# 生物策略表

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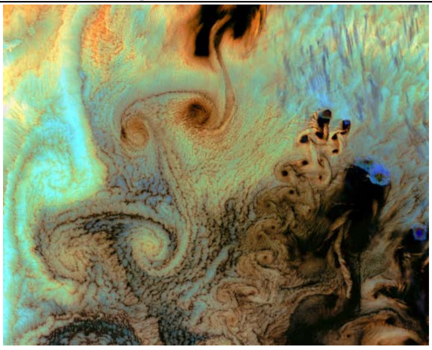
|---|---|
| **類別** | 生物策略 (Strategy) |
| **生物策略**<br>STRATEGY | 身體運用渦流來節能<br>(Body uses vortices to save energy) |
| **生物系統**<br>LIVING SYSTEM | 虹鱒與硬頭鱒 *Oncorhynchus mykiss*<br>(Rainbow trout and steelhead) |
| **功能類別**<br>FUNCTIONS | #改變位置 #在液體中移動<br>#Modify position #Move in/on liquids |
| **作用機制標題** | 在流體環境中，虹鱒運用身體與渦流的交互作用，來降低游動時所需的能量<br>(The body of rainbow trout decreases energy required for swimming by interacting with vortices in its fluid environment.) |
| **生物系統/作用機制示意圖** |   |

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

許多魚類是運用身體的波形動作來進行游泳；在穩定和持續的游動期間，彎曲身體與產生波形動作的肌肉活動，會耗費大量能量。但像是虹鱒的某些魚類，會採取特殊的游泳行為，由附近的渦流 (vortice) 來獲取能量，或許可以保存自身能量。在流體環境中，當迎面而來的水流或氣流通過靜止物體和其他生物體 (包括魚類) 時，會釋出旋流，此即渦流。鱒魚利用來自上游的水體渦流，並調整其典型的游泳行為，有利於產生渦流間的「彎曲迴轉」動作。彎曲身體可增加幅度和曲率，同時尾部拍打的頻率配合上游來的渦流頻率。沿著身體的肌肉活動模式也改變了，只有靠近頭部區域的肌肉是活躍的。不同於典型的波形動作，即沿著身體的肌肉都會收縮，收縮從頭部移向尾部，產生一個運行的身體波動，推動魚體往前。研究人員假設藉由肌肉活動和身體動作的變化，有助於鱒魚定位身體位置，才使其能與渦流以特殊方式產生交互作用。這種交互作用的確切性質仍在研究中，但有一個解釋是魚控制其身體的角度，使得渦流產生的局部水流在魚體上產生持續往上游的動力。科學家 James Liao 比喻「…我們假設鱒魚運用他們的身體，像帆一樣逆流而上。」

利用在其他物體後方所改變的流體流向，以減少動作的能量消耗，這種普遍的概念也可在人類行為中發現到，例如單車騎士彼此以氣流牽引來節省能量。

Many fish swim using an undulating motion of their bodies. The muscle activity that bends the body and produces these movements during steady, continuous swimming can cost a significant amount of energy. But some fishes, such as rainbow trout, can adopt a special swimming behavior that likely enables them to save their own energy by extracting energy from nearby water vortices. In a fluid environment, vortices are swirls of water or air often released (or "shed") from stationary objects and other living creatures, including other fish, that are in the path of an oncoming flow. Trout use water vortices that come their way from upstream sources to their advantage by adjusting their typical swimming behavior to produce a 'slalom' movement between vortices. Body bends increase in amplitude and curvature, and the tail beats at a frequency that matches the frequency at which vortices are shed upstream. The pattern of muscle activity along the body also changes, where only muscles close to the head are active. This differs from typical undulating motion where muscles contract all along the body, starting from the head and moving toward the tail to produce a traveling body wave that pushes the fish forward. Researchers hypothesize that these changes in muscle activity and body motion help the trout position its body so that it interacts with the vortices in a specific way. The exact nature of this interaction is still under investigation, but one explanation is that the fish controls the angle of its body so that local flow from the vortices produces a continuous upstream force on the body. Scientist James Liao uses the analogy, "...we hypothesize that trout use their body like a sail to tack upstream."

The general concept of taking advantage of altered fluid flows behind other objects to reduce the energetic cost of motion is found in human behaviors too, for instance, in cyclists that draft behind one another to save energy.

**文獻引用** (REFERENCES)

「已知水生動物以單獨和成群方式游泳時，都可以從環境水流的渦流中獲得能量，顯著地減少運動所需的肌肉活動。該現象相關的渦旋動力學模型已開發出來，顯示能量的提取機制，藉由流體中相對於身體的渦流，能以其運動學控制的簡易準則加以描述。透過這種方式，我們無須使用流體動力學，這會比運動學更難以估算。表現在游泳魚類和目前能量轉換裝置的這些原理，其範例將加以描述。此開發架構的優點，在於流體-結構交互作用的潛在無限維度參數空間 (infinite-dimensional parameter space)，能被減少到最多三個參數的八個組合。該模型可能有助於設計和評估不穩定空氣和水體動力的能量轉換系統，並能超越穩定流體動態能量轉換系統的 Betz 效率極限。」(Dabiri 2007: L1)

「魚類在湍流間或編隊中游動時，經常暴露在渦流中。生活在流體環境的動物們，儘管經常從渦流中捕獲能量，但魚類和渦流之間的流體動力學，以及交互作用的神經控制，其實驗數據都是欠缺的。我們使用定量流動視覺化/顯影 (quantitative flow visualization) 和肌電圖 (electromyography)，顯示鱒魚只需啟動前軸肌 (anterior axial muscle)，就可採用新穎的運動模式，而能在實驗所產生的渦流間彎曲迴轉。與進行波形游泳的魚類活動相比，利用渦流時會減少肌肉活動，顯示其減少運動的消耗，也提供瞭解魚類在河流環境和群聚中分布模式的機制。」(Liao et al. 2003：1566)

「…在大多數魚類中，沿著身體分佈的機械感應細胞之排列，潛在地使牠們能偵測壓

力的不連續性，因而在流體中選擇最有利的動力條件。」 (Sutterlin＆Waddy 1975; Braun ＆Coombs 2000) (Beal et al. 2006: 385)

“Aquatic animals swimming in isolation and in groups are known to extract energy from the vortices in environmental flows, significantly reducing muscle activity required for locomotion. A model for the vortex dynamics associated with this phenomenon is developed, showing that the energy extraction mechanism can be described by simple criteria governing the kinematics of the vortices relative to the body in the flow. In this way, we need not make direct appeal to the fluid dynamics, which can be more difficult to evaluate than the kinematics. Examples of these principles as exhibited in swimming fish and existing energy conversion devices are described. A benefit of the developed framework is that the potentially infinite-dimensional parameter space of the fluid–structure interaction is reduced to a maximum of eight combinations of three parameters. The model may potentially aid in the design and evaluation of unsteady aero- and hydrodynamic energy conversion systems that surpass the Betz efficiency limit of steady fluid dynamic energy conversion systems.” (Dabiri 2007: L1)

“Fishes moving through turbulent flows or in formation are regularly exposed to vortices. Although animals living in fluid environments commonly capture energy from vortices, experimental data on the hydrodynamics and neural control of interactions between fish and vortices are lacking. We used quantitative flow visualization and electromyography to show that trout will adopt a novel mode of locomotion to slalom in between experimentally generated vortices by activating only their anterior axial muscles. Reduced muscle activity during vortex exploitation compared with the activity of fishes engaged in undulatory swimming suggests a decrease in the cost of locomotion and provides a mechanism to understand the patterns of fish distributions in schools and riverine environments.” (Liao et al. 2003: 1566)

“...an array of mechanosensory cells distributed along the body of most fish, potentially enables them to detect pressure discontinuities so as to select favourable hydrodynamic conditions in the flow” (Sutterlin & Waddy 1975; Braun & Coombs 2000). (Beal et al. 2006: 385.)

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**延伸閱讀**

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

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

**撰寫/翻譯/編修者與日期**

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**AskNature 原文連結**

https://asknature.org/strategy/body-uses-vortices-to-save-energy/