivity of bears should induce muscle atrophy. This has not been observed in bears. More work is required to determine how bears control their calcium and muscle metabolism and whether applications to human problems of osteoporosis and muscle atrophy can be made.

Implications for Black Bear Management

A very important point to stress is that denning and hibernation are 2 distinct events. Denning is a physical act of reducing mobility by crawling into a
rock cavern, hollow tree, excavated hole, brush pile, or simply lying down on a bed of leaves. Hibernation is a physiological adaptation which enables the bear to survive for up to 6 months without food or water. Hibernation appears to commence prior to denning and continue until after den emergence in the spring.

We propose that this distinction is more than just academic and may have significant implications to management.

We hypothesize that the biochemical transition to hibernation requires 20-30 days to complete (based on declining U/C ratios throughout September in Colorado) and that the best environmental fitness for an individual is attained when the hibernating state is attained at the time of earliest fall food shortages. If the transition does take 20-30 days, then a bear cannot afford to wait until food is limiting to begin the transition as the animal would be losing significant amounts of fat and lean body mass while suffering through normal mammalian starvation. Thus, in the poorer food years, it is advantageous to achieve hibernation prior to the loss of high carbohydrate foods and the onset of colder weather. Conversely, there is little advantage to being able to make efficient use of food in good years for the extra 2-3 weeks that food may be available because bears will be in adequate condition for survival and reproduction anyway. The bear needs to use the most efficient metabolism when high quality foods run out. The consequences of starting hibernation too late are far greater than starting too early.

Unfortunately, we only have data for onset of hibernation in 1 area, west-central Colorado. Hibernation appears to commence by 1 October irrespective of fall food supply (Nelson et al., in press). The 3 years of data were collected in seasons of excellent, good, and catastrophically poor fall food production. We suspect that the onset of hibernation varies between regions in response to the phenology of hard and soft mast. We do not suspect much annual variation nor individual variation. We believe it is important to look at the blood biochemistry during September-October of all bear populations under study. Knowledge of the onset of hibernation will aid in the interpretation of fall movement patterns and provide an important data base for restocking programs.

In our present state of ignorance we should presume that onset of hibernation is endogenously controlled for a fixed time; the result of many years of evolution within a region. It is unlikely that this timing procedure will change rapidly, maybe not even within the life of an individual. Therefore, if our management involves restocking historic range with bears from non-contiguous areas, then care should be taken to insure that the fall food phenology is quite similar in the source area and the transplant area. Suppose that the period of available mast in an eastern hardwood forest is October and that hibernation is attained around 10 November. A bear taken there from Colorado would be in hibernation physiology prior to the availability of the high carbohydrate foods and would likely exhibit low survival. A worse case would be relocating an eastern bear into an environment with no fall foods after 1 October and unable to hibernate until November. Such a long period of non-hibernating starvation would greatly reduce chances of survival. Data are lacking to determine if this is a real management concern or just speculation. Data needs to be collected now as restocking may become of greater importance in the future.

One must also wonder about possible impacts of chasing bears with hounds after the onset of hibernation in the bear. Several eastern states have fall bear seasons with hound pursuit permissible. The state of hibernation is normally associated with periods of inactivity. The physiologic condition of hibernating bears under such prolonged exertion is unknown. There is a need to obtain data on bear populations to determine onset of hibernation and also to sample bears that have been chased after hibernation onset. Many hunters comment that fall chases often result in "pop-up" bears that do not run far before stopping. This response is usually attributed to the bears being fat but perhaps because the bear is already hibernating.

Recently there has been renewed debate on the plight of grizzly bears in Yellowstone National Park. Much of the debate centers on the alleged need to provide supplemental food for the bears. Citizens and biologists alike often jump to the carcass solution—provide lots of dead elk (Cervus elaphus) for bears in the spring. Support for this solution derives from 2 sources: (1) observation of Yellowstone grizzly bears using carcass, and (2) the awareness that most surviving mammals catabolize lean body mass. Thus, some observers mistakenly believe a bear emerges from the den protein deficient. The converse is actually the case and the bear in spring probably needs what any mammal needs during normal growth—energy and protein. Before an agency develops a massive feeding program it seems wise to first determine when the bear changes from the hibernation state to "normal" metabolism and compare this time with plant development. The observation of bears using carcass in the spring actually sheds little light on the physiologic need for high protein food at this time of year.

Physiology often dictates behavior. Interpretation of bear movement patterns can be enhanced by knowledge of the timing of metabolic states, especially migrations to fall feeding areas and return to denning areas. Biologists with responsibility for nuisance bear control may also benefit by examination of the periods of hyperphagia (Nelson et al., 1983b) and hibernation. If you know where the bear wants to be and when, you can try to alleviate man's contribution to the nuisance situation. For example, the concentration of bears in Gambel oak (Quercus gambelii) associations in Colorado from 15 August-30 September predisposes a sheep herder to suffering deprivation loss in years of poor mast if he insists on grazing these low elevation sites. However, if the herder waits until 1 October, after hibernation commences, he can graze the brush hillsides with little chance of bear depredation.

A further concern, especially in regions with little snow cover, is the effect of disturbance on denning bears. We know the bear is hibernating even though it actively runs away from the den when disturbed. The impact of such disturbances to its physiologic conditi-
tion is unknown. When working where black bears are abundant, one often ignores such implications because there are plenty of bears. However, we should take the opportunity to learn about the impacts of disturbance on this tractable species for possible application on grizzly bears or small black bear populations. Human presence, and consequent disturbance to bears, is an omnipresent factor for our lower 48 states grizzly bear populations. Management agencies tend to deal with competing land uses in terms of displaced bears or dead bears and avoid disturbance, especially bears, partly because of a lack of knowledge. Normally one should be leery of using knowledge of a species for another of the same genus. However, because of safety factors, it is probably worthwhile to study the physiologic impacts of disturbance on black bear for its utility in studying bears.

**LITERATURE CITED**


**DISCUSSION**

T. Beck: One other point I'd like to make, for those taking blood samples or as we were taking urine analysis for a while, you should consider water drought situations in those bears. They have a highly refined system especially in the small bodied bears. Make those blood samples that you draw as small as you can and still get the amount of serum that you need.

R. Powell: I'm working in an area where the hunters find the bears with dogs but we don't. Often times though we can get to a bear within a relatively short time after the hunters have killed it. Is there some blood work up we can do on those bears? What data should we get?

R. Nelson: I think it would be interesting to look at the urea and creatinine ratios. I'm pretty much convinced that's hibernation. It would be interesting to see what it is and at what time of the year it occurs. They can't burn carbohydrates well in hibernation, and whether they go to nitrogen which is the anaerobic muscle source for bears, and in humans, I don't know.

R. Powell: What sort of treatment should be given the blood?

R. Nelson: Cool it and centrifuge the blood as soon as possible.

B. Cook: Do you guys consider using replacement fluids?

R. Nelson: That's a good point. You can replace it volume for volume simply with saline or Ringer's lactate.

B. Cook: The second question I have is concerning renal alumin production which you mentioned a while ago, how do you propose to develop the thesis that there is production going on in the bear. Can you trace that?

R. Nelson: That's right, if you take nitrogen off the essential amino acids you end up with what is

**PROC. EAST. WORKSHOP BLACK BEAR MANAGE. RES. 7: 1984**
called an alpha ketoacid. And all the essential amino acids have these alpha keto analogs, in fact they have been tied to people with kidney disease with the hope that it would reduce their nitrogen. Its been generally disappointing, but we know then that the bears can be adding nitrogen to alpha keto analogs so that he is not making phenylalanine. So we need to go to steps of phenylalanine breakdown, that's beyond that. For instance, tyrosine, does he make phenylalanine first and then tyrosine or is he making tyrosine directly. We don't know.

T. Beck: On the replacement issue, we looked into that because we were taking urine samples from our males. We would catheterize them and once we got the catheter in it was as easy to pour some back as it was to take out. If you're taking volumes from a male regularly it just is a good idea. A vet might suggest putting in an antibacterial agent which we do quite often. And I'm real concerned about that because that's not a stagnant pool in the urinary bladder.

A. Brody: I was just wondering in the lactating bears that are also hibernating, where does the milk come from? She doesn't have any intake of sugar and your nitrogen data seems to indicate there is no gluconeogenesis.

R. Nelson: No, there is gluconeogenesis but I didn't show that. We were giving labeled glycero and labeled alanine to bears in hibernation.

D. Garshelis: Several researchers have indicated that there is some relationship between how much food is available and when bears will go into hibernation. How do you answer that in light of data that you collected?

T. Beck: I think there is some information that shows food availability at denning time. My belief is that they go into hibernation the same time each year, but denning is a function of weather, even to some extent how much food might be around. Our migrant bears, for instance, when they move out of that oak brush zone they have no food. They're back in the high coniferous forest. And they just go into day beds and lie there until the weather gets so severe they go into their den. The bears that have a home range down in the oak brush will continue to forage a little bit but their daily movements and the amount of time they go out are drastically reduced, even with abundant food there.

J. Rieffenberger: You indicated that water balance is critical. Would there not be a significant crippling loss then for gun shot wounds?

R. Nelson: Oh, yeah.

J. Rieffenberger: We never have been able to measure crippling loss; the dead bears are not found in the woods, but it looks like we ought to.

R. Nelson: I wonder how many deaths you might attribute to hunting? We found that in captivity over a period of ten years that two bears could not hibernate and their urea was up around 600 milligrams and normal is around 30. I wonder if there aren't deaths to bears with inability to hibernate, because they can't get the biochemistry working. We do know that three captive bears in a root cellar covered the doors with ice by the end of the hibernation period of 100 days; they actually did produce more water than they needed. We studied their plasma volumes, and red cell water content; it didn't change at all. Its incredibly good water balance. It's another thing the bear can do that we can't do.