Warm Water Runs Short of Oxygen Mainly Because More Is Needed, Not Because Less Dissolves

— from 0 to 30 degrees saturated dissolved oxygen falls only by a factor of **1.934281**, while metabolism with $Q_{10} = 2$ rises eightfold and the balance worsens **15.4742** times — split on a logarithmic scale, **0.759148** of the worsening lies on the side of demand — [Paper 572]

Yuuki YAMAGISHI (山岸 勇輝)
Yamagishi Complexity Torus Lab, Japan
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— From thinking to syncing. —

Abstract

It is often said that less oxygen dissolves in warm water.What this paper shows is that this is true but is not the main reason warm water runs short of oxygen: three quarters of the shortfall comes from the rise in what living things need.No new theorem or law is claimed. First, what dissolves follows from a formula——saturated dissolved oxygen is 14.6208 mg/L at 0 degrees and 7.5588 at 30, a ratio of 1.934281 and a fall of 48.3012 per cent; the formula reproduces four points of the standard table to within 0.02 mg/L (Section 2). **Second, what is needed rises with Q_{10} ——with $Q_{10} = 2$ metabolism at 30 degrees is 8.0000 times that at 0, and the balance worsens 15.4742 times** (Section 3). **Third, and this is the core.Split on a logarithmic scale, 0.759148 of the worsening lies on the side of demand——"less dissolves" is true but is not the main reason** (Section 4). **Fourth, the boundary is $Q_{10} = 1.245967$ ——the cube root of the supply ratio; as long as metabolic Q_{10} exceeds it, demand wins** (Section 4). **Fifth, the same holds degree by degree——at 20 degrees what dissolves falls by 1.986169 per cent per degree and what is needed rises by 6.931472, a ratio of 3.4899** (Section 4). **Sixth, the separator is whether metabolic Q_{10} exceeds the cube root of the supply ratio——a contest between two sensitivities to temperature with different roots, the dissolving of a gas and the pace of life** (Section 5). **Keywords**: dissolved oxygen, water temperature, metabolic Q10, fish, gas solubility.

Scope of this paper (scope note): **No new theorem or law is claimed——the temperature dependence of gas solubility and the Q_{10} of metabolism are standard.The cause of fish deaths is not settled by this alone——gill ventilation, the oxygen-carrying power of blood and acclimation to temperature are not included.Only fresh water at one atmosphere and saturation is considered——real water often falls below saturation at night or near the bottom; here only the ceiling on what dissolves is compared.Q_{10} is representative——it varies with species and range; values from 1.5 to 3 are listed and 2 is used for the core. Near lethal temperatures Q_{10} stops being constant, which is not included.Ecology is not treated——stratification, the respiration of algae and the supply of oxygen by currents lie outside this paper.The absolute need is not given——only ratios are compared, and how many mg/L suffice is not stated.Relation to earlier papers**: **Paper 386 showed that the rate of dissolution rose a thousandfold while the solubility did not move at all——a quantity of equilibrium and a quantity of rate are different; here the equilibrium quantity (the ceiling on what dissolves) moves too, but the rate quantity (metabolism) moves much more.Paper 382 showed that the brain's "tenfold" specific power comes from the lowness of what it is compared with——this paper also asks what metabolism is compared with, and sets it against the supply.Paper 300 showed that sharing a root is decidable——"less dissolves" and "more is needed" have distinct roots, which is why they multiply independently.**What is added is **deriving the ratio $\mathbf{1.934281}$ after checking the formula for saturated oxygen against four points of the table**, **splitting the worsening logarithmically between demand and supply and finding the demand share $\mathbf{0.759148}$**, **placing the boundary Q_{10} in the closed form of the cube root of the supply ratio, $\mathbf{1.245967}$**, **confirming the degree-by-degree ratio $\mathbf{3.4899}$ by numerical and analytic derivatives**, and **placing the separator on the contest between Q_{10} and that cube root**.

1. Notation and the Question

Setting: **let $C^*(T)$ be the ceiling on oxygen dissolved in fresh water at one atmosphere in equilibrium with air, and $D(T) = D_0 Q_{10}^{(T-T_0)/10}$ the oxygen a living thing needs.Whether there is enough is set by D/C^*, and warming from 0 to 30 degrees worsens it by**

$$\frac{D(30)/C^*(30)}{D(0)/C^*(0)} = Q_{10}^3 \cdot S, \qquad S = \frac{C^*(0)}{C^*(30)}.$$

Observation 1.1

"less oxygen dissolves in warm water" is often said, and is true.Fish gasping at the surface of a pond in summer are often explained this way——the question is how much it matters.

Question: **of the worsening on warming, how much comes from less dissolving and how much from more being needed?**

2. What Dissolves

Computation 2.1: saturated dissolved oxygen from the formula of Benson and Krause, set against the standard table.

water temperature	formula (mg/L)	table (mg/L)
0 degrees	**14.6208**	14.62
10 degrees	**11.2879**	11.29
20 degrees	**9.0924**	9.09
30 degrees	**7.5588**	7.56

Observation 2.2

the formula reproduces four points of the table to within 0.02 mg/L.The formula and the table were held separately, and they agree——a slip in copying either would show here.

Observation 2.3

from 0 to 30 degrees what dissolves falls by a factor of **1.934281**.A fall of **48.3012** per cent, a little under half——this is the size of “less dissolves in warm water”.

3. What Is Needed

Computation 3.1: metabolism warmed with Q_{10}; at 30 degrees it is Q_{10}^{3} times that at 0.

Q_{10}	need at 30 degrees (relative to 0)	worsening of the balance
1.5	**3.3750**	**6.5282**
2.0	**8.0000**	**15.4742**
2.5	**15.6250**	**30.2231**
3.0	**27.0000**	**52.2256**

> **Observation 3.2**
>
> with $Q_{10} = 2$ the balance worsens $\mathbf{15.4742}$ times.Not only does what dissolves fall by nearly half; what is needed rises eightfold——the two multiply.

4. The Shares

Computation 4.1: the logarithm of the worsening $Q_{10}^{3} S$ was split into demand, $\ln Q_{10}^{3}$, and supply, $\ln S$.With $Q_{10} = 2$ the demand share is $\ln 8 / \ln(8S) = \mathbf{0.759148}$.

> **Observation 4.2**
>
> this is the core.Three quarters of the worsening lie on the side of what is needed——"less dissolves" is true but is not the main reason. Warm water runs short of oxygen mainly because living things use it faster.

Computation 4.3: the Q_{10} at which supply and demand weigh equally follows from $Q_{10}^{3} = S$: $S^{1/3} = \mathbf{1.245967}$ (its cube returns S to 10^{-12}).

> **Observation 4.4**
>
> the boundary is low.As long as metabolic Q_{10} exceeds 1.245967, what is needed wins——metabolic Q_{10} is often put near 2, well above the boundary.

Computation 4.5: degree by degree.At 20 degrees what dissolves falls by $\mathbf{1.986169}$ per cent per degree (numerical and analytic derivatives agree to 10^{-6}).With $Q_{10} = 2$ what is needed rises at the continuous rate $\ln 2 / 10$, $\mathbf{6.931472}$ per cent per degree.The ratio is $\mathbf{3.4899}$.

> **Observation 4.6**
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> degree by degree, the need still rises three and a half times as fast as the ceiling falls.Over thirty degrees at once or one degree at a time, the answer points the same way——a check that the choice of interval does not change the conclusion.

5. The Separator

Observation 5.1

the separator is whether metabolic Q_{10} exceeds the cube root of the supply ratio, 1.245967.It is a contest between the sensitivity to temperature of the pace of life and that of the dissolving of a gas——for a creature with Q_{10} below 1.245967, less dissolving would be the main reason; such creatures are not usually found.

Observation 5.2

under Paper 300 the two have distinct roots.Less dissolving is a property of the solution of a gas; more needing is a property of the rate of the chemistry of life——so the two do not interact and multiply independently.

Observation 5.3

a counterpart to Paper 386.There the rate of dissolution rose a thousandfold while the solubility did not move at all——a quantity of equilibrium and a quantity of rate are different. Here the equilibrium quantity moves too, but the rate quantity moves much more.

Observation 5.4

the question is posed as in Paper 382.There the brain's "tenfold" came from comparing it with resting tissue ——here too the rise in metabolism is set against something, the fall in what dissolves.

Observation 5.5

what is not said.The cause of fish deaths is not settled by this alone——gill ventilation, the oxygen-carrying power of blood, acclimation, stratification and the respiration of algae are not included. What is shown is only how the ceiling on what dissolves and the need should be compared.

6. Roll Call and Closing

1. **14.6208 mg/L at 0 degrees, 7.5588 at 30** (Computation 2.1): **agrees with four table points.**
2. **what dissolves falls by 1.934281** (Observation 2.3): **a fall of 48.3012 per cent.**
3. **with $Q_{10} = 2$ the need is 8.0000 times** (Computation 3.1): **the balance worsens 15.4742 times.**
4. **demand share 0.759148** (Computation 4.1): **the core.**
5. **boundary $Q_{10} = 1.245967$** (Computation 4.3): **the cube root of the supply ratio.**
6. **per degree 1.986169 against 6.931472 per cent** (Computation 4.5): **a ratio of 3.4899.**
7. **the interval does not change the answer** (Observation 4.6): **thirty degrees or one.**
8. **the separator is Q_{10} against the cube root** (Observation 5.1): **two sensitivities compared.**
9. **the two have distinct roots** (Observation 5.2): **so they multiply.**
10. **a counterpart to Paper 386** (Observation 5.3): **equilibrium and rate.**

Closing: **It is often said, truly, that less oxygen dissolves in warm water.Yet that is not the main reason warm water runs short of oxygen——saturated dissolved oxygen is 14.6208 mg/L at 0 degrees and 7.5588 at 30, with the formula reproducing four table points to within 0.02 mg/L; what dissolves falls only by a factor of 1.934281, 48.3012 per cent. Meanwhile metabolism with $Q_{10} = 2$ rises eightfold, and the balance worsens 15.4742 times.Split on a logarithmic scale, 0.759148 of the worsening lies on the side of what is needed——supply and demand weigh equally only at $Q_{10} = 1.245967$, the cube root of the supply ratio, and metabolic Q_{10} usually lies well above it. Degree by degree at 20 degrees, what dissolves falls by 1.986169 per cent and what is needed rises by 6.931472, a ratio of 3.4899; the choice of interval does not change the direction.The separator is whether metabolic Q_{10} exceeds the cube root of the supply ratio——a contest between two sensitivities to temperature with different roots, the dissolving of a gas and the pace of life; under Paper 300 they are distinct, and so they multiply independently.Placed among the earlier papers——in Paper 386 the equilibrium quantity stood still while the rate moved; here the equilibrium quantity moves as well, but the rate moves more. As in Paper 382, asking what a quantity is compared with is what separates which side matters.To be honest——the cause of fish deaths is not settled by this alone. Gills, blood, acclimation, stratification and the respiration of algae are left out, the water is taken as saturated, Q_{10} is representative, and its breakdown near lethal temperatures is not included. What is shown is only how the ceiling on what dissolves and the need should be compared.**

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Yuuki YAMAGISHI (山岸 勇輝)

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