The following supplement accompanies the article

Measurement of sardine-generated turbulence in a large tank

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a. Calculation of e_d and η

We recalculate e_d, the rate of energy expenditure to overcome drag by an individual animal and η, the propulsive efficiency, based on Huntley and Zhou (2004). The rate of energy expenditure is shown as:

$$e_d = Dv, \tag{S1}$$

where D is the drag force and v is swimming speed. D is given as:

$$D = \frac{1}{2}\rho v^2 S_W C_D, \tag{S2}$$

where ρ is the density of seawater calculated from the international equation of state of seawater (UNESCO 1981), S_W is the total wetted surface area, and C_D is the drag coefficient. S_W is approximated as $S_W = 2WL$, where W is the average body width and L is the average body length. C_D is approximated as $C_D = 0.072\ \mathrm{Re}^{-0.2}$ (Hoerner 1965). η is defined as a ratio of e_d divided by the total rate of energy utilized by a single animal and approximated as (Weihs 1977, Wardle et al. 1996):

$$\eta = 0.39\, v^{0.24}. \tag{S3}$$

The measured swimming speeds were $v_{avoidance} = 1.08 \pm 0.11$ m s^{-1} (mean ± standard deviation) for the avoidance behavior and $v_{feeding} = 0.72 \pm 0.09$ m s^{-1} for the feeding behavior. Assuming that the possible ranges of the swimming speeds are within one standard deviation, we obtain $e_d = (1.9 \text{ to } 3.3) \times 10^{-2}$ W and $\eta = 0.39 \text{ to } 0.41$ for the avoidance behavior, and $e_d = (5.6 \text{ to } 11.3) \times 10^{-3}$ W and $\eta = 0.35 \text{ to } 0.37$ for the feeding behavior.

b. Estimation of n/V

To estimate population density n/V of the sardines, we assume the hexagonal close-packing (hcp) of equal spheres. Hcp is a concept that is common in crystallography and has been used for estimating animal distributions in the water (e.g. Mackie and Mills 1983). The volume of a cell V_C is expressed as:

$$V_C = 8\sqrt{2}\, r^3, \tag{S4}$$

where r is the radius of the spheres. The number of spheres in a cell is two, $n_{spheres} = 2$. The density of spheres $n/V_{spheres}$ is shown as:

$$n/V_{spheres} = \frac{n_{spheres}}{V_C}. \tag{S5}$$

We take $r \sim L = 0.173$ m; thus, we obtain $n/V_{spheres} = 34.1$ spheres m^{-3}. Assuming that each sphere corresponds to an individual sardine, we obtain $n/V = 34.1$ individuals m^{-3}.

LITERATURE CITED

Hoerner SF (1965) Fluid-dynamic drag. Self-published, Midland Park, NJ

Huntley ME, Zhou M (2004) Influence of animals on turbulence in the sea. Mar Ecol Prog Ser 273:65–79

Mackie GO, Mills CE (1983) Use of the Pisces IV submersible for zooplankton studies in coastal waters of British Columbia. Can J Fish Aquat Sci 40:763–776

UNESCO (1981) Tenth report of the joint panel on oceanographic tables and standards. UNESCO Tech Pap Mar Sci 36, UNESCO, Paris, p 25

Wardle CS, Soofiani NM, O'Neill FG, Glass CW, Johnstone ADF (1996) Measurements of aerobic metabolism of a school of horse mackerel at different swimming speeds. J Fish Biol 49:854–862

Weihs D (1977) Effects of size on sustained swimming speeds of aquatic organisms. In: Pedley TJ (ed) Scale effects in animal locomotion. Academic Press, New York, p 333–338