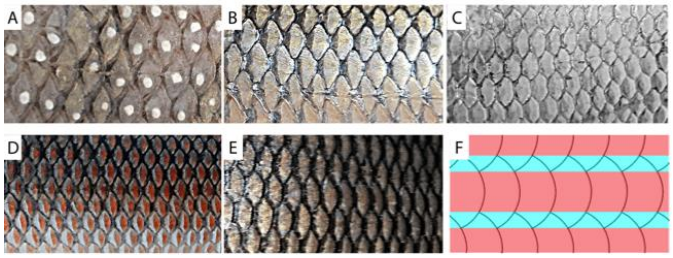
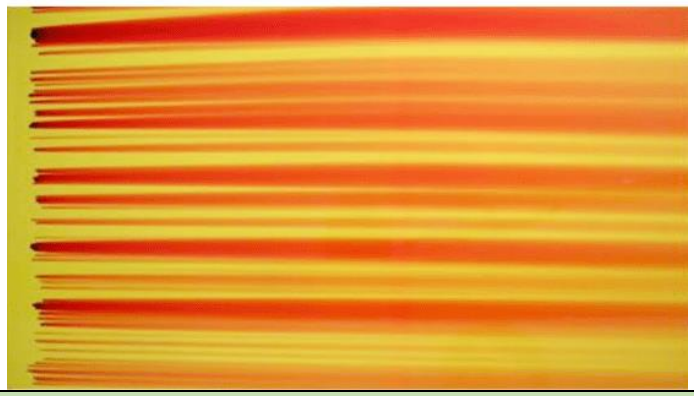
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	為何魚鱗不會成為一種阻力 (Why fish scales aren't such a drag)
生物系統 LIVING SYSTEM	魚 (Fish)
功能類別 FUNCTIONS	#改變液體流動 #調節湍流 #Move in/on liquids #Manage turbulence
作用機制標題	魚鱗的形狀造成水流線型流過魚身，減緩湍流和最小化阻力。 (The shape of scales causes water flow to streak across fish skin, reducing turbulence and minimizing drag.)
生物系統/作用機制示意圖 (確認版權、註明出處；畫質)	 Flow (from left to right) across a flat plate  Flow (from left to right) across a scaled surface 
作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)	

魚鱗的非平滑表面並不像其他的粗糙表面。儘管形狀和大小隨著物種而有不同，魚鱗本質上就是一排排重疊的貝殼形狀之凸起物。這些凸起鱗片的頂端在他們身後製造了緩慢的水流 (wake)。而重疊造成的山谷處，讓大部分的水快速流過。所以當魚隻游泳時，這些鱗片改變了鱗片頂端後緩流的流量和山谷處後的急流的流量。這種線形的水流模式防止鱗片像其他的非平滑表面一樣，因為這樣能夠讓水流平均的流過魚身，像是溪中平靜的水流。

Bruecker 解釋說一隻在海裡游泳的魚不會干擾到 100 英尺外的水，而遠處的水也不會造成魚隻要往前游的阻力。甚至短距離外的水也只會造成微小的影響。它是緊貼著魚身臨界的毫米厚體積的水 (the critical millimeters-thick volume of water) 所造成的阻力。

Bruecker 表示要是這邊界處的水流變得湍急，這樣摩擦阻力將增加將近五倍。所以鱗片透過在魚身保持平均、層流 (laminar flow)來降低阻力。在一個實驗中，研究者用染劑來表現水流流過一個平滑的表面對比水流流過一個有鱗片的表面。在平滑表面的組別中，水流因為沒有有效結構來減緩而迅速轉變成打旋、混合的急流。 而在對照組中，透過紅色線條橫穿能看出有鱗片表面的層流側視比起平滑的表面有更長的距離。當然，當魚隻愈游愈快時，水流最終還是會變得湍急。但鱗片能夠延長這個轉變的過程。

the roughness of fish scales doesn't act like typical roughness of other materials. Although shape and size vary across species, fish scales are essentially rows of overlapping seashell-shaped bumps. The peaks of the bumpy scales create wakes of slower water behind them. The overlapping sides of scales form valleys where most of the water rushes through. So as a fish swims, it has alternating bands of "low flow" behind the scale peaks and "high flow" behind the valleys.

Bruecker explains a fish swimming in an ocean would not disturb water 100 feet away, and neither does that faraway water contribute to the friction the fish has to overcome to move forward. Even water a few inches away has little impact. It's the critical millimeters-thick volume of water right against a fish's skin that causes drag.

If the flow in this thin boundary layer becomes turbulent, Bruecker says the friction drag increases nearly five-fold. So the scales are keeping drag low by maintaining an even, laminar flow across the fish's body. In one experiment, the researchers used dye to visualize flow across a flat, smooth plate and compared it to a scaled surface. Across the smooth plate, the flow quickly decayed into turbulent swirling and mixing because no structures were present to even it out. In contrast, red streaks across the scaled surface indicated a laminar profile was preserved over a much longer distance than the smooth plate. Of course, as a fish swims faster and faster, the flow will eventually become turbulent. But scales delay the transition.

文獻引用 (REFERENCES)

通常，當水流變得湍急，層流在魚身的磨擦係數上升至兩倍。表面上全部的阻力是來自魚身摩擦曲線下的區域，因此，對比上平滑表面的條件時，曲線下的區域減少魚鱗排列……。我們展示了魚鱗排列能夠延遲過渡來減緩淨阻力。

"Generally, if a flow becomes turbulent the skin friction coefficient rises to almost twice its value for laminar flow at a particular location. The total drag of the surface is the area under the skin friction curve, therefore, the area under the curve reduces for fish scale array when compared with the reference flat plate case . . . We have demonstrated that the fish scale array could delay transition to reduce the net drag."

參考文獻清單與連結 (REFERENCE LIST) **Harvard 或 APA 格式**

JOURNAL ARTICLE

Streak formation in flow over biomimetic fish scale arrays

Journal of Experimental Biology | 2020 | Muthukumar Muthuramalingam, Leo S. Villemin, and Christoph Bruecker **https://journals.biologists.com/jeb/article/222/16/jeb205963/223497/Streak-formation-in-flow-over-biomimetic-fish**
延伸閱讀: Harvard 或 APA 格式（取自 AskNature 原文；若為翻譯者補充，請註明）
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
撰寫/翻譯/編修者與日期
謝向傑翻譯(2022/4/10)；許秋容編修 (2022/5/14)
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