生物策略表

類別	生物策略 (Strategy)Strategy
生物策略 STRATEGY	葉片在減少阻力和陽光照射間取得平衡 (Blades balance drag reduction and solar exposure)
生物系統 LIVING SYSTEM	巨藻 *Nereocystis luetkeana* (Bull kelp)
功能類別 FUNCTIONS	#適應外表型 #獲取、吸收或過濾能量 #應付亂流 #改變大小/形狀/質量/體積 #形狀/材料最佳化 #Adapt phenotype #Capture, absorb, or filter energy #Manage turbulence #Modify size/shape/mass/volume #Optimize shape/materials
作用機制標題	巨藻藉由改變葉片寬度及平整度，能在不同流動環境中在減少阻力和陽光的照射間取得平衡 (Blades of bull kelp balance drag reduction and sunlight exposure in different flow environments via changes in width and flatness.)
生物系統/作用機制示意圖	
作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)	

巨藻 (*Nereocystis luetkeana*) 是一種海洋大型藻類，生長在阿拉斯加與加州中部之間的沿海水域。他的外形類似藤蔓植物，具有長達 30 公尺的細柄（莖狀結構），並透過固著器（根狀結構）固定在海床中。在細柄的另一端有一個充滿氣體的浮球，連接著 30-60 片能行光合作用的葉片，每片葉片的長度可達 4 公尺，並靠近水面。許多海洋大型藻類必須承受潮汐、波浪和海面的拉扯所施加的巨大流體動力。如果液體流動所施加的作用力超過海帶細柄或固著器的斷裂強度，則藻類可能會斷裂並且死亡。因此，應付施加在海帶上的阻力可能是有利的生存適應。

巨藻的葉片形狀是一個例子，在流動程度不同的生長環境會有不同的改變。與在較平靜且受保護的環境長成波浪狀（起皺的）的寬闊葉片相比，曝露於快速流動水域中的巨藻葉片長得狹窄且平整。在水流較快的水域中，窄而扁平的葉片會以較小幅度的擺動，使他們集結成多束流線型的葉片。實驗證明葉片的狹窄程度及平整度都有助於葉片凝聚在一起，葉片的形狀會根據機械應力而發生變化 (這種變化是可塑的)。甘藍菜狀的無柄海藻 (*Saccharina sessile*) 和梨形囊巨藻 (*Macrocystis pyrifera*) 兩者在快速和緩慢水流中均表現出相似的葉片形狀差異，顯示這種葉片形狀差異是對抗拉力 (drag) 的一種常用方法。

如果狹窄度及平整度減少了拉力，那為什麼海帶會有寬闊、皺褶的葉片呢？葉片呈現流線形束狀的代價就是自我遮蔽，這導致光合作用速率降低。透過以較大及多變的幅度擺動，寬大且有皺褶的葉片可以散開來防止自我遮蔽，從而增加陽光的照射。巨藻在以形成流線形減少阻力和散開獲得陽光之間取得了平衡。由於拉力隨流速而增加，曝露於強烈海浪和潮汐棲地中的巨藻投資在使拉力最小化但犧牲光合作用；而生長在受到較多保護棲地者，則不需投資太多在減少拉力而可增加日照量。

Bull kelp (*Nereocystis luetkeana*) is a marine macroalga that grows in coastal waters between Alaska and central California. It resembles a vine-like plant with a long, thin stipe (stem-like structure) up to 30 meters long, anchored into the sea floor by a holdfast (root-like structure). At the stipe's other end is a gas-filled float that holds 30-60 photosynthetic blades, each reaching up to 4 meters in length, near the water's surface. Many marine macroalgae must withstand significant hydrodynamic forces imposed by tidal currents, waves and surface chop. If the mechanical force exerted by fluid flow exceeds the breaking strength of a kelp stipe or holdfast, the macroalga can break away and potentially die. Thus adaptations managing drag exerted on the kelp can be advantageous.

One example is the blade shape of bull kelp, which varies between habitats with differing degrees of flow. Bull kelp exposed to rapidly moving water grow flat, narrow blades compared to those found in calmer, protected sites that grow undulate (ruffled), wide blades. In faster flowing waters, narrow, flat blades flutter at smaller amplitudes allowing them to clump into more streamlined bundles. Experiments demonstrate that both the narrowness and flatness of a blade contributes to how well the blades can clump together, and that blade shape changes in response to mechanical stress (the changes are plastic). Both the cabbage-like kelp *Saccharina sessile* and the giant kelp *Macrocystis pyrifera* exhibit similar differences in blade shape between fast and slow flow environments, suggesting this difference in blade shape is a common way to manage drag.

If narrowness and flatness reduce drag, why would any kelp have wide, ruffled blades? Streamlining of bundles comes at the cost of self-shading, which leads to a reduction in photosynthetic rate. By moving at greater and more varied amplitudes, wide and ruffled blades prevent self-shading by spreading themselves apart and increasing their exposure to sunlight. Bull kelp experience a trade off between minimizing drag by streamlining and maximizing photosynthesis by spreading out. Since drag increases with flow speed, kelp in habitats exposed to powerful waves and tides invest in minimizing drag at the cost of photosynthesis while kelp in more protected habitats need not invest so heavily in drag reduction and can increase solar exposure.

文獻引用 (REFERENCES)

「低流速水域巨藻的波浪狀葉片在水流中保持散開並不規則的擺動，這不僅增強了對光的截取，也增加了阻力。相反，某些棲地的巨藻因快速的水流而收合成流線型束狀，並在水流中以低幅度擺動，從而減少阻力又可獲取陽光。野外的移植實驗顯示巨藻的葉片形狀是具

有可塑性的性狀。實驗室對來自不同地點的葉片進行了實驗，模擬了葉片在不同流速的流體力學阻力，結果表明葉片形狀的變化是由機械應力引起的。」 (Koehl et al. 2008: 834)

「野外測量顯示當巨藻的帶狀葉片於曝露的位置收合成流線形束狀並以低幅度擺動時，到達葉叢內葉片的光合作用有效輻射 (PAR) 通透量與頂部的葉片相比減少了約 70%…相反地，在受到保護的地區，野外測量顯示波浪狀（起皺的）巨藻葉片下的光，由於隨著起伏的葉片不規則的擺動，並在流動的水中保持散開，進入葉叢內下部的 PAR 光量僅降低了 16%。因此，巨藻展示了葉片皺褶可以減少有著多數葉片的大型藻類在水流中自身遮蔽的程度。」 (Koehl et al. 2008: 837)

"The undulate blades of N. luetkeana from sites with low flow remain spread out and flutter erratically in moving water, thereby not only enhancing interception of light, but also increasing drag. In contrast, strap-like blades of kelp from habitats with rapid flow collapse into streamlined bundles and flutter at low amplitude in flowing water, thus reducing both drag and interception of light. Transplant experiments in the field revealed that shape of the blade in N. luetkeana is a plastic trait. Laboratory experiments in which growing blades from different sites were subjected to tensile forces that mimicked the hydrodynamic drag experienced by blades in different flow regimes showed that change in shape is induced by mechanical stress." (Koehl et al. 2008: 834)

"Field measurements showed that when the strap-like blades of a N. luetkeana at an exposed site collapsed into a streamlined bundle and fluttered at low amplitude, the flux of photosynthetically active radiation (PAR) reaching blades within the clump was reduced by about 70% compared with the PAR flux encountered by the blade at the top of the bundle…In contrast, field measurements of light under the ruffled blades of N. luetkeana at a protected site showed that the PAR flux to the lower blades in a clump was reduced by only about 16% as the undulate blades flapped erratically and remained spread out in flowing water. Thus, N. luetkeana illustrate that a ruffled blade shape can reduce self-shading for macroalgae with multiple blades in flowing water." (Koehl et al. 2008: 837)

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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/Nereocystis
https://www.onezoom.org/life/@Saccharina=690480?img=best_any&anim=flight#x827,y242,w1.0786
https://eol.org/pages/902899

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AskNature 原文連結

https://asknature.org/strategy/blades-balance-drag-reduction-and-solar-exposure/