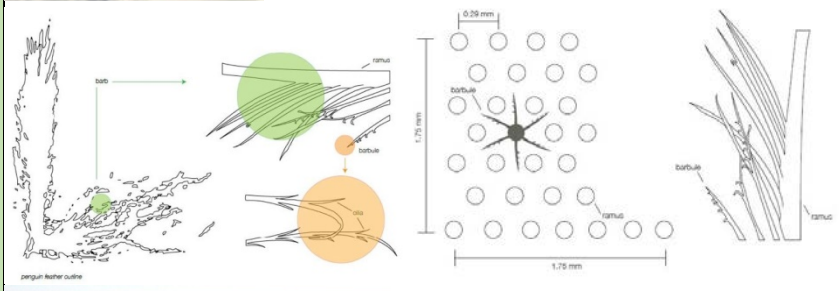
生物策略格式

KJC, 2019/10/21

類別	生物策略 (Strategy)
生物策略 STRATEGY	羽毛攫取空氣以提供溫暖 (Feathers trap air to provide warmth)
生物系統 LIVING SYSTEM	皇帝企鵝 *Aptenodytes forsteri* (Emperor penguin)
功能類別 FUNCTIONS	#保護免受溫度危害 #Protect from temperature
作用機制標題	企鵝羽毛利用絲狀結構並在身體周圍形成連續層，以捕獲空氣來維持溫暖 (Feathers of penguins trap air to retain warmth by being filamentous and forming a continuous layer around the body.)
生物系統/作用機制示意圖	    

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

企鵝的羽毛提供動態隔離的模式，可在空氣及水中提供良好的隔離效果，並在壓縮後自動恢復原來的蓬鬆。企鵝不尋常的地方，在其羽毛不像其他鳥類為成束的排列，而是均勻地覆蓋體表。企鵝的羽毛由外層「廓羽」 (pennaceous) 或羽片 (vane) 區域，以及內層「絨毛狀的副羽」(downy after-feather) 所組成的，相對於其他鳥類來說是短且硬的。羽毛的軸 (shaft) 上有肌肉連接，在水下時可以將它下壓成一緊密壓縮的水屏障，當他們回到陸地上時會再次豎直。羽片上半部會和鄰近羽毛平坦地重疊，像是重疊的磁磚，有助於形成

風和水的屏障。

較深的隔離層是由副羽構成的，副羽是由更小的部分組成，可形成有次序的網狀結構以製造攫取空氣的空間。例如巴布亞企鵝 (Gentoo penguin)，其每一根羽毛約有 47 個倒鉤，每一個倒鉤可有 1250 個羽小枝，由中央羽枝 (或軸) 以 60-80 度角度伸出，形成螺旋狀排列。每一羽小枝有自己的細微延伸物，即纖毛 (cilia)，一般認為可提供附著到其他倒鉤的相鄰羽小枝的機制，透過一種「滑黏」機制，使它們彼此只能在一個方向上移動。該結構的總體效果是產生羽小枝的均勻排列，從而在絕緣層內形成攫取空氣空間的均勻區域和厚度。一般認為這種滑黏機構在水下壓縮時與倒鉤中存儲的彈性能會相互作用，使得在返回陸地時可重新建立倒鉤和羽小枝之間的正確間隔，以獲得最佳的靜態空間並因此具有絕緣值。生物工程師不僅正在研究企鵝羽毛元件的結構排列，還研究它們的機械性能，以便開發出更有效的絕緣材料，這些材料可以捕捉到這種巧妙的自我組織特性，以及壓縮後可重新恢復「蓬鬆」 (loft) 的能力。

Penguin feathers offer a model for dynamic insulation, providing excellent insulation in both air and water and regaining loft automatically after compression. Penguins are unusual in that their feathers are not arranged in tracts, as in other birds, but instead are evenly packed over their surface. The feathers are short and stiff relative to other birds, comprised of an outer ‘pennaceous’ or vane region and a ‘downy’ inner ‘after-feather’. The shaft of the feathers have a muscle attached to them that can pull them down into a compressed water tight barrier when under water, and then erect them again when they come back onto land. The upper parts of the vanes of the feathers overlap their neighboring feathers flatly like overlapping tiles, contributing to a wind or water barrier.

The deeper insulating layer is made up of after-feathers that are comprised of ever smaller components that create an ordered network of elements to create trapped air spaces. In Gentoo penguins, for example, there are about 47 barbs per feather and each of the barbs may have 1250 barbules emerging at a 60-80 degree angle from the central ramus (or stalk) in a spiral arrangement. Each barbule has its own tiny extensions, cilia, that are thought to provide a mechanism for attachment to neighboring barbules of other barbs, allowing them to only move in one direction relative to each other by a sort of ‘slip-stick’ mechanism. The overall effect of this structure is to create a uniform arrangement of barbules and thus a uniform division of and thickness of the trapped air space within the insulative layer. This slip-stick mechanism is thought to interact with the stored elastic energy in the barbs during compression under water to re-establish the correct spacing between barbs and barbules when back on land, for optimal still air space and thus insulative value. Bioengineers are studying not only the structural arrangements of the feather elements of penguins but also their mechanical properties in order to develop more effective insulative materials that could capture this clever self-organizing characteristic and ability to regain ‘loft’ after being compressed.

文獻引用 (REFERENCES)

「作為絕緣體，羽毛比毛皮更有效。只有一類鳥—企鵝—可以在地球上最寒冷的地方，存活於冬天的南極冰帽上。企鵝的羽毛可完全勝任此項任務。它們是絲狀的，並將空氣捕獲在體表的連續層內。加上皮下的厚脂肪層加強，就算沒有進食來補充其體內溫暖，溫血的企鵝也能在暴風雪的零下 40 度的溫度中站立，並在那裡停留數週。」(Attenborough 1979: 178-179)

"As insulators, feathers are even more efficient than fur. Only a bird–the penguin–can survive on the Antarctic ice-cap in winter, the coldest place on earth. The penguin's feathers are devoted entirely to this task. They are filamentous and trap the air in a continuous layer all round the body. This, reinforced by a thick coat of fat just beneath the skin, enables the hot-blooded penguins to stand about in a blizzard in temperatures of forty degrees below freezing and remain there for weeks on end, even without stoking their internal warmth with a meal." (Attenborough 1979: 178-179)

參考文獻清單與連結 (REFERENCE LIST)

Attenborough, D. (1981). *Life on earth: a natural history.* Little Brown & Co.

延伸閱讀:

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/aptenodytes_forsteri

文章貢獻/編修者與日期:

羅東昇翻譯 (2019/05/13)；朱天愛編修 (2019/12/19)；吳晧編修 (2020/01/04)；
譚國鎏編修 (2020/05/26)；紀凱容編修 (2020/11/26)；施習德編修 (2020/12/15)

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https://asknature.org/strategy/feathers-trap-air-to-provide-warmth