March 1972

AVIAN THERMOREGULATION AND ITS SIGNIFICANCE IN STARLING CONTROL

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The ability of birds and mammals to maintain a relatively stable internal body temperature while under a considerable range of ambient environmental temperatures results in distinct ecological and physiological advantages. A constant body temperature facilitates the activity of homeothermic (warm-blooded) animals in cold environments because the many temperature-dependent physiological and biochemical processes of the body are unimpeded. Conversely, poikilothermic (cold-blooded) animals lack the ability for precise thermoregulation and can function at top physiological efficiency only when ambient environmental temperatures are within a rather narrow optimum range.

Homeothermia is accomplished by a system of physiological feed-back mechanisms which maintain a thermal balance in the body by regulating the rate of heat production and the amount of heat loss. An optimum temperature range (thermoneutral zone) exists in which the expenditure of energy for heat production and heat loss is minimal. However, seldom is the temperature of the environment precisely that which is best suited for the physiological requirements of the animal. Thus, a homeotherm is nearly always either passing excess body heat to the environment, or is producing heat to replace that lost to the environment. Because both heat transfer and heat production require some degree of energy expenditure and, since the energy budget in birds is usually relatively small, excessive energy demands for thermoregulation can be lethal.

Several years ago, biologists at the Patuxent Wildlife Research Center proposed that the elimination of pest bird populations might be accomplished by interfering with the animal's ability to regulate its body temperature. Essentially, this scheme consists of applying a wetting agent to dissolve the oil layer covering the feathers and thus reduce the insulating properties of the feather coat. Without protection of this oil layer, feathers can become saturated with water and physically disorganized. This limits the ability of the bird to form an insulating air layer between the skin and the environment via raising or fluffing of the feathers. Thus, at low environmental temperatures an excessive amount of heat loss from the skin surface may result in fatal hypothermia.

This paper presents a brief description of the physical-physiological mechanisms for avian thermoregulation and reports the results of preliminary experiments to determine the effects of wetting agents when applied to the feathers of the European starling, Sturnus vulgaris.

PHYSICAL PROPERTIES OF HEAT TRANSFER

Heat is transferred to or from biological systems by the processes of radiation, conduction, convection, and evaporation. These heat transfer mechanisms are subject to certain physical characteristics of the animal's body and of the ambient environment.

The second law of thermodynamics (which applies essentially as well to biological as to non-biological systems) states that all elements of a system tend toward a uniform temperature. Thus, heat will tend to be lost to the environment at ambient temperatures lower than the bird's body temperature. Conversely, a bird will tend to absorb heat from the environment when exposed to ambient temperatures warmer than the body temperature. According to Newton's law of cooling, the rate of heat loss or gain by an object (either the animal or the environment) is proportional to the temperature gradient between the surface and the surrounding air. Thus, the amount and rate of body heat lost to, or gained from, the environment is dependent upon the ambient temperature of the environment as well as the temperature of the animal's body. Further, the ratio of body mass to the surface area of the animal also influences the amount of heat gained or lost.

REGULATION OF THE BODY TEMPERATURE IN BIRDS

Birds have evolved several general methods to control their body temperature during exposure to the considerable range of environmental temperatures which they normally experience in middle latitudes. This paper will cover only the physiological responses of birds to cold environments since responses to hot environmental temperatures have little application with respect to potential bird control strategies.

1. Neural control of avian thermoregulation

The integrative control of the various thermoregulatory mechanisms is apparently a function of the central nervous system. Although the precise control mechanism(s) is still uncertain, the primary control centers apparently lie in the hypothalamus of the brain. Lesions of the posterior hypothalamus have resulted in overcooling, whereas lesions of the anterior hypothalamus caused overheating (Selkurt 1966). Thus, although the functional separations of these two hypothalamic centers are probably not completely discrete, it appears that the anterior portion deals with responses to increased temperatures whereas the posterior portion is primarily concerned with responses as a result of decreased temperatures. Impulses reaching the hypothalamus come from cutaneous (skin) temperature receptors and also from temperature-sensitive cells within the hypothalamus itself. Thus, temperature fluctuation of either the internal or the external portion of the body can independently stimulate hypothalamic function resulting in employment of various physical and chemical thermoregulatory mechanisms to maintain a relatively constant temperature within the deep body core.

2. The importance of body size and temperature distribution in avian thermoregulation

There is copious evidence that body temperatures of small birds are generally higher than those of large birds. This is probably due to small birds having a relatively (for their size) larger surface area/body mass ratio from which to lose heat as compared to the surface area/body mass ratio of larger birds. Furthermore, a small body size limits the amount of space available for fat and plumage which in larger birds may be efficient factors with respect to insulating the body temperature from that of the environment (Sturkie 1965). The differential surface area/body mass ratios of small and large birds may contribute to the specificity of the effects of wetting agents since the impact of the treatment would probably be considerably greater on small birds than on larger birds.

Essentially, the avian body can be considered as consisting of two specific thermal regions. The innermost region, or core, in which the temperature is maintained at a relatively constant level, consists of the central nervous system, visceral organs, and part of the skeletal musculature. This core region is the site of most of the heat production and of the physiological processes vital to the life of the bird. The outermost portion of the body, or shell region, includes the remaining skeletal musculature, the skin, the feathers, the un-insulated extremities, and in many species a subcutaneous layer of fat. The temperature of the shell region is regulated as a response to the environmental temperature and thus acts as a variable insulating layer separating the core region from the ambient environment. Essentially, the shell region serves to maintain the core temperature by regulating the amount of heat transfer to or from the environment.

3. Physical and behavioral regulation of body temperature

Physical regulation of the body temperature includes mechanisms which decrease the amount of heat lost to the environment by reducing the effective exposure of the core region temperatures to the colder environmental temperature. Essentially, the physical regulation of body temperature is accomplished by varying the insulating effect of the shell region thus reducing the gradient between the body core and the environmental temperatures. Generally, this is a function of the feather insulation covering the body surface and of the amount of blood carried by vessels in the shell region.

Convective heat loss from blood circulating from the interior to the exterior regions of the body can be appreciably lowered by reducing the blood flow to the periphery. This is accomplished by vasoconstriction (reducing the diameter) of peripheral blood vessels and by shunting blood from peripheral to more interior vessels. Further, the blood returning via the peripheral veins shifts to vessels (venous plexuses) which closely surround the arteries as a function of cold environmental temperatures. Since venous blood returning from the periphery is colder than the arterial blood coming from the core regions, a temperature gradient facilitating heat transfer occurs between venous and arterial blood. Thus, heat transported toward the periphery of the animal via arterial blood is transferred to venous blood and returned toward the interior regions of the animal rather than being lost to the environment. This mechanism, known as the counter-current heat exchange, is very important in the extremities of the bird. For example, since the feet, legs, and to some extent the thighs, have little or no feather insulation, the amount of body heat reaching these regions must be reduced to prevent undue heat loss during exposure to cold environmental temperatures. In fact, at low environmental temperatures, the temperatures of the leg and foot approach that of the environment. This minimizes body heat loss since the temperature gradient between these extremities and the ambient environment is very slight.

The role of the feather coat in decreasing the temperature gradient between the body surface and the environment is of extreme importance with respect to thermoregulation. The downy feathers reduce the amount of air flow near the skin surface and thereby reduce heat loss via convection. The larger contour feathers cover the inner layer of feathers and waterproof the body surface. Oil secreted from the preen gland straightens the feathers and waterproofs their surface. During exposure to cold ambient temperatures, the feathers are raised from the skin surface creating a trapped air layer between the feathers and the skin surface. This air layer greatly increases the insulating properties of the plumage. The importance of the insulating effect of the feather coat is illustrated by the relatively high skin temperature of feathered areas as contrasted to lower skin temperature in areas not protected by feather insulation (Irving and Krog 1955; Steen and Enger 1957).

Birds also exhibit a variety of behavioral mechanisms which aid in the maintenance of thermal equilibrium. For example, when exposed to cold air temperatures, many species will utilize protective shelters and/or reduce the amount of body surface exposed by placing the head, feet, and legs under the wings or close to the body. Some species group together during extreme cold and thus reduce the total surface area and the amount of heat lost via conduction, convection, and radiation. Migratory birds avoid temperature extremes by moving to more temperate localities.

It seems reasonable, however, that physical thermoregulatory mechanisms and behavioral mechanisms (except for migration) cannot by themselves maintain thermal equilibrium in birds exposed to extremely cold temperatures. At a certain low thermal level, known as the critical temperature, these physical and behavioral mechanisms are not adequate to prevent heat transfer from the inner core to the body surface. Thus, the temperature gradient between the animal's body and the environment increases and body heat is lost. At, or below the critical temperature, heat balance is maintained by additional heat production. This is accomplished by increasing metabolic heat production via oxidation of foodstuffs, mobilization of body energy stores, and by muscular thermogenesis.

4. <u>Chemical regulation of body temperature</u>

Chemical regulation of body temperature is the result of heat production attained by increasing the metabolic level. Within the bird's thermoneutral range (the range of temperature under which physical mechanisms alone can maintain body temperature) the only heat produced is that resulting from the animal's basal metabolic processes and normal muscular activity. However, at environmental temperatures below the critical level, metabolism is increased and additional heat is produced to maintain internal heat balance. This increased metabolism is caused, in part, by increased muscular movement and shivering. Additional heat may also be produced as a result of increased food uptake and associated metabolism of the absorbed food particles, i.e., the specific dynamic action of the diet.

EXPERIMENTS ON THE REGULATION OF BODY TEMPERATURE IN THE EUROPEAN STARLING

1. <u>Daily fluctuations in deep body temperature</u>

Maintenance of the deep body temperature within relatively narrow limits is of prime importance for proper physiological functions in homeothermic animals. However, the deep body temperature can, and indeed does, fluctuate in predictable daily cycles.

Deep body temperatures were continuously monitored for several weeks via temperature-sensitive radio transmitters implanted within the coelomic cavity of three adult female European starlings. During this period, the animals were maintained in large outdoor pens and thus, the temperatures monitored from these animals should be comparable to those of non-captive starlings under natural environmental conditions at this locality. Data reported here was taken on 21 February 1972. Environmental conditions on this date include a daily photoperiod of 11 hours light (sunrise - sunset), wind velocities of 1-3 miles per hour, and ambient air temperatures from 14 to 19°C. Under these conditions, the deep body temperature of the three starlings exhibited typical average daily fluctuations of 4.5°C, from a low of 38.5°C. during hours of darkness to a high of 43.0°C. during the daylight hours (Figure 1).

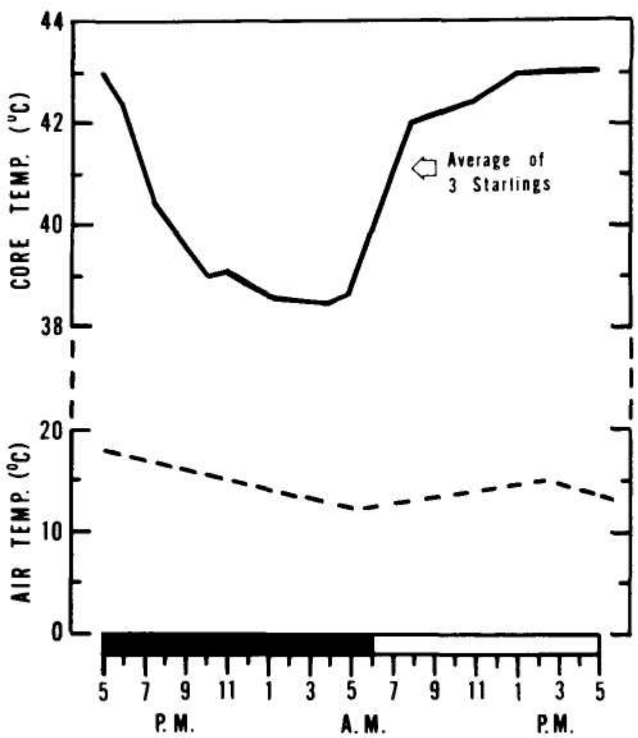

Figure 1. Daily cycle of the deep body temperature in adult female European starlings, Sturnus vulgaris. The upper portion of the figure indicates the average core temperatures of three individuals as monitored continuously via temperature-sensitive radio transmitters implanted within the coelomic cavity. All animals were maintained in large outdoor aviaries. Ambient air temperatures are given as a broken line in the lower portion of the figure. Wind velocities were 1-3 miles per hour. Duration of darkness (solid horizontal bar) and light (open horizontal bar) are given at the base line, as is the time of day. Data are for 21 February 1972.

The lowest daily levels in deep body temperature are correlated with the lowest daily levels of the ambient air temperature. However, this correlation is not an expression of a causal factor since we have documented comparable daily core temperature cycles in starlings maintained under stable ambient air temperatures. Thus, it seems plausible that the daily nadir in deep body temperature is a function of the basal level during sleep and/or during the night-time reduction in activity. Essentially, the low deep body temperature levels observed during the hours of darkness are probably the general result of an overall lowering of metabolic and muscular thermogenesis.

2. Temperature levels at various regions of the body

In addition to the relatively minor daily cycles in deep body temperature, European starlings also exhibit pronounced differences in temperature levels at various regions of the body shell. These differences are a direct function of the physical thermo-regulatory mechanisms previously discussed and are of extreme importance in the facilitation of the relatively stable deep body temperature.

The temperature levels at various regions of the body shell were measured from restrained starlings via thermocouples located at: a) the skin surface of the breast, b) the interface between the breast feathers and the ambient environment, c) the skin surface of the sparsely feathered thigh, d) the leg, e) the top portion of the foot and, f) the deep body via cloacal probe. Temperature determinations at the above sites were made from five adult female starlings exposed to ambient air temperatures of 7°, 14°, and 21°C. The temperature levels presented are those measured at equilibrium between the particular region of the body and the ambient air temperature (Table 1).

Table 1. Temperature of various body regions in European starlings, Sturnus vulgaris, as a function of ambient air temperatures (see text for methods and sites of temperature determinations).

	AMBIENT AIR TEMPERATURES											
	21° Centigrade				14° Centigrade				7° Centigrade			
MEASUREMENT SITE	N	$\bar{x}$	SE	Range	N	$\bar{x}$	SE	Range	N	$\bar{x}$	SE	Range
Deep Body Core	5	42.8	0.15	42.5-43.3	5	42.9	0.25	42.1-43.6	5	42.9	0.33	41.9-43.7
Skin Surface	5	39.1	0.21	38.5-39.8	5	32.4	0.72	30.5-34.0	5	28.3	1.13	25.8-32.1
Thigh	5	38.2	0.16	37.9-38.8	5	29.4	0.71	28.0-32.0	5	22.3	0.46	21.3-23.8
Feather Surface	5	35.2	0.20	34.9-36.0	5	27.1	0.78	24.0-28.2	5	17.2	0.21	16.8-18.0
Leg	5	36.2	0.31	35.5-36.9	5	18.9	1.07	17.0-23.0	5	11.9	0.63	10.0-13.9
Feet	5	34.3	0.21	34.0-35.1	5	18.3	0.37	17.0-19.2	5	10.9	0.60	9.3-12.3

The temperatures measured at various regions of the body shell document the operational efficiency of physical thermoregulatory mechanisms under the ambient air temperatures to which the starlings were exposed (Figure 2).

The deep body temperature of European starlings remains remarkably constant regardless of the ambient air temperature to which the animal is exposed. In contrast, regions of the body shell and the extremities exhibit temperatures appreciably lower than that of the body core as a function of exposure to cold environmental temperatures.

The skin surface in the vicinity of the breast was the site of the highest temperatures measured from the body shell. Even so, the temperatures of this region are considerably lower than that of the body core, especially in animals exposed to low ambient air temperatures. These high skin temperatures can only be physiologically tolerated because of the efficiency of the feather insulation which essentially isolates the skin surface in this region from the ambient environmental temperature. The efficiency of the feather coat is documented by the relatively low temperatures at the interface of the feather coat and the ambient air temperature.

The efficiency of physical thermoregulatory mechanisms such as the reduction of the peripheral blood flow and the counter-current heat exchange are prominently illustrated by the reduced temperatures of the sparsely feathered thigh and the near-ambient temperatures which occur in the leg and foot regions when the animal is exposed to low ambient air temperatures. Thus, the European starling is able to cope with low ambient air temperatures without appreciably affecting the necessary stability of the core temperature. However, negation of the insulating properties of the feather coat would most likely over-tax the physical as well as the metabolic thermoregulatory mechanisms resulting in excessive heat loss from the body core and ultimate functional failure of the central nervous system. Such a failure would result in the animal's death. The energy budget of a relatively small bird such as the European starling is not sufficiently great to counteract undue body heat loss for any appreciable duration of time. For this reason, the feather insulation is of critical value for the survival of this animal.

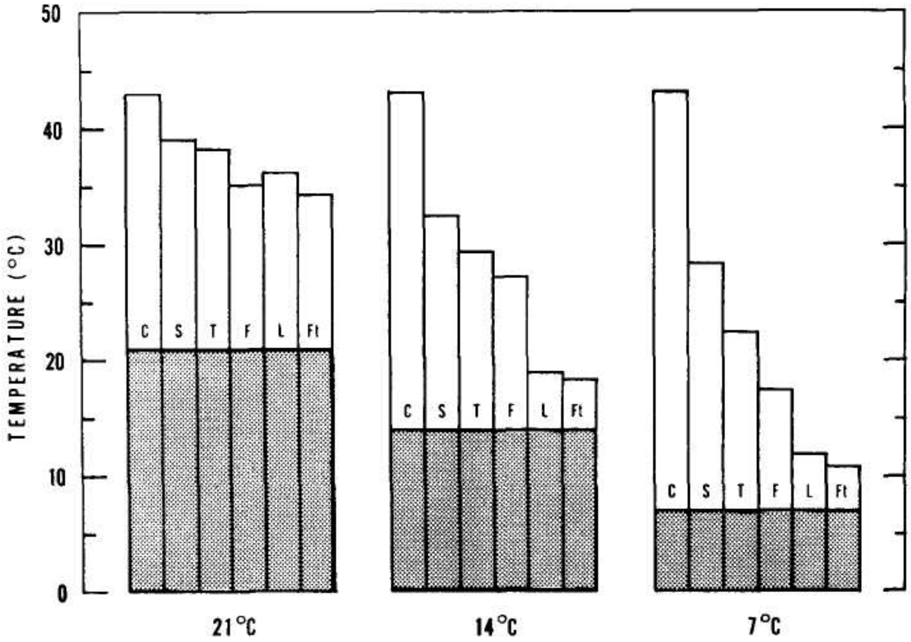

Figure 2. Temperature of the body core and various regions of the body shell in adult female European starlings, Sturnus vulgaris, as a function of the ambient air temperature. Histobars present the average temperature for five individuals at each ambient air temperature. The site of temperature measurement is given within each histobar where: "C" = deep core temperature, "S" = temperature of the skin surface over the pectoral muscles of the breast, "T" = temperature of the skin surface of the sparsely feathered thigh, "F" = temperature at the interface between the breast feathers and the ambient air temperature of the environment, "L" = temperature of the leg and, "Ft" = temperature of the top portion of the foot. All temperature measurements were made in an environmental chamber via thermocouple. All temperatures presented are those at the time the temperature of the body region reached equilibrium with the ambient air temperature. The shaded portion of the figure indicates the ambient air temperature to which the animals were exposed.

EXPERIMENTS ON NEGATION OF FEATHER INSULATION

1. Feather removal

The value of feather insulation with respect to thermoregulation was studied by clipping the feathers (except from the wings, head, and tail) from adult female European starlings. These animals were subsequently exposed to several ambient air temperatures and a 12-hour daily photoperiod. All animals were previously maintained in outdoor aviaries under natural environmental temperatures which had a daily range from about 10 to 23° C.

Removal of much of the feather coat results in a relatively acute stress condition when the animals experience cold environmental temperatures. Groups of four birds each were exposed for 72 hours in an environmental control chamber to ambient air temperatures of 7°C. (two of the four animals died), 14°C. (two of the four animals died), and 21°C. (no deaths occurred). Food and water were provided *ad libitum*.

2. Chemical negation of feather insulation

a) Starlings exposed to natural ambient temperatures.

Temperature-sensitive radio transmitters were implanted within the coelomic cavity of three adult female starlings. These animals were then maintained in an outdoor aviary for several weeks which is sufficient time for complete recovery from the implant surgery.

At sundown on 21 February, 1972, two of the three animals were thoroughly soaked with a 33% v/v solution of Turgitol® Nonionic TMN (trimethyl nonyl ether of polyethylene glycol) in water and promptly returned to the outdoor aviary. Ambient air temperature was 16°C. and wind velocity about 2 miles per hour at the time the animals were treated with the wetting agent. Deep body temperature was continuously monitored from these animals prior to and following application of the wetting agent. Food and water were readily accessible at all times.

The deep body temperature of all birds was 43°C. at the time two were treated with the wetting agent solution. The core temperatures of these animals was drastically reduced upon application of the wetting agent and both died within 45 minutes after treatment at which time the deep body temperature had decreased to about 25°C. The untreated control bird maintained a deep body temperature of 43°C. The ambient air temperature remained at approximately 16°C. during the duration of time between application of the wetting agent and the death of the treated animals (Figure 3)

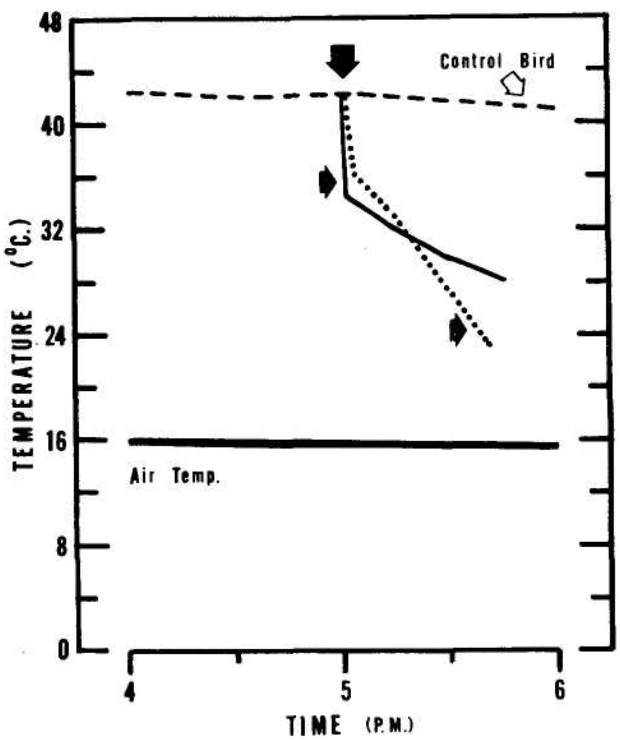

Figure 3. Deep body temperature of three adult female European starlings, Sturnus vulgaris, maintained under natural environmental air temperatures. Deep body temperatures were continuously monitored via temperature-sensitive radio transmitters implanted within the coelomic cavity of each animal. The broken line to the left of the large solid arrow indicates the average deep body temperature of all birds, to the right of this arrow the broken line indicates the deep body temperature of a single, non-treated starling. The large solid arrow indicates the time that two of the three starlings were thoroughly soaked (except for the head region) with a 33% solution of Turgitol® TMN in water and promptly returned to the large outdoor aviary. The deep body temperatures of these animals subsequent to treatment with the wetting agent are given by the solid and the dotted lines designated by the numbered arrows. The termination of the solid and dotted lines indicates time of the animal's death. The treatment with the wetting agent was made at sundown on 21 February 1972 when the ambient air temperature (shown as the heavy solid line in the lower portion of the figure) was about 16°C, with wind velocity about 1-3 miles per hour. Ambient air temperatures and wind velocities were essentially stable from the time of treatment to the time of death of the two starlings.

The dramatic demise of the two animals treated with the 33% wetting agent solution documents that the European starling cannot survive chemical negation of the feather insulation when exposed to moderately cold ambient air temperatures.

b) <u>Starlings exposed to relatively warm ambient air temperatures</u>.

Three adult female European starlings were implanted with temperature-sensitive radio transmitters and maintained indoors for several weeks at an ambient air temperature of 23°C. and natural photoperiods penetrating through several large windows. At sundown on 21 February 1972, two of the animals were treated with 33% wetting agent as previously described. Deep body temperature was continuously monitored from all three animals.

Both of the treated animals exhibited an initial drop in deep body temperature after application of the wetting agent. However, their subsequent core temperatures were not appreciably different from those of the control animal (Figure 4).

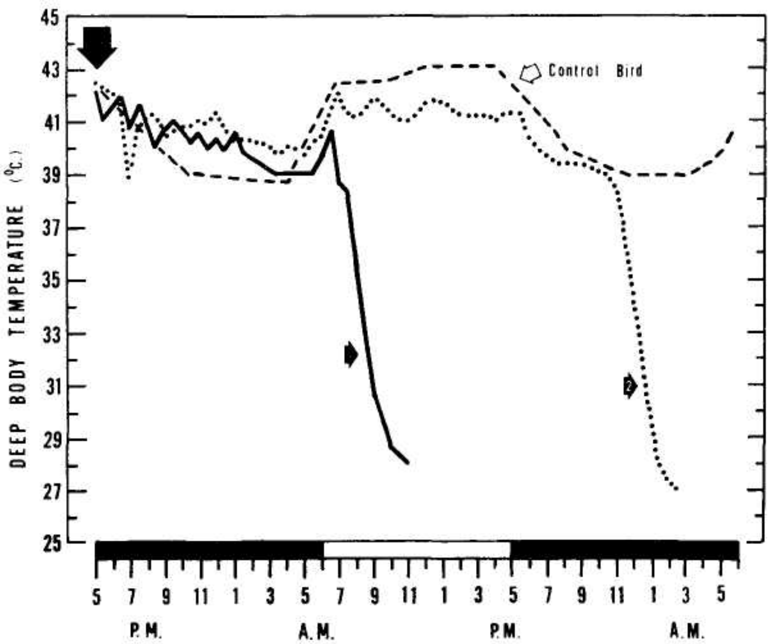

Figure 4. Deep body temperature of three adult female European starlings, Sturnus vulgaris, maintained under relatively warm and stable ambient air temperatures. The temperature of the body core of all animals was continuously monitored via temperature-sensitive radio transmitters implanted within the coelomic cavity. All animals were maintained indoors at a stable ambient air temperature of 23°C, and the natural daily photoperiod (hours of light and of darkness are respectively shown as open and solid bars along the base line of the figure) of 21 February 1972. The large solid arrow indicates the time that two of the animals were thoroughly soaked (except for the head region) with a 33% solution of Turgitol® TMN in water. The deep body temperatures of the animals treated with the wetting agent are presented as solid and dotted lines indicated by the numbered arrows. The termination of these lines indicates the time of death for these two starlings. The deep body temperature of the untreated starling (control bird) is given as a broken line indicated by the open arrow.

Further, the deep body temperature of the treated animals did not drop to as low a level as that of the non-treated starling during the hours of darkness. All animals exhibited a rise in core temperature beginning at dawn but neither of the treated animals achieved a core temperature as high as the control bird. Moreover, one of the treated animals lost thermoregulatory ability and showed a drastic drop in deep body temperature with death resulting about five hours after dawn. At this time the animal's deep body temperature had decreased to 27.5°C.

The remaining treated starling maintained deep body temperature (although considerably lower than that of the control bird) throughout the daylight hours. However, at about sundown, this animal also showed a loss of ability to maintain core temperature and succumbed during the night with a deep body temperature of 25.5°C. This animal exhibited symptoms of severe chemical irritation to the dermal surfaces and it may well be that this was the proximate cause of death. Regardless, these results indicate that the 33% wetting agent solution is not as efficient (in terms of time to death of the animal) at 23°C. as it is at 16°C.

EXPERIMENTS ON THE EFFECTIVENESS OF WETTING AGENTS AS A FUNCTION OF THE CONCENTRATION OF THE SOLUTION AND THE AMBIENT AIR TEMPERATURE

Studies were conducted to determine the effects of several concentrations of the wetting agent when applied to adult female starlings maintained under several different ambient air temperatures. Groups consisting of four birds each were treated with the wetting agent solution as previously described. However, each of these groups was treated with a different concentration (33%, 20%, 10%, and 1% v/v) of the wetting agent. After application of the wetting agent, these four groups were promptly placed under an ambient air temperature of 7°C. An additional four groups were treated as above and exposed to an ambient air temperature of 14°C, and another four groups were treated and exposed to ambient air temperature of 21°C. All groups were given a 12-hour daily photoperiod, and wetting agent treatments were made at sunset. Food and water were provided ad libitum. The results of this investigation are presented in Table 2.

Table 2. Mortality of adult female European starlings (number of deaths/number of birds treated) as a function of treatment with various concentrations of wetting agent (Turgitol® TMN) and exposure to various ambient air temperatures. (See text for method of application of the wetting agent.)

CONCENTRATION OF WETTING AGENT (%)	AMBIENT AIR TEMPERATURE		
	7° Centigrade	14° Centigrade	21° Centigrade
33	4/4	4/4	4/4
20	4/4	4/4	3/4
10	4/4	3/4	3/4
1	2/4	2/4	0/4

The higher concentrations of wetting agent applied (20 and 33%) were lethal to nearly all the birds regardless of the ambient air temperature. Animals which survived longer than eight hours after treatment at these concentrations exhibited a pronounced dermal rash. Those that died prior to eight hours after treatment were not so afflicted at time of death. The 10% concentration was also quite effective in causing mortality at any of the ambient air temperatures tested but no skin irritation was noticed regardless of time from treatment to death of the animal. The 1% concentration resulted in death to one half the individuals maintained at 7 and 14°C, but was not lethal to starlings held at 21°C. These data represent the near-maximum efficiency of the wetting agent solution (given without additional water applied after treatment) since the animals were thoroughly soaked except for the head region. Such a complete soaking would be difficult to achieve under operational field conditions.

DISCUSSION

The introduction of the European starling to North America has created many problems including: a) replacement of several native birds in certain areas of the country, b) distress to the human inhabitants of many metropolitan areas, c) at least one documented crash of a commercial airplane fatal to the passengers and, d) damage to agricultural crops and feedlots which reportedly runs into millions of dollars annually.

The concept that the number of pest bird species could be reduced by destroying the insulation efficiency of their feathers was apparently first formulated in the late 1950s at the Patuxent Research Center, U.S. Department of the Interior, Bureau of Sport Fisheries and Wildlife. Since that time, there have been a number of attempts to employ this technique on an operational basis. Generally, the method has been to treat the problem birds with a wetting agent (via aerial application) at the time they are gathered into large flocks on the roosting area and for this reason are relatively vulnerable to such a procedure.

Most attempts to reduce the numbers of pest birds via application of wetting agents have been made in the eastern, northern, and the mid-western sections of the U.S. These attempts have met with varied success, essentially as a function of prevailing environmental conditions. Relatively cold temperatures and/or precipitation following the application of the wetting agent are environmental conditions which greatly increase the efficiency of this method of bird control. Applications of wetting agents during mild temperatures and/or with no following precipitation have not been as successful in reducing pest bird populations. Thus the question arises as to just what are the physiological and environmental parameters operant with respect to the success or failure of wetting agents to induce lethal hypothermia in pest birds.

Our investigations on the thermoregulatory biology of the European starling are admittedly still preliminary. However, the results of these studies have provided some information on the effects of negation of the feather insulation in this species. These are:

1. The European starling has a pronounced regular daily cycle of the deep body temperature, the range of which is about 4.5°C. This daily cycle is probably the direct result of a general reduction in metabolism and muscular activity during the hours of darkness, and in no way represents an abnormal physiological condition. In fact, this daily reduction in deep body temperature may have a distinct survival value since it represents an energy-conserving mechanism. However, since vital process must be maintained, it seems reasonable that starlings would physiologically resist reduction of core temperatures much below that which occurs during hours of darkness.

2. The body shell provides very efficient insulation for the interior regions of the body. The temperature of body extremities of the starling fall to low levels during exposure to cold air temperatures. This reduces the temperature difference between these regions of the body and a cold ambient air temperature and thus greatly reduces the amount of heat lost from the extremities (and hence from the body core) to the environment. Skin temperatures over the major portions of the body may remain relatively high, but these regions are protected from excessive heat loss by the highly efficient feather insulation.

3. Mechanical removal of the feather coat via clipping does not appear to be as effective a means of inducing lethal hypothermia as chemical negation of the feather insulation. A plausible explanation for this is that the chemical negation, in addition to destroying the insulating properties of the feathers, also facilitates evaporative heat loss because of the water component of the wetting agent solution. Mortality of feather-clipped birds was probably not the result of psychological shock since only those held under the lower air temperatures (7 and 14°C.) succumbed to this treatment.

4. Starlings thoroughly soaked with a high (33%) concentration of the wetting agent die about 45 minutes after treatment even when maintained under relatively warm (16°C, 61°F.) ambient air temperatures and very low wind velocities. The rapidity of death of the two animals so treated is somewhat surprising and it may well be that psychological shock operates synergistically with the hypothermic effects of the wetting agent application. Regardless, it is indeed doubtful that such a complete soaking as these animals experienced could be attained during operational field applications.

5. Both the concentration of the wetting agent and the severity of the ambient air temperature influence the effectiveness of this method for pest bird control. Thoroughly soaking starlings in high concentrations (20 and 33%) of wetting agent is lethal to nearly all the treated birds regardless of ambient air temperatures. However, reduced mortality results from the application of lower concentrations of wetting agent and warmer air temperatures.

A Parting Comment

During these investigations we became increasingly impressed with the possibilities of this method for pest bird control. We believe that it can be effective even under the relatively mild climatic conditions generally prevailing in the vicinity of the major starling roosting sites in California. Because of this, we plan to investigate the feasibility of this technique in considerable depth in a series of future studies. These will include many other environmental parameters such as wind velocity, relative humidity, food availability, circadian susceptibility rhythms, age-sex factors, regions of the body treated with wetting agent, degree of treatment, and many others.

ACKNOWLEDGEMENTS

This study was made possible by the Agricultural Commissioners of Napa and Sonoma Counties who furnished the starlings, by facilities furnished by the Institute of Ecology, University of California at Davis, and by financial support from the State of California, Starling Control Project. (We thank Rex E. Marsh for his critical review of this manuscript.)

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