Adaptations of Vertebrates to Extreme Polar Environments

Polar environments are regions found in and immediately close to the Arctic and Antarctic Circle. The Arctic Circle is everything with latitude north of 66.5ºN whereas the general term 'arctic' can refer to non-forested areas found north of the coniferous forests of the Northern Hemisphere *(Lomolino MV et al, 2010)*. The term 'Antarctic' can be viewed as its Southern Hemisphere compliment. In the context of this essay, the generalized term will be used because these regions comprise of extreme polar environments. Available habitats for vertebrate life in these areas are characterized by sporadic blizzards of intermittent lengths, winter temperatures as low as -60ºC, scarcity of food and regular seasonal differenced in photoperiod *(Blix AS, 2016)*. Due to this harsh environment, the species richness found in polar regions is relatively low compared to other habitats. Vertebrate species that do live in these regions have highly specialized adaptive methods that allows them to prosper and fill the unique ecological niches present in the habitats. This essay will discuss three of major unusual features of polar environments and how different morphological, physiological and behavioural traits have evolved in different vertebrates to cope with these changes.

Adaptations to the Cold

Perhaps one of the most obvious characteristics of polar environments are the extreme low temperatures. The ambient air temperature often persists at -40ºC for prolonged periods and the lowest ever recorded temperature on earth was found in a polar region at -89.2ºC in Antarctica *(Turner J et al, 2009)*. The surrounding oceans may have temperatures close to or even below 0ºC. It is therefore evident that animals which rely on external ambient temperatures cannot survive easily in these conditions, therefore the vast majority of terrestrial animals are endothermic not ectothermic. Only four species of reptiles can be found in the Arctic region *(Huntington HP, 2001)*. Homeothermic vertebrates must maintain a huge gradient between external and internal temperatures and have thus acquired adaptations to balance heat loss against a minimum rate of metabolic heat production. This is most favorably achieved by reducing the amount of heat loss to the external environment. This adaptation can be easily divided between morphological, physiological and behavioural modifications.

One of the major morphological defenses against particularly cold temperatures in polar regions by vertebrates is the growth of fur, plumage or a layer of blubber to insulate the body and prevent heat loss. For example, this type of morphological adaptation can be observed in the Arctic *Rangifer tarandus*, commonly referred to as reindeer. The fur of such species during winter months consists of hollow and thick guard hairs with a layer of dense underfur beneath. It would be metabolically inefficient to maintain this fur throughout the entire year and thus during summer months the fur is slightly thinner. In the winter coat, the length of guard hairs exceed the actual coat thickness because they are not entirely perpendicular the skin. However, through piloerection they can be erected to reduce heat dissipation by approximately 30% by trapping warmer air closer to the skin. The individual hairs are especially broad due to the presence of an air-filled medullary space providing yet more insulation. The underfur is much denser than the guard hairs and is important as it reduces air movement within the fur itself. This means that less heat will be lost through the process of convection. The calves are born with wool-like fur which is also hollow to provide immediate protection, and by their first autumn the fur coat structurally resembles that of adult hairs, taking approximately just half a year to reach full fur maturity *(Timisjärvi J et al, 1984)*.

Although fur is an efficient adaptation to reduce heat loss in response to polar environments, its capability is greatly reduced when wet. This is likely to be due to the fact that water conducts heat 25 times faster than air *(Blix AS, 2016)*. This has caused aquatic homeothermic vertebrates to adopt a different morphological trait to reduce heat loss in the form of blubber. Blubber is a form of fat that is much thicker and contains many more blood vessels. In some marine polar animals, such as bowhead whales, this blubber may be as thick as 30 cm *(Blix AS, 2016)*. It is clear that these two morphological adaptations aid the survival of polar vertebrates by decreasing the amount of bodily heat loss in the extreme low temperatures.

As well as these morphological adaptations, vertebrates have evolved to have a variety of different and often unique physiological mechanisms which increase their ecological fitness in cold conditions, again by preventing heat loss. A major problem to overcome in vertebrates regarding heat loss is the large surface area of appendages with a relative lack of insulation. Excessive heat loss is avoided by efficient vascular mechanisms which facilitate counter-current heat exchange between the veins and arteries. Although there are slight differences between species, the general mechanism relies on the same structure. Two concentric conduits (a vein and an artery) run close together resulting in arterial blood being cooled by venous blood which has been chilled in the appendages and vice versa, without any liquid exchange *(Blix AS, 2016)*. Another circulatory mechanism which is adaptively significant is the cutaneous vascular plexus present in the arctic fox *Alopex lagopus*. The tissues found in the feet of these animals naturally come into direct contact with the surrounding substrates. Four unbranched arteries carry blood straight through the paw pad to a cutaneous plexus on the surface but no major vessels supply the core of these pads. The actual surface therefore is specialized for maximum efficiency due to its location in the tissue that comes into contact with the below freezing substrate. These tissues are therefore the place where the freezing of cells due to temperature of the substrate theoretically would take place, and thus must be selectively perfused with blood to avoid this phenomenon. Although metabolically this is expensive, it results in a mechanism that is advantageous to the organism. It has also been theorized that is it probably this mechanism that shunts excess heat from metabolic reactions to the snow surface *(Henshaw RE et al, 1972)*.

The actual chemical composition of blood found in vertebrates may also differ to counteract the freezing temperatures. For example, certain Antarctic fish species are able to avoid freezing despite the fact their habitat is sub-zero seawater laden with ice crystals. This is especially unusual because fish are ectotherms and therefore do not maintain their own body temperature but rely on external temperatures to control their internal conditions. The blood of these fish, such as the species *Trematomus borchgrevinki*, contains specific glycoproteins. These are adsorbed onto the surface of ice crystals thus disrupting their formation and thus reducing the freezing point of the blood to approximately -2°C *(Devries AL, 1971)*. These examples of circulatory vascular adaptations demonstrate how vertebrates can be physiologically adapted to overcome problems present in cold polar environments.

As well as morphological and physiological adaptations, many vertebrates have evolved certain behaviours to deal with the cold. For example, many birds in sub-polar and polar regions, such as the redpoll, exhibit the behaviour known as 'balling up'. This is when the head is folded back over the shoulder and the beak is buried in between the nape and back transforming the bird into a roughly spherical shape. This is advantageous because spheres are the shapes with the lowest surface area to volume ratio. This means that the surface area over which heat is lost decreases but the actual heat producing mass itself remains constant *(Steen J, 1958)*.

As well as on individual scales, animals living in colonies may also reduce the overall surface area through behavioural methods to reduce heat loss, for example through the process of huddling. By remaining close together the group's mass remains the same but the surface area is reduced. However, this is a surprisingly uncommon behavioural strategy, observed in no arctic mammals or birds. Nonetheless, emperor penguins found in Antarctica are known to extensively huddle during harsh winters *(Blix AS, 2016)*.

The morphological, physiological and behavioural adaptations discussed thus far all benefit an organism's survival with regard to extreme low temperatures in polar environments. However, other adverse and unusual conditions persist in these regions which vertebrates must also respond to on an evolutionary scale.

Adaptations to Food Availability Variation

Much as the air temperature and photoperiod length changes seasonally in polar regions, as does the availability of food, and naturally these different inconsistencies are intrinsically linked. Vertebrates deal with this by having again a variety of different morphological, physiological and behavioural responses to seasonal changes in food availability.

One metabolic physiological response to low food availability is the reduction of basal metabolic rates. This makes it possible for certain vertebrates to save energy and thus they are not required to consume as much. This adaptation can be observed in muskoxen and reduces the rate by up to 30% *(Blix AS, 2016)*.

Behavioural adaptations to food variation and scarcity may also include migration such that a vertebrate species can move geographically to find the best supply of food. For example, this can be observed in the species *Bubo scandiacus*, or snowy owl. The species breeds in the Arctic Circle where there is generally an abundance of lemmings. If this abundance is maintained throughout the year then the species can over winter in these regions. However, often lemming numbers drop in the winter months and so snowy owls migrate southwards to find more suitable areas of habitat with a greater abundance of food *(Parmelee DF et al, 2015)*.

Hibernation is another behavioural adaptive strategy whereby organisms may halt metabolic processes when food is in short supply. For example, pregnant polar bears will do this by accumulating as much as 40% of their body mass as fat before entering a den. They will then remain here for many months without eating, urinating or defecating while fat is combusted for energy *(Blix AS, 2016)*. This allows these vertebrates to avoid times of extreme food scarcity due to the polar environment.

Adaptations to Photoperiod Variation

Polar regions are unique in the sense that they have long continuous days in summer and continuous nights during the winter months. In between this time, there are periods of alternating day and night where the length of the day may change by more than 30 minutes per day. This is highly unusual compared to habitats of other latitudes, and is something that must be sensed and dealt with by vertebrate species. This is because the photoperiod may determine many important ecological behaviours of an individual, such as time of foraging. It is thought that vertebrates have evolved a complex mechanism whereby information on lighting conditions is received in the eyes and then transmitted to the pineal gland which produces melatonin to synchronize the inherent daily rhythms of the body and behaviour *(Blix AS, 2016)*. This is an example of how polar vertebrates have evolved a mechanism to respond to a unique environmental factor in polar regions.

Conclusion

This essay has discussed a range of morphological, physiological and behavioural adaptations that have evolved in vertebrate species in response to unusual and adverse conditions experienced in polar regions. However, it must be noted that although it is possible to split the environmental conditions and subsequent adaptations up as such, in reality they do not exist as distinct factors but all have an effect on each other or require the others to exist. For example, different adverse weather conditions throughout the year may affect the population size of available prey for predators or other weather-related events such as over-icing may change the amount obtainable plant material for herbivores and omnivores. Therefore, food availability and the discrepancy in consistency of this availability over time is not in itself a distinct environmental condition, but is affected by many other circumstances which a vertebrate must simultaneously respond to on an evolutionary scale.

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