Morphology and Kinematics of Metachronally Swimming Organisms Collected from the Literature

Website: https://www.bco-dmo.org/dataset/967862
Data Type: Other Field Results
Version: 1
Version Date: 2025-07-10

Project
» Collaborative Research: Individual Based Approaches to Understanding Krill Distributions and Aggregations (Krill Aggregation)

Contributors	Affiliation	Role
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Abstract
This spreadsheet contains morphological and kinematic parameters of various organisms which swim by beating their multiple appendage pairs in a metachronal pattern. These values were gathered from the literature, and the source of each is also recorded. The spreadsheet also contains calculations for various nondimensional numbers which can be used to describe this type of locomotion. A second tab in the spreadsheet contains similar data for swimming organisms which have only 1 pair of appendages. These data were collected from the literature in 2021-2022 and will be useful to biomechanics researchers.

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Methods & Sampling

These data were gathered from the published literature, and the source of each is also recorded. The spreadsheet also contains calculations for various nondimensional numbers which can be used to describe this type of locomotion. A second tab in the spreadsheet contains similar data for swimming organisms which have only 1 pair of appendages. These data were collected from the literature in 2021-2022 and will be useful to biomechanics researchers. The original morphological and kinematics data were gathered by photographing and/or filming the swimming animals. The data span a time period from 1974 to 2021. Studies were included if they included the relevant data needed to calculate the necessary parameters. In some cases (as recorded in 'Notes'), we measured body or appendage length from images of the organisms in the paper.

BCO-DMO Processing Description

* merged files for single-pair appendage swimmers and metachronal swimmers into 1 data file
* added figures as supplemental files

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Related Publications

Alexander, D. E. (1988). Kinematics of Swimming in Two Species ofIdotea(Isopoda: Valvifera). Journal of Experimental Biology, 138(1), 37–49. https://doi.org/10.1242/jeb.138.1.37
IsDerivedFrom

An analysis of swimming in remipede crustaceans. (1994). Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 346(1316), 213–221. https://doi.org/10.1098/rstb.1994.0142
IsDerivedFrom

Blake, J. (1974). Hydrodynamic calculations on the movements of cilia and flagella I. Paramecium. Journal of Theoretical Biology, 45(1), 183–203. https://doi.org/10.1016/0022-5193(74)90050-2
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Campos, E. O., Caldwell, R. L., & Vilhena, D. (2012). Pleopod Rowing Is Used to Achieve High Forward Swimming Speeds During the Escape Response of Odontodactylus havanensis (Stomatopoda). Journal of Crustacean Biology, 32(2), 171–179. https://doi.org/10.1163/193724011x615596
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Catton, K. B., Webster, D. R., Kawaguchi, S., & Yen, J. (2011). The hydrodynamic disturbances of two species of krill: implications for aggregation structure. Journal of Experimental Biology, 214(11), 1845–1856. https://doi.org/10.1242/jeb.050997
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Cowles, D. L. (1994). Swimming Dynamics of the Mesopelagic Vertically Migrating Penaeid Shrimp Sergestes similis: Modes and Speeds of Swimming. Journal of Crustacean Biology, 14(2), 247. https://doi.org/10.2307/1548905
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IsDerivedFrom

Garayev, K., & Murphy, D. W. (2021). Metachronal Swimming of Mantis Shrimp: Kinematics and Interpleopod Vortex Interactions. Integrative and Comparative Biology, 61(5), 1631–1643. https://doi.org/10.1093/icb/icab052
IsDerivedFrom

Garayev, K., & Murphy, D. W. (2024). Hydrodynamic scaling of metachronal swimming. Physical Review Fluids, 9(11). https://doi.org/10.1103/physrevfluids.9.l111101 https://doi.org/10.1103/PhysRevFluids.9.L111101
Results

Jana, S., Um, S. H., & Jung, S. (2012). Paramecium swimming in capillary tube. Physics of Fluids, 24(4). https://doi.org/10.1063/1.4704792
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Katsu-Kimura, Y., Nakaya, F., Baba, S. A., & Mogami, Y. (2009). Substantial energy expenditure for locomotion in ciliates verified by means of simultaneous measurement of oxygen consumption rate and swimming speed. Journal of Experimental Biology, 212(12), 1819–1824. https://doi.org/10.1242/jeb.028894

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Kiørboe, T., Andersen, A., Langlois, V. J., & Jakobsen, H. H. (2010). Unsteady motion: escape jumps in planktonic copepods, their kinematics and energetics. Journal of The Royal Society Interface, 7(52), 1591–1602. https://doi.org/10.1098/rsif.2010.0176
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Matsumoto, G. I. (1991). Swimming movements of ctenophores, and the mechanics of propulsion by ctene rows. Coelenterate Biology: Recent Research on Cnidaria and Ctenophora, 319–325. https://doi.org/10.1007/978-94-011-3240-4_46
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Murphy, D. W., Webster, D. R., Kawaguchi, S., King, R., & Yen, J. (2011). Metachronal swimming in Antarctic krill: gait kinematics and system design. Marine Biology, 158(11), 2541–2554. https://doi.org/10.1007/s00227-011-1755-y
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IsDerivedFrom

Zaret, R. E., & Kerfoot, W. C. (1980). The shape and swimming technique of Bosmina longirostris1. Limnology and Oceanography, 25(1), 126–133. Portico. https://doi.org/10.4319/lo.1980.25.1.0126
IsDerivedFrom

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Parameters

Parameter	Description	Units

Locomotion	Locomotion type: metachronal swimmers or single-pair appendage swimmers	unitless
Common_name	Common name of organismn	unitless
Latin_name	Scientific name of organism	unitless
Body_length	Length of the body of the organism (L)	meters (m)
Swimming_speed	Swimming speed of the organism (average) (V)	meters per second (m/s)
Frequency	Beat frequency of the reciprocating appenages of the swimming organism (f)	Hertz (Hz)
Appendage_length	Length of the appendages of the organism. In cases where appendage length differs somewhat among appendages, the average is used. (l)	meters (m)
Stroke_amplitude_I	Stroke amplitude of the appendages of the swimming organism. In cases where stroke amplitude differs somewhat among appendages, the average is used. (θ)	degrees (deg)
Stroke_amplitude_II	Stroke amplitude of the appendages of the swimming organism. In cases where stroke amplitude differs somewhat among appendages, the average is used. (θ)	radians (rad)
Angular_velocity	Angular velocity of the appendage, calculated as 2*Stroke Amplitude (radians)*Frequency (ω)	radians per second (rad/s)
Appendage_tip_speed	Average speed of the tip of the appendage, calculated as 2*Stroke Amplitude (radians)*Frequency*Appendage Length (U)	meters per second (m/s)
Water_Temperature	Temperature of the water the animal is swimming in; taken from published paper when available	degrees Celsius (deg C)
Kinematic_viscosity	Viscosity of the water the animal is swimming in; taken from published paper when available (or calculated from temperature of water) (v)	square meters per second (m2/s)
Re_body	Reynolds number of the body of the swimming organism. Calculated as Body Length*Swimming Speed/Kinematic Viscosity	unitless

Re_appendage	Reynolds number of the appendage. Calculated as Appendage tip speed*Appendage Length/Kinematic Viscosity	unitless
Advance_ratio	A ratio of the Swimming Speed divided by the Appendage Tip Speed (J)	unitless
L_l	A ratio of the Body Length divided by the Appendage Length	unitless
Re_b_Re_aR	A nondimensional number calculated by multiplying the Advance Ratio and the Ratio of the Body Length Divided by the Appendage Length. This represents the Body Reynolds number divided by the Appendage Reynolds Number	unitless
Strouhal_number	Nondimensional Number. Calculated as 2*Frequency*Appendage Length*sin(Stroke Amplitude in radians/2)/Swimming Speed (St)	unitless
Swimming_number	Nondimensional Number. Calculated as Appendage Tip Speed*Tip Excursion*Body Length/Kinematic Viscosity (Sw)	unitless
Tip_excursion	Describes straight distance traveled by appendage tip over its stroke; Calculated as 2*Appendage Length*SIN(Stroke Amplitude/2) (A)	meters (m)
Number_of_appendage_pairs	Number of pairs of appendages used for swimming by the organism (n/2)	unitless
Normalized_advance_ratio	Ratio of Advance Ratio divided by Number of Appendage Pairs (Jn)	unitless
Number_of_appendages	Total number of appendages used for swimming by the organism (n)	unitless
Source	Scientific paper from which data were drawn	unitless
Notes	Notes by Garayev and Murphy on how data were drawn from paper	unitless
References	Reference to publication	unitless
DOI	DOI of publication	unitless

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Project Information

Collaborative Research: Individual Based Approaches to Understanding Krill Distributions and

Aggregations (Krill Aggregation)

NSF Award Abstract:
Antarctic krill (Euphausia superba) are an ecologically important component of the Southern Ocean's food web, yet little is known about their behavior in response to many features of their aquatic environment. This project will improve understanding of krill swimming and schooling behavior by examining individual responses to light levels, water flow rates, the presence of attractive and repulsive chemical cues. Flow, light and chemical conditions will be controlled and altered in specialized tanks outfitted with high speed digital camera systems so that individual krill responses to these factors can be measured in relevant schooling settings. This analysis will be used to predict preferred environments, define the capacity of krill to detect and move to them (and away from unfavorable ones). Such information will then be used to improve models that estimate the energetic costs of behaviors associated with different types of environments. Linking individual behavior to those of larger krill aggregations will also improve acoustic assessments of krill densities. Understanding the capacity of krill to respond to environmental perturbations will improve our understanding of the ecology of high latitude ecosystems and provide relevant information for the management of krill fisheries. The project will support graduate and undergraduate students and provide training for as post-doctoral associate. Curricular materials and public engagement activities will be based on the project's aims and activities. Project investigators will share model results and predictions of krill movements and school structure with experts interested in krill conservation and management.

The project will use horizontal and vertical laminar flow tunnels to examine krill behavior under naturally relevant conditions. Horizontal (1-10 cm per second) and vertical (1-3 mm per second) flow velocities mimic naturally relevant current patterns, while light levels and spectral quality will be varied from complete darkness to intensities experienced across the depth range inhabited by krill. Attractive phytoplankton odor will be created by dosing the flumes to obtain background chlorophyll a levels approximating average and bloom conditions, while repulsive cues will be generated from penguin guano. Behavior of individual krill in all conditions will be video recorded with cameras visualizing X-Y and Y-Z planes, and 3D movements will be reconstructed by video motion analysis at a 5 Hz sampling rate. The distribution of horizontal and vertical swimming angles and velocities will be used to create an individual based model (IBM) of krill movement in response to each condition, where krill behavior at each model time step is based on random draws from the velocity and angular distributions. Since krill commonly travel in groups, further experiments will examine the behavior of small krill schools in these same conditions to further parameterize variables such as individual spacing. Researchers will examine krill aggregation structure from 3D video records of krill swimming in a specially designed kriesel tank, and compute nearest neighbor distances (NND) and correlations of swimming angles among individuals within the aggregation. Krill movements in the IBM will be constrained to adhere to observed NND and angular correlations. Large scale oceanographic models will be used to define spatial environments in which the modelled krill will be allowed to move using simulated schools of 1000-100,000 krill. Model output will include the school swimming speed, direction and structure (packing density, NND). Researchers will compare available acoustic data sets of krill schools in measured flow and phytoplankton abundance to evaluate the model predictions.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

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Funding

Funding Source	Award
NSF Office of Polar Programs (formerly NSF PLR) (NSF OPP)	OPP-1840941

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