Basic Course in Ornithology
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Lecture -7
Physiology

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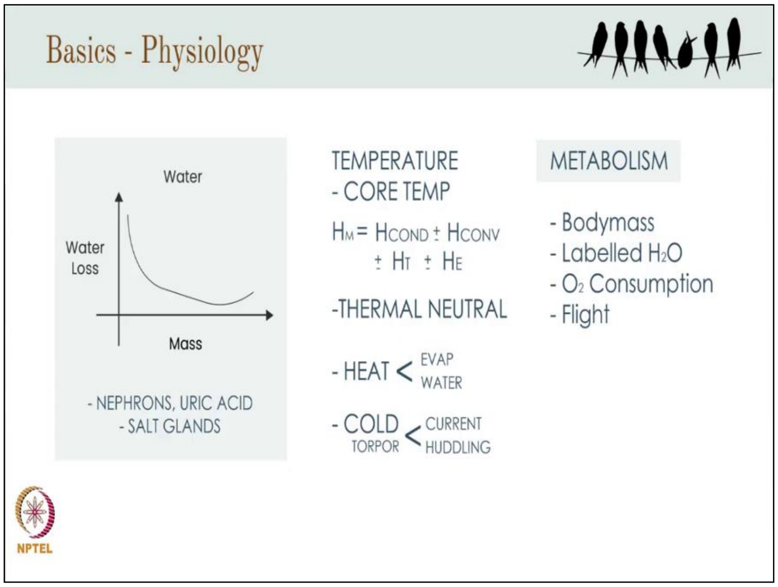

Hi everyone! So, to follow up on the basics of anatomy lecture that we just finished up, I am now going to cover the next step which is the basics of physiology. Physiology is aimed at understanding how the anatomical components that make up a bird or any other organism work. So, you have got all the structures in place now we tend to talk a little bit about function and again this is not a comprehensive lecture in that with the time available I do not want to go through each and every system and how it works.

But I want to underline the basic themes of comparative physiology. Comparative physiology seeks to understand broad principles by looking at a number of different organisms all right. This is based on the philosophy of one of the founding fathers of physiology August Krogh. His principle stated that for every question there is an organism in which it can be most conveniently studied.

And that is the guiding principle of comparative physiology which is all themed around three… a very simple idea let us start with that very simple idea and then we will go ahead from there okay. That simple idea is called the surface area to volume ratio of every organism it is the most important parameter that dictates everything. We are going to talk about three of the most important components of physiology right now.

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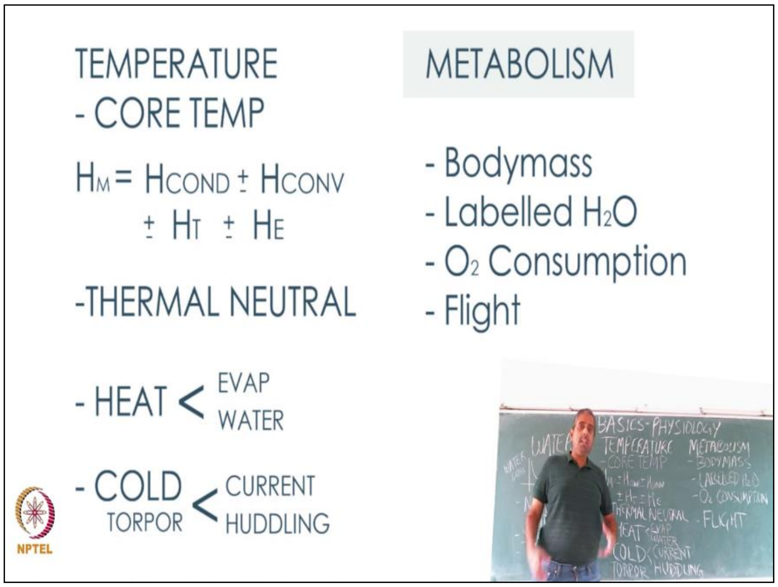

We are going to talk about water we are going to talk about temperature and we are going to talk about metabolism and all of these are significantly influenced by the surface area to volume ratio because smaller organisms have a higher ratio. They have more surface area per unit volume and that means they lose water faster that means they lose heat faster and that means they have to have a higher metabolic rate to keep up with all of these.

And I hope you can understand therefore that the constraints of body size are very different for different animals. So, you smaller animals experience completely different physiological conditions than larger animals and this drives the diversity of physiological strategies that you see in the animal kingdom. And so let us discuss this big use this basic principle as a platform to then discuss how birds have thanks to a bunch of physiological adaptations managed to colonize some of the most extreme environments on the planet.

You have got Emperor penguins in Antarctica that can survive in temperatures of minus 50 or minus 60 degrees and on the other end of the spectrum you have got the Greater hoopoe lark which in the Sahara desert and the Arabian peninsula can tolerate ground temperatures as high as nearly 70 degrees Celsius that is a huge range of temperatures. And birds' physiology enables them to actually survive these temperatures and not only survive, thrive in them.

And that is comes down again to three things water, temperature and metabolism these three are not exclusive of each other as you realize they are very interrelated and I hope that interrelation will come out as I progress with this lecture. So, let us talk about water. Now as I mentioned earlier small organisms tend to lose more water all right per unit mass. So, per unit mass smaller obviously they are not going to lose absolutely as much water.

Because a small bird and me will not hold the same absolute amounts of water but if you divide it by the mass if you get water loss per unit mass smaller birds lose water faster and that comes down to the surface area to volume ratio. Remember most things in physiology can be explained by the surface area of the volume ratio and in order to do that they have systems in place to conserve water because water is the primary solvent for the salts and ions that are.

So, necessary for a bird to function and if the water balance changes. So, to does the osmotic balance of a bird and osmotic even though birds are more tolerant than mammals. So, because they do not feed or excrete for long periods of time they can tolerate higher salt concentrations that does not mean this can go on indefinitely. So, birds are ways of conserving water one of them being the nephrons okay.

Because birds need a lot of water in order to carry out flight and other demands nephrons as you well know consist of convoluted tubules and the Loop of Henle and all of these have differing osmotic concentrations with the surrounding fluid. So, that they draw out water from the urine after when it passes into the kidneys and they concentrated. So, that they save as much water as possible and get rid of as much unnecessary salt as possible. At the same time they can also be used to absorb certain ions back into the bloodstream all those are very critical.

Because the nephrons of birds that live in desert areas where water scarcity is high are large and very good at water reabsorption. So, birds can take up a lot of water and retain a lot of water because losing water could be fatal. In addition, birds unlike mammals excrete uric acid. Now uric acid is non-soluble it is highly concentrated. So, therefore it draws out very little water and most of the salts can be avoided in this way and water can be conserved.

So, that is very important in areas where you need to maintain salt but some birds live in marine environments where they are exposed to way too much salt partly because they are often drinking salt water like Petrel and Albatross that live out in the sea ,they have specialized salt glands up here in the forehead that actually excrete or chuck out the excess salt as crystals. They excrete the additional salts and that way they can maintain their osmotic balance at the other extreme.

So, all the physiology is about dealing with opposing extremes too little of something is bad too much if something is bad you want to maintain things within a range and you have regulatory mechanisms that help you maintain things within a range. And the more water you have and the more salt balance you have the less likely you are to be affected by other extremes. And in particular that is true of extremes in temperature.

Now birds have a slightly higher body temperature than mammals do and as a result a slightly higher metabolic rate as well why do you think that might be well it is because bird fly. And when something flies it has to maintain a certain higher metabolic rate and therefore ends up with a certain higher body temperature why is that because metabolic reactions produce heat. The heat produced by a metabolic reaction is balanced out in four ways.

Heat can either be acquired or lost by conduction, by convection, by radiation or by evaporation okay. Evaporation is very important for birds living in hot environments arid areas like deserts because when water evaporates it brings the temperature down. Because of the latent heat of evaporation. So, many of us sweat for instance because sweat is a form of evaporative cooling all right and all of this serves to stay safe keep a bird in what is called the thermal neutral zone.

The thermal neutral zone means that a bird does not have to change its metabolic rate to maintain its temperature within this zone. If the temperature drops lower than this the bird has to increase metabolism to produce more heat if the temperature goes above this the bird has to decrease metabolism and lose heat. Again, the fundamental principles surface area to volume ratio maintaining things within a certain range always.

And of course, the thermal neutral zone differs from species to species depending on what heat adaptations they possess but smaller birds tend to lose and gain heat faster. So, when they are outside the thermal neutral zone their metabolic rates have to change much more rapidly to keep up with with changes in the external temperature. So, what can a bird do about this I will let you pause I will pause for a minute to let that sink in.

I hope you have had a couple of ideas now. Birds that have this trade-off within the thermal neutral zone can do what we do if things get too cold that we have to produce metabolic heat to keep up we come inside out of the cold. We can also come inside out of the heat move into the shade and birds often do that. Many birds and one of my favorite examples of that is Lapwings in warmer areas tend to stand under sources of shade during the heat of the day that helps them to get as close to their thermal neutral zone as possible.

So, that they do not have to dump all this excess heat all right. Other birds that live in colder areas tend to roost in hollows in trees which are warmer than the outside because they retain heat. And when they retain heat these birds can actually maintain their thermal neutral zone and conserve energy they do not have to burn as much as much fuel to produce heat if they can rely on slightly more friendly ambient temperatures.

I hope this is making sense to all of you but you may ask surely you know birds cannot always find you know shade or warm areas to get away from extreme temperatures and this is especially true of smaller birds like the Golden-crowned Kinglet. Okay. So, one of my favorite physiologists Bernd Heinrich has done a series of these experiments with Golden-crowned Kinglets in New England, USA.

And these birds are about so big and can survive temperatures of minus 50 degrees that is not usually true of smaller birds. Because they lose heat very quickly and they freeze Golden-crowned Kinglets use tree hollows where they are available to roost but there are occasions where they cannot get away from the cold or from. And similarly, there are other birds like the Greater hoopoe lark that cannot escape extreme heat because it lives in flat desert areas with no shade.

What can they do about it? when gotten this way. One way out of extreme heat is to cool by evaporation. Okay. and you will see many birds do this their throats appear to flutter and their bills are open this is called gular flutter. Gular flutter helps evaporate water faster and is a means of keeping yourself cool through evaporation. But evaporation comes with another problem in order to have evaporative cooling work you need a lot of water.

If you do evaporative cooling in areas where water is scarce you could dehydrate and die extremely quickly if you are a bird. So, what do they do about this some birds get water from their diets that allows them to support a certain degree of evaporative cooling. Others like Sandgrouse fly large distances in the early morning and the late evening when temperatures are cooler they fly to water holes and drink a huge amount of water and that supports the ability to cool evaporatively later on in the day okay.

They actually some of them will go and soak themselves in water this is partly to take water back to their nestlings as well. So, the breast feathers of the sand grass are adapted to hold water. So, that the nestlings can pull the water out of the feathers and they do have enough water to carry out evaporative cooling okay. One of the best examples of that is a camel. A camel is not a bird but a dehydrated a dehydrated camel has larger fluctuations in temperature than a well hydrated camel.

So, to go back to what I mentioned earlier water temperature and metabolism are inextricably linked as is all of physiology they are not isolated systems they are all interconnected and in order for that interconnection to work you have to have enough water available for evaporative cooling and you have to be able to do other things too you can reduce your metabolic rate. So, the Greater hoopoe lark has a low metabolic rate for its size because it does not want to be producing too much heat or it will overheat.

The Greater hoopoe lark also has lipids called ceramides in its skin which minimize water loss. So, as opposed to trying to evaporatively cool the Greater hoopoe lark tries to keep as much water in itself as possible and it also keeps a lower metabolic rate and as a result you can survive some of the highest temperatures of any bird. Again, adjust metabolism, adjust water and you can trade off and survive in an extremely hot environment.

What do you do when things are cold? One way is to boost your metabolism to produce more heat but that like evaporative cooling comes with the cost. You burn fuel extremely quickly and if food is scarce, you cannot burn fuel that quickly because what are you going to replace it with? You have to replace it with something some food and food is not always easy to find in harsh conditions. So, birds have a number of ways of dealing with the cold.

One of those is to maintain their core temperature all of us have a core temperature the closer we are to the core the closer we are to a certain optimum temperature for our physiology to function and our extremities often are at a slightly lower temperature. Birds can take that to great extremes using all their energy to make sure that their core their vital organs stay warm and allowing the other extremities to drop in temperature.

That is one way of keeping yourself going without overloading your energetic cost. These extremities like the feet of birds also have what you call a counter current. So, the blood vessels form like a U-shape and warm blood going this way towards the feet actually exchanges heat with cold blood going the other way and warms it up. So, that way the warmth is sent back to the core of the bird you know the blood the oxygen that goes to the feet still happens.

So, the blood carrying oxygens is still sent to the feet but without losing any heat in the process because obviously when blood is pumped out from the heart it is warm but you do not want that warmth leaking out through your feet. So, you warm up the blood going in the opposite direction and you get the heat back to the core this is called a counter current heat exchanger. They are very common in mammals as well some mammals use them to cool their brains down others use them to prevent heat loss through their fins like whales and dolphins.

And you find this counter current pattern rather widespread in biology because it is a very efficient way of conserving heat. But this by itself is not going to work particularly for Emperor penguins in Antarctica okay and what you find Emperor penguins do many of you have probably seen this in nature documentaries is they huddled together. What happens is when they huddle together, they effectively lower the surface area to volume ratio of the entire flock and therefore reduce heat loss.

This is particularly good for the birds that are in the center but the birds on the outside will lose heat faster. So, how would this system persist you cannot have birds on the outside losing heat faster eventually they are all freeze. So, what they do is they take turns birds go from the center to the outside from the center to the outside and through this process they effectively reduce the surface area of the volume ratio and make sure individual birds do not get too cold.

Golden-crowned Kinglets also do this and huddling is a great way of conserving heat without increasing the energetic costs of metabolism. And this is particularly true when food is scarce because when food is scarce you do not want to waste precious energy keeping yourselves self warm. And in some cases, now a lot of people are under the misconception that these things happen because of temperature because it is too cold.

So, birds do this and mammals do this and other things like that but in reality, the phenomenon known as torpor, which is seen in some Nightjars and particularly Hummingbirds and is not because of cold temperatures it is because they have a failure to maintain the metabolic energy required to be active. So, imagine if it is gotten too cold but you do not have enough nutrition to be able to produce the heat.

So, you go into essentially sleep mode you are going to torpor your metabolic rate drops your metabolic reactions and body temperature all drop and only the most essential functions are maintained until such a time as energy becomes available again to arouse the birds from torpor. So, rather it is a well calibrated sort of emergency response to falling nutrition levels not necessarily falling temperatures and the same is true of hibernation in mammals etc.

Mammals that can find enough nutrition to maintain heat will not hibernate those that cannot will hibernate and that is to save energy rather than expended in metabolic heat production required to be active. So, as a result of all of this the trade-off between water between your metabolic rate and between the external temperature birds are able to regulate themselves within a certain range and are able to survive even the most extreme conditions.

Even birds that have a very high metabolic rate like Hummingbirds. Why do hummingbirds have a high metabolic rate? It is not just because they eat carbohydrate-rich diets but it is because hummingbirds are very small, they have a low body mass. All right? And metabolic rate per unit body mass is much higher for a small bird. Why is that again? Let us go back to the original concept I explained the surface area of the volume ratio.

You have to produce more heat to do the same things because you have a higher surface area to volume ratio and so lose heat faster. Does that make sense? If you are going to lose heat faster you need to produce more heat and so smaller birds have higher metabolic rates. Hummingbirds go to great extremes on that part. Because they have some of the highest metabolic rates known of any bird.

And per unit mass larger birds such as the Ostrich have much lower metabolic rates. And metabolic rate in order to maintain a metabolic rate and produce heat this exothermic reaction you need to actually use up oxygen and that is what ties into the respiratory system that I mentioned in the previous lecture on an anatomy that is one of the reasons birds need so much oxygen.

Because metabolic activities like flight and others are energetically expensive. They need huge amounts of energy and produce large amounts of heat per unit body mass. So, you need to be able to maintain high oxygen consumption. How can we figure this out? We can actually inject birds with doubly labeled water. So, whether the hydrogen and the oxygen of water are labeled? And when we do this, we can actually track the utilization of hydrogen and oxygen and figure out how much oxygen a bird is consuming.

The other way to do that is sometimes to fit them with a mask and measure them using a respirometer that will also tell you how much oxygen birds consume. And because of flight, the exercise physiology of birds is off the charts they have higher metabolic rates on average than mammals of the same size and that is all down to flight in large part. Because flight is energetically expensive, it consumes a huge amount of oxygen and in order for that to happen birds must not only have lungs that are very good at absorbing oxygen they must also have hemoglobin, the oxygen binding pigment that has a higher affinity for oxygen.

Many birds that have very demanding flights have more red blood cells again to absorb more oxygen and their flight muscles the muscles that power flight, the thoracic muscles are supplied with a very rich network of capillaries and veins. So that, a lot of oxygen can be supplied to these muscles simultaneously. So, again all of these physiological adaptations are related to oxygen consumption which in turn produces heat which in turn is related to water consumption and you see where I am going with this.

If you want to not overheat yourself. When flying you need to cool yourself down, you need to pay attention to water consumption and so on and so forth. You can think about this, when any of you are exercising because our exercise physiology is not that different in principle but the values of these can actually change quite a bit. All right? And the exercise physiology of flight is particularly pronounced in birds that live and fly at high altitudes.

Many birds are known to fly at ridiculous heights. Ruppell’s griffon vulture in Africa collided with the plane at I think 8000 meters and the Bar-headed goose which is one of the champions has been seen flying over Mount Everest, that is how high these birds can fly. Sometimes at 9000 meters above sea level where the oxygen content of the air is very low compared to down here in the low lens where I currently I am. And all these adaptations help them pull as much oxygen out of the air as possible to power this extremely strenuous energetically demanding activity that gets them from point A to point B.

They also of course have to pay attention to other nutrients because it is not just oxygen that is going to give them the energy oxygen helps metabolize or oxidize other nutrients which then produces the ATP that they need to power flight and in particular carbohydrates but more importantly fats are very important in the exercise physiology of long distance flight. That is why many birds fatten themselves up before migration okay.

Shore birds especially have staging points, they stop at various points around their migration routes and stuff themselves with fat rich foods triglyceride rich foods. So, that they put on weight and are able to burn this nutrition on these long flights, with a lot of oxygen to produce the power needed to fly at long distances. All right? So, that is something that I want to leave you with all of these are inextricably linked metabolism temperature and water are all linked to each other.

and I had use these as examples to illustrate that physiological systems are not independent of each other. Nervous system sensory physiology which you will hear a little bit more about when we talk about colour is also dependent on ionic balance which is dependent on water and metabolism. So, all the systems of a bird digestive systems how well you absorb nutrients dictates all of these parameters it can dictate your water balance.

It can dictate your ability to respond to different temperatures by regulating your metabolic rate. Okay? So, all of these are also linked to the digestive system of the bird physiological systems do not operate in isolation they are all linked and if you want to go to the bottom physics level principles that underlie bottom level physics principles that underlie most of bird physiology it is the surface area of the volume ratio and the constraints it imposes on a lifestyle of a bird.

And that is something that I hope, I have made clear to you with this lecture. With that I will end my lecture on the basics of physiology, it is not a comprehensive lecture like I said but it should serve the purpose to illustrate the general concepts that birds use when they are trying to get around and live in extreme often very harsh environments.

Thank you.