Extracellular enzymes

Foraging strategy for free-living marine bacteria

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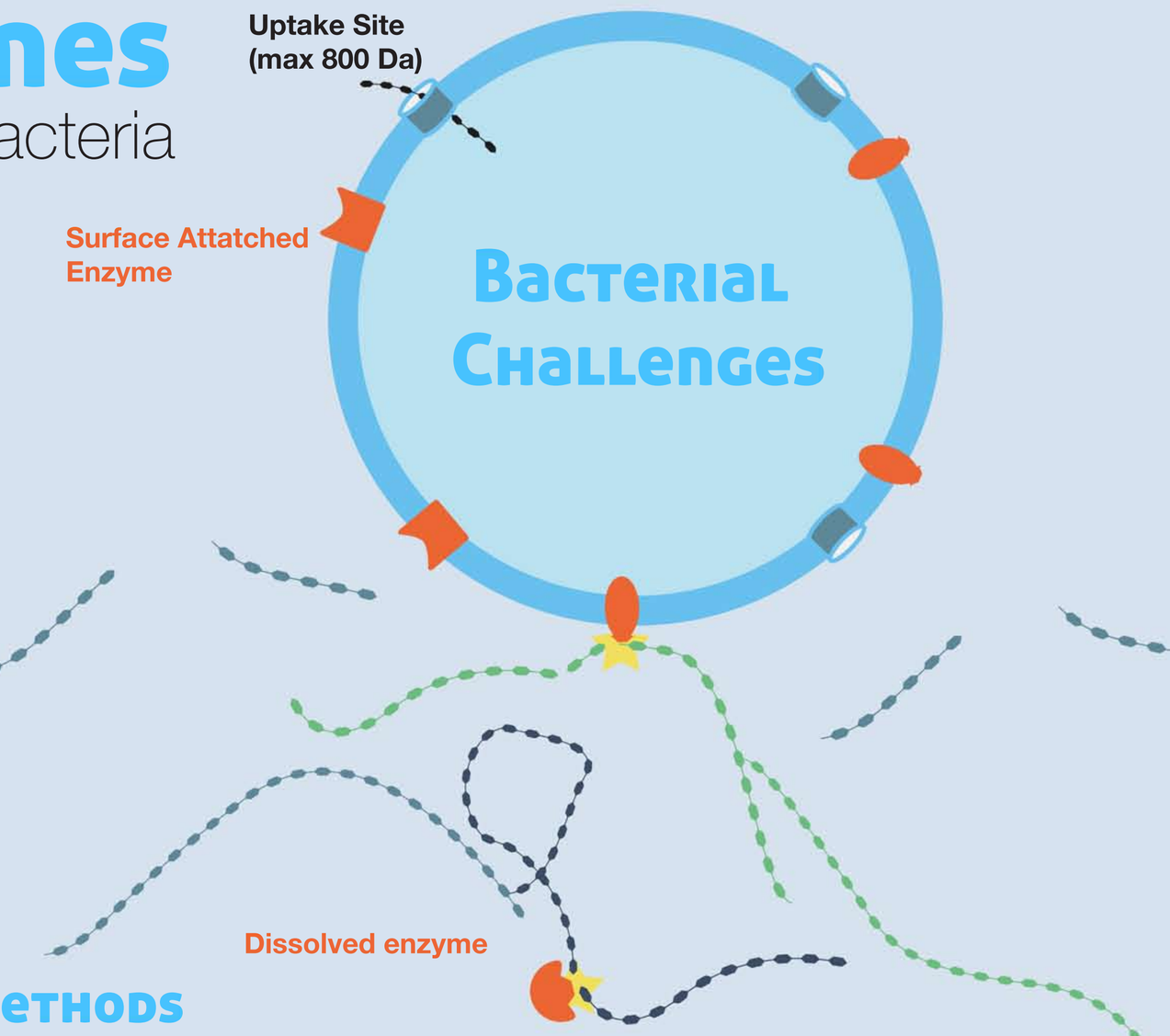

Introduction

Dissolved organic matter (DOM) in the oceans is one of the largest reservoirs of carbon in the biosphere. The entire ecosystem contributes to the DOM pool, but the DOM is almost exclusively exploited by the bacterioplankton through the microbial loop and this represents a major trophic pathway. Up to 50% of marine carbon fixation is processed through the bacterioplankton (Cole et al. 1988) and play an important role in biogeochemical fluxes, marine productivity and food web structure.

Enzyme Model

There are two main extracellular enzyme strategies: surface-associated; and dissolved (freely released). Here we present the results of a model study on the efficiency of the two strategies, for single free-living bacteria under open ocean conditions.
We ask **1) do extracellular enzymes (as in freely released) have a role in the foraging strategy of free-living bacteria in the open ocean?** and **2) is it possible to deduce a threshold concentration of a substrate, below which enzymatic activity ceases to be an advantage to the cell?**

Methods

Mathematical analysis: We determine the spatial distribution of substrate and enzymes by solving governing PDEs, and from this find the uptake by the bacterium. We score the efficiency by comparing with an idealized cell which absorbs substrate directly. The threshold concentration of substrate is where the resulting carbon uptake equals the carbon used in enzyme production.

Results

Enzyme strategy

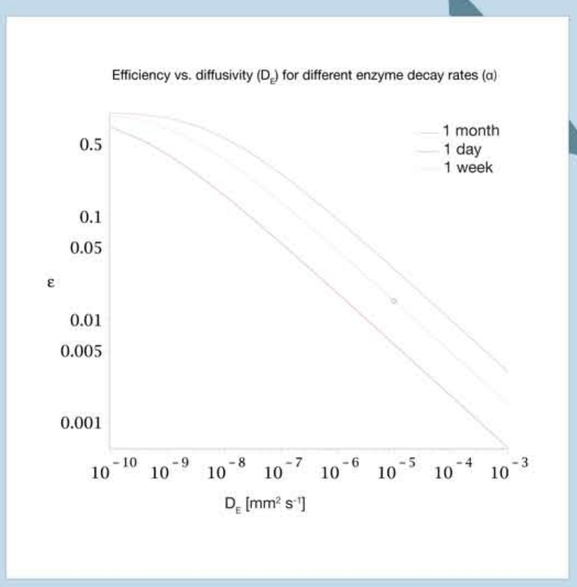

Figure 1
The efficiency decrease with enzyme diffusivity (D_E) and increase with the lifetime of the enzyme (decrease in decay rate). For a lifetime of 1 week, with the reference parameters listed in table 1, an enzyme would have an efficiency of 1.5 % (diamond).

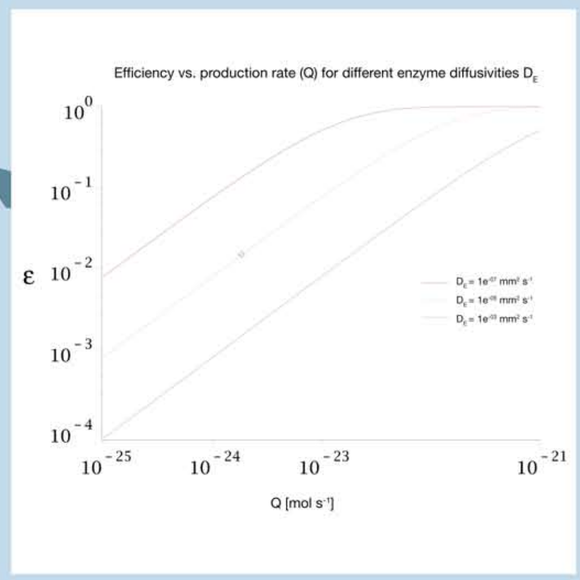

Figure 2
The efficiency increase with production rate (Q) but decrease with diffusivities. That means for a diffusivity corresponding to an enzyme of approximately 100 kDa, with the reference parameters listed in table 1, the efficiency is 1.5 % (diamond), far from saturation. **This and figure 1 point towards surface associated enzymes as the most efficient strategy.**

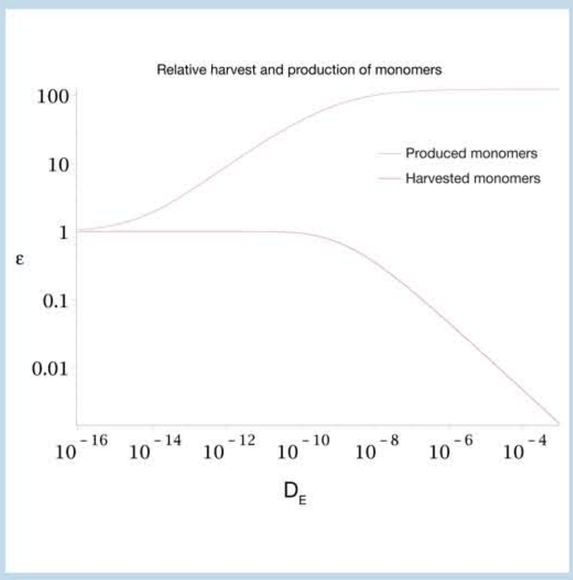

Figure 3
The efficiency increases with decreasing diffusivity. For a dissolved (freely released) enzyme, the majority of the products (monomers) never reach the cell (–). However, the plot also show the potential for "social foraging" under the right conditions; such as high cell density, where the efficiency of dissolved enzymes would yield a monomer production high enough to support mutualistic efforts of a consortium.

Table 1

Symbols	Description	Values	Units
M	(monomer) substrate	< 800	Dalton
P	substrate	~100,000	Dalton
a	radius of cell	$0.3e^{-3}$*	mm
D_E	diffusivity enzyme	$1e^{-5}$*	$mm^2\ s^{-1}$
D_P	diffusivity substrate	$1e^{-5}$*	$mm^2\ s^{-1}$
Q	enzyme production in C	$1e^{-24}$[a]	$mol\ s^{-1}$
α	enzyme decay rate	1 day, 1 week, 1 month	
β	reaction rate	4.1[b]*	$s^{-1}\ \mu M^{-1}$

*reference parameters.
[a]enzyme production equal to the cell's own weight in a week.
[b]average of bacterial α-amylases (Chessa et al. 1999).

Threshold concentration

$$\text{eq. } P_{lim} = n_E/n_M * \alpha/\beta$$

setting $n_E/n_M = 1000$

result in a threshold value of:

$$P_{lim} = 0.4\ nM$$

The currency is based on carbon atoms, deriving a price for the enzyme (N_E) relative to a monomer (N_M). At substrate concentrations below P_{lim}, production of enzymes does not pay off.
DOM concentrations in the open oceans are relatively stable, around 40-60 µmol C kg-1 (Carlson et al. 2011), when considering the complexity of the many thousands of compounds that make up the DOM pool, and the specificity of enzymes, **the threshold concentration may explain the persistence of "old" fractions of DOM; not as refractory but persisting at concentrations so low that there is no energetic gain for producing the specific enzymes needed.**

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