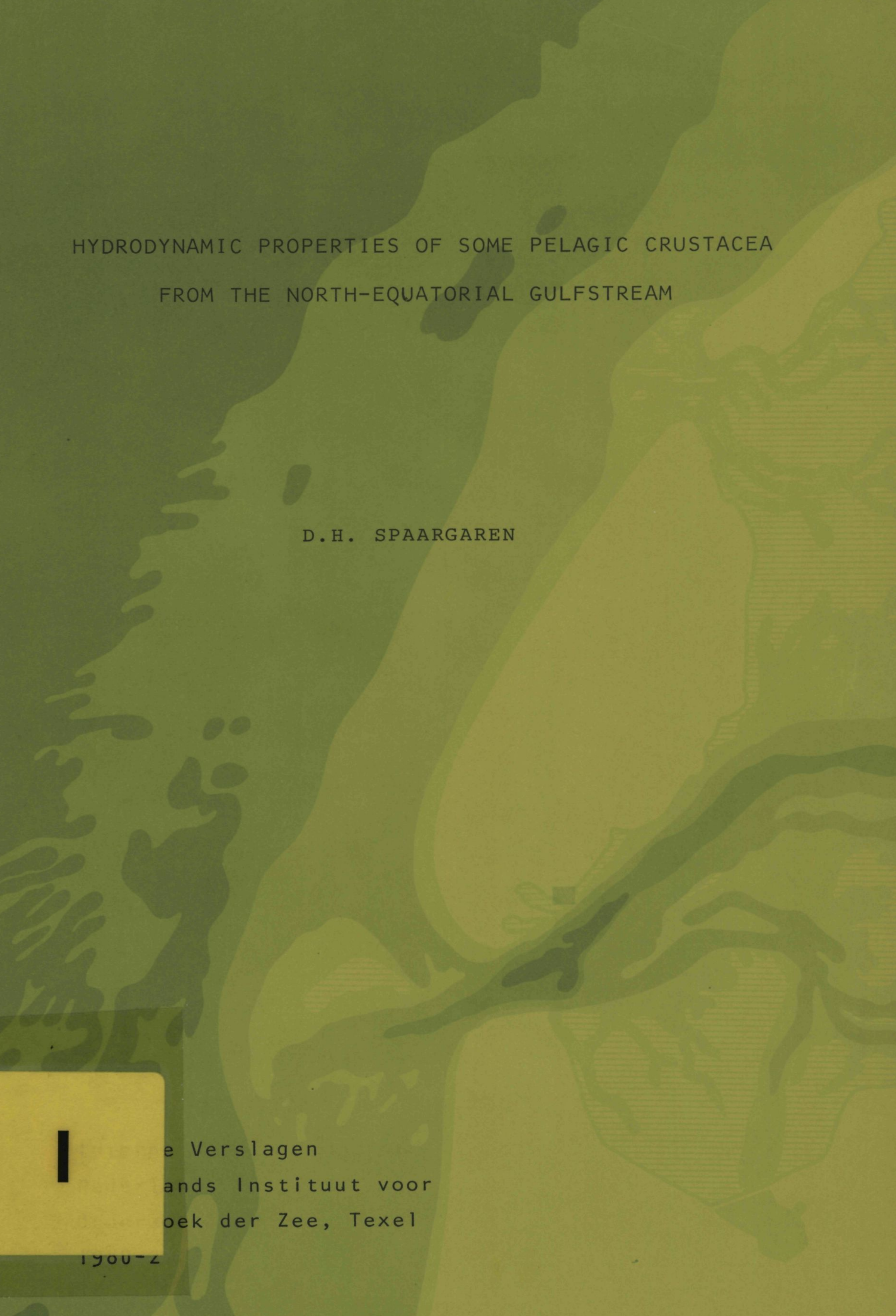

HYDRODYNAMIC PROPERTIES OF SOME PELAGIC CRUSTACEA FROM THE NORTH-EQUATORIAL GULFSTREAM

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e Verslagen
ands Instituut voor
oek der Zee, Texel
1980-2

printed by NIOZ texel

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door

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I. SUMMARY

Measurements on underwater weight, weight in air and terminal sinking rate were collected using 8 different species of pelagic crustacea from the North-Equatorial Gulfstream. From these data (1) animal density, (2) shape constant, determining frictional resistance at terminal sinking velocity and (3) an estimate for the minimum power requirement for keeping depth were derived.

Densities varied between 1.036-1.1112 $g.ml^{-1}$; shape constants ranged between 465 and 1280; power demand (per gram) ranged between 4.5 and 24 μWatt/gram fresh weight.

In species found at different localities a clear intraspecific variation of density and shape constant is observed; by the contribution of the exoskeleton to the density of crustaceans, density and shape constant are positively related.

The relatively low densities correspond to the pelagic modes of life; the low shape constants, which do not contribute

very much to reduce the energy consumption for keeping depth, are probably related to a high mobility in these species, whereas large protrusions would inhibit their locomotion.

II. INTRODUCTION

The pelagic mode of life of crustaceans, living in the open ocean requires, especially in the larger species, adaptations to maintain a certain depth position. When animal density exceeds that of the surrounding water sinking will occur, unless active swimming movements prevent this sedimentation. The rigid exoskeleton of crustaceans increases their relative density; lipids, which may decrease the density, are usually present only in small amounts (2-5%, MORRIS, 1971); a high watercontent, however, may play an important role in decreasing the density (CHILDRESS & NYGAARD, 1974).

Swimming movements to maintain a constant position in the vertical will cost energy. The amount of energy required cannot be estimated accurately as it depends on the swimming mode (velocity, direction) which alters from moment to moment. However, it can be made plausible that the minimum power requirement is related to the product of underwater weight and sinking rate in the absence of swimming movements (SPAARGAREN, 1980). The underwater weight depends on the density of the animal and the surrounding water; sinking rate is also related to the underwater weight but also depends on the shape (surface to volume ratio) of the animal.

This paper presents some data on density and shape constants (as can be derived from measurements of weight in air, underwater weight and sinking rate) of 8 species of pelagic crustaceans from the North-Equatorial Gulfstream.

Acknowledgements

I am much indebted to those who made the material available; in this I like to mention especially the contribution of H. Witte. The taxonomical help to Prof. Dr. L.B. Holthuis (State Museum for Natural History, Leiden) and Dr. T.E. Bowman (Smithsonian Institution, Washington) was greatly appreciated. I also like to thank Dr. J.J. Zijlstra (NIOZ, Texel) for his stimulating interest in this work.

III. MATERIAL AND METHODS

The measurements were carried out using the following species: *Systellaspis debilis* (A. Milne Edwards), *Phyllosoma* larvae (Palinuiridae); *Glaucothoe* larvae (Paguridae), *Streetsia challengeri* (Stebbing), *Phrosima semilunata* Risso, *Parapronoe crustallum* Claus, *Phromina sedentaria* (Forskal) and *Sergestes henseni* Ortman.

The animals were collected during the "NECTAR" expedition in November 1978 with the vessel "H.M. Tydeman", using an Isaacs-Kidd mid-watertrawl, meshsize 5 mm, trawling time 1.3-2.5 hour at depths between 0-300 m. Positions were: 18°13'WL/ 23°24'NB (station 2); 23°20'WL/19°49'NB (station2) and 27°40'WL /19°54'NB (station 3). The animals obtained were fixated in 4% formaline/seawater; measurements of weight in air, underwater weight and sinking rate were carried out at the laboratory on Texel. Animal density was derived from the values for weight in air and underwater weight; as fixation in formaline might affect density (by watersubstraction and reactions of formaline with body proteins) the values should be considered with great care. Fixation in formaline is supposed to have no influence on body shape, determining the drag coefficient viz, the ratio of underwater weight and terminal sinking velocity.

IV. RESULTS AND INTERPRETATION

1. Density

Table I shows the densities of the various crustacean species as derived from measurements of underwater weight and weight in air. All densities obtained are relatively low compared to those obtained for semi-benthic crustacea (ranging from 1.10-1.28 $g.ml^{-1}$; SPAARGAREN, 1979); furthermore it appears that the densities of animals collected at station 2 are higher than those of the same species collected at the stations 3 and 4 (see also Fig. 2), suggesting an intraspecific variation of density related to site of occurrence. It is less likely that formaline fixation affected densities of animal from the three stations in a different way.

2. Size and shape

At terminal sinking velocity (v_∞) frictional forces are in equilibrium with the underwater weight (G_S). In previous experiments with brown shrimps *(Crangon crangon)* it appeared that increase of the underwater weight of an animal (by inserting pieces of lead in the branchial chambers) resulted in a linear increase in terminal sinking rate, indicating that the frictional resistance force (F_f) is linearly related to sinking rate: $F_f = G_s = k.v.$

A linear relation between frictional resistance and velocity indicates a non-turbulent (Stokes') flow regime. The constant k depends on size and shape; according to Stokes' Law the constant for spherical objects follow from: $k = 6\pi r \eta$(r = radius of sphere; η = medium viscosity. The quotient of underwater weight and terminal sinking rate as measured here for the various animals also depends on size and shape. Plots of log k against log w (Fig. 1a-g) show linear relationships with a slope

Table I.

Density ($S_a^{20^{\circ}}$), shape constant (c) and power requirement (P_i) for maintaining constant depth for various pelagic crustaceans from the North Equatorial Gulfstream (N, number of animals; σ, standard deviation).

Genus and species	Sta.	W_{min}-W_{max} (gram)	N	S_a^{20} (g.ml^{-1})	σ	c	σ	$\bar{w}$ (gram)	P_i (µWatt.g^{-1})
Decapoda									
Systellaspis debilis	2	0.19-2.34	20	1.066	0.009	72.4	121	0.17	10.8
	3	0.14-4.34	20	1.063	0.007	594	159	0.17	12.7
	4	0.09-2.94	20	1.045	0.007	501	101	0.17	4.5
	av.		60	1.058	0.012	607	157		
Phyllosoma larvae	2	0.04-0.36	15	1.050	0.014	1280	683	0.16	2.4
	3	0.03-0.22	15	1.041	0.010	1033	376	0.16	1.4
	4	0.04-0.26	3	1.033	0.009	628	106	0.16	0.7
	av.		33	1.044	0.013	1109	552		
Glaucothoe larvae	2	0.04-0.07	10	1.112	0.012	896	122	0.05	24.0
	3	0.04-0.07	15	1.084	0.008	740	135	0.05	15.5
	4	0.03-0.05	15	1.086	0.032	918	396	0.05	13.2
	av.		40	1.092	0.024	846	271		
Amphipoda									
Streetsia challengeri	2	0.01-0.15	15	1.084	0.021	811	230	0.08	16.2
Phrosima semilunata	2	0.09-0.52	10	1.055	0.009	505	101	0.31	6.7
	3	0.24-0.39	3	1.036	0.008	520	224	0.31	1.8
	av.		13	1.051	0.009	508	129		
Parapronoe crustullum	3	0.06-0.15	3	1.057	0.011	483	210	0.10	9.38
	4	0.04-0.14	8	1.054	0.011	465	149	0.10	8.0
	av.		11	1.055	0.010	470	157		
Phromina sedentaria	4	0.03-0.25	4	1.040	0.012	784	547	0.14	1.6
Euphausiacea									
Sergestes henseni	2	0.04-0.10	20	1.078	0.010	643	120	0.07	15.1
	3	0.03-0.13	20	1.060	0.007	521	84	0.07	9.4
	4	0.02-0.13	20	1.060	0.009	503	115	0.07	9.7
	av.		60	1.066	0.012	555	123		

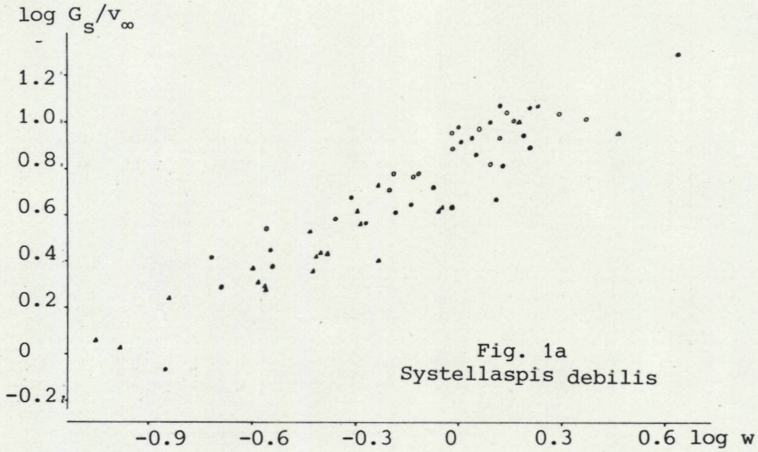

Fig. 1a
Systellaspis debilis

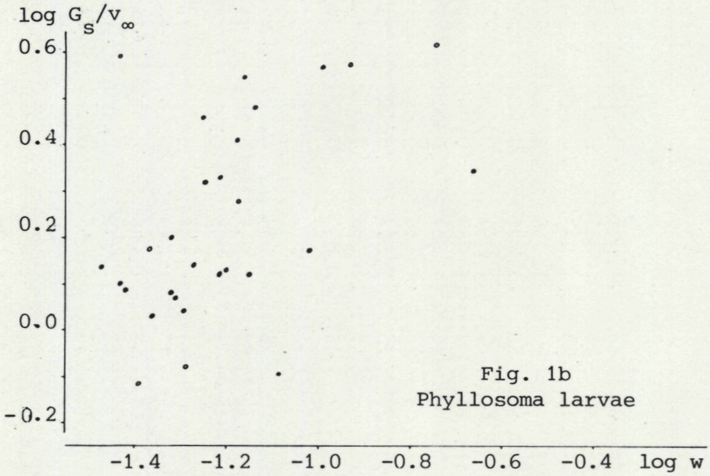

Fig. 1b
Phyllosoma larvae

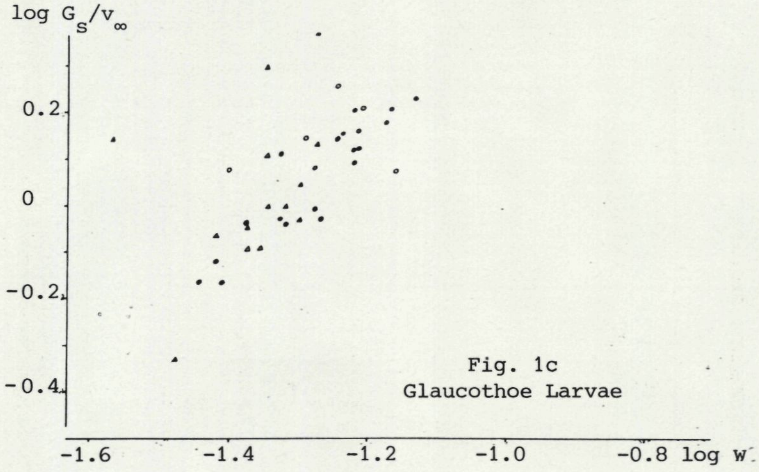

Fig. 1c
Glaucothoe Larvae

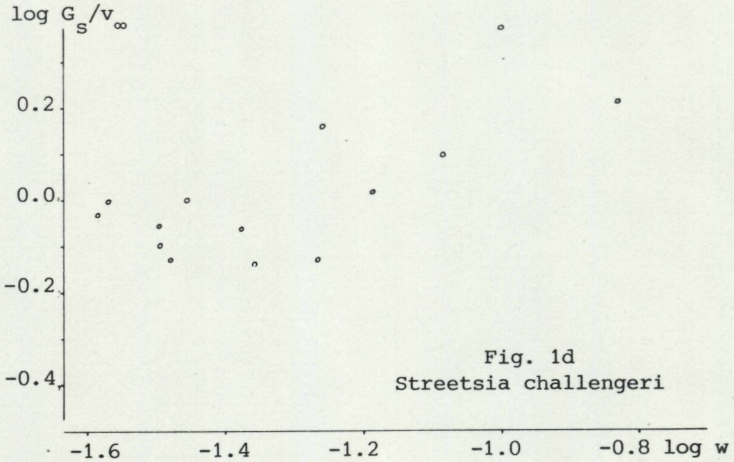

Fig. 1d
Streetsia challengeri

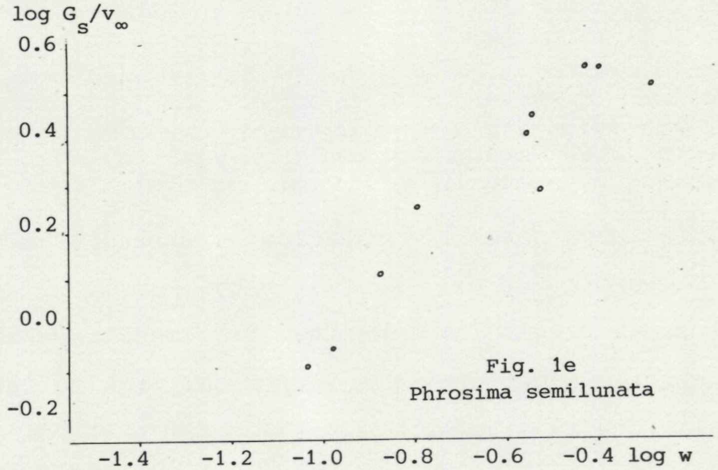

Fig. 1e
Phrosima semilunata

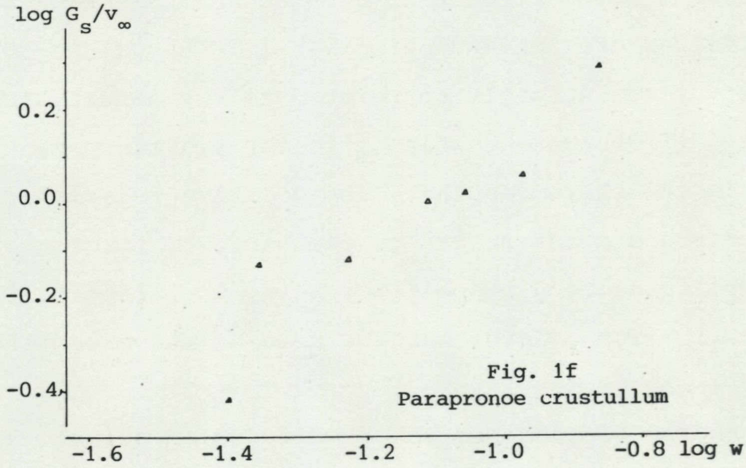

Fig. 1f
Parapronoe crustullum

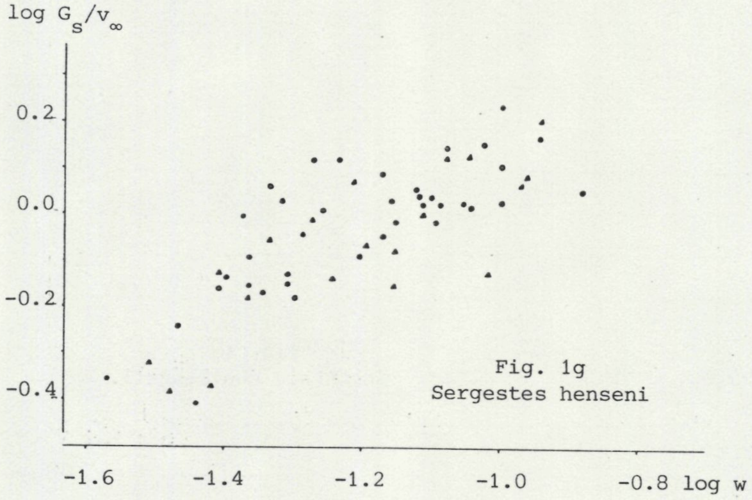

Fig. 1. Ratio of underwater weight (G_s) and terminal sinking rate (v_∞) as a function of size (fresh weight, w) in various pelagic crustaceans: a. *Systellaspis debilis;* b. *Phyllosoma* larvae; c. *Glaucothoe* larvae; d. *Streetsia challengeri;* e. *Phrosima semilunata;* f. *Parapronoe crustullum;* g. *Sergestes henseni*. o, station 2; ●, station 3; Δ station 4.

of about 2/3 (in some cases the relation is masked by a high variation). Therefore, we will express k by: $k = c.\eta w^{2/3}$.

Table I shows values for c derived from measurements of underwater weight, weight in air and terminal sinking rate, using the relations as given above. It appears that compared to similar data for semi-benthic crustaceans (SPAARGAREN, 1979) the values are not exceptional high. The values for the shape constant are strongly correlated to the densities (Fig. 2); density differences between different stations are also reflected in the shape constant. The positive relation between density and shape constant can be explained by the fact that a more complicated body shape (increasing the frictional resistance) also implies a large surface area of the exoskelton, hence also a higher density.

Complicated body shapes as often found in pelagic animals

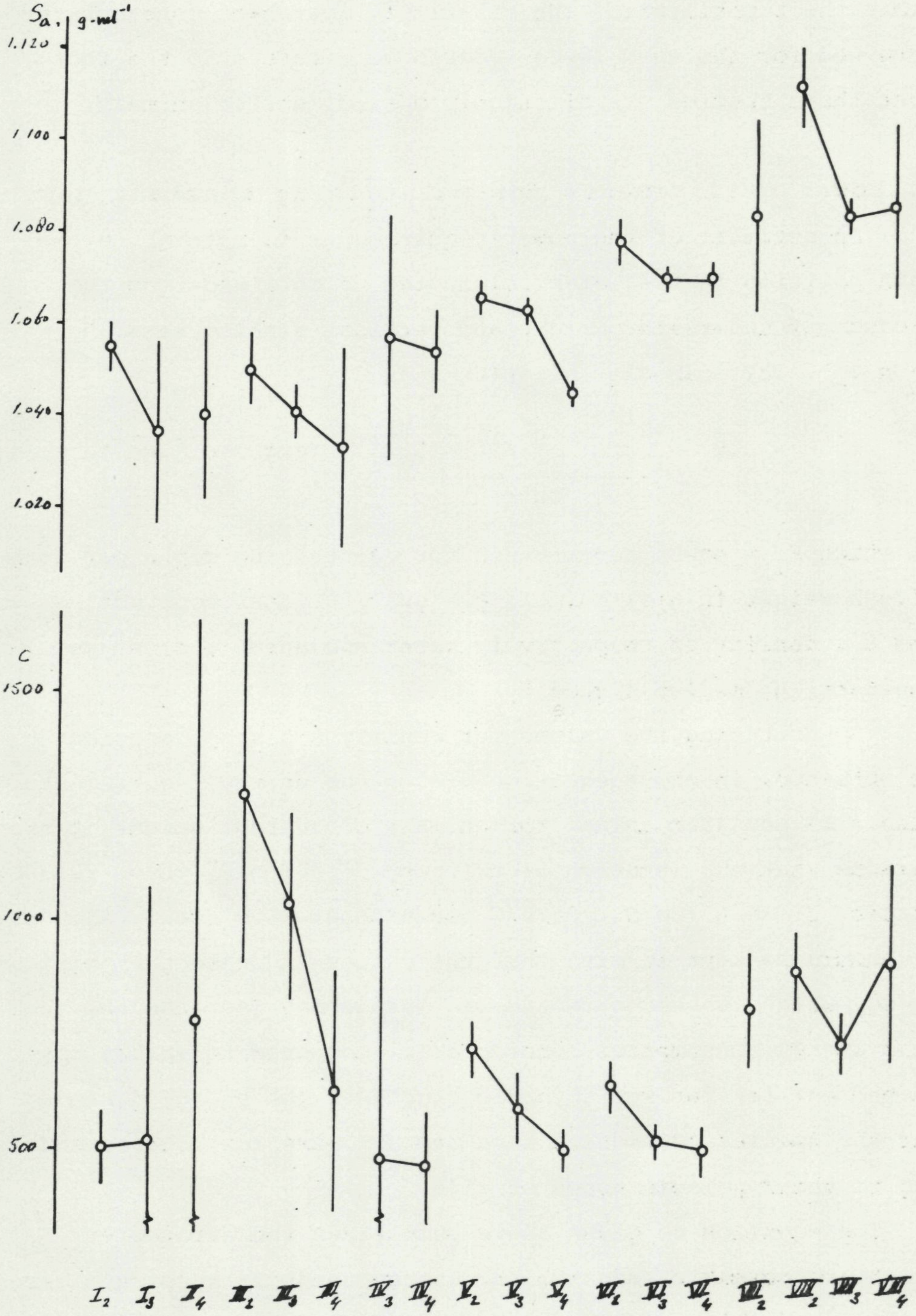

Fig. 2. Density (s_a) and shape constant (c) in various pelagic crustaceans: I. *Phrosima semilunata;* II. *Phromina sedentaria;* III. *Phyllosoma* larvae; IV. *Parapronoe crustullum;* V. *Systellaspis debilis;* VI. *Sergestes henseni;* VII. *Streetsia challengeri;* VIII. *Glaucothoe* larvae. The indices refer to the different stations of collection.

limit their mobilities. The relatively low shape constants as obtained for the animals considered here refers to the fact that these species are all highly mobile, active animals.

3. Power requirements for maintaining constant depth

An estimate of the power requirements to maintain a certain position in the water column can be obtained from the product of underwater weight and terminal sinking rate: $P_i = G_s \times v_\infty$. This can also be written as:

$$P_i = \frac{W^{1/3} \cdot g^2 \left(1 - \frac{S_w}{S_a}\right)}{c\eta} \quad (\mathrm{erg.sec^{-1}.g^{-1}})$$

in which P_i = power requirement for maintaining depth per gram (fresh weight in air) animal; g = gravitational constant; S_w and S_a, density of respectively water and animal; c, shape constant; η, medium viscosity.

Substituting the values for density and shape constant as obtained, in above equation yields the energy requirements (Table I) per gram animal for animals of average weight at the various stations (station 2: salinity 36.3^o/oo S, temp. 22.3^{o}C; station 3: 36.4^o/oo S, 25.5^{o}C; station 4: 36.9^o/oo S, 25.6^{o}C). It should be kept in mind that the values indicate the minimum energy which is needed; metabolic losses may increase the actual energy consumption considerably. Compared to values obtained earlier for semi-benthic crustacea the energy demands for the species considered here are all very low, corresponding to their pelagic modes of life.

The equation as given above summarizes the strategies which are possible reducing the energy needs in keeping a certain depth: (1) a small size *viz.* low (wet) weight, (2) a low difference in density between animal and medium, (3) a high shape constant and (4) a high medium viscosity, which means a low water temperature. The data obtained suggest that all animals considered here are mainly adapted by applying the first two strategies.

V. REFERENCES

CHILDRESS, J.J. & M. NYGAARD, 1974. Chemical composition and buoyancy of midwater crustaceans as a function of depth of occurrence off South California.—Mar. Biol. 27: 225-238.

MORRIS, R.W., 1971. Comparison of the fat composition of oceanic copepods from different depth.—Comp. Biochem. Physiol. 40B: 275-281.

SPAARGAREN, D.H., 1979. Hydrodynamic properties of benthic marine Crustacea. I. Specific gravity and drag coefficients.—Mar. Ecol. Prog. Ser. 1(4): 351-359.

——, 1980. Hydrodynamic properties of benthic marine crustacea. II. Energy requirements for maintaining vertical position.—Mar. Ecol. Prog. Ser. 2(1): in press.