Electronic Supplementary Material (ESM)

for

Underwater attachment using hairs: the functioning of spatula and sucker setae from male diving beetles

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This document includes:

Tables S1-S3

Captions for Supplementary Movies S1-S4

Table S1. Summary of information for museum specimens.

ID#	Seta type	BA (mm^2)	Est. BM (g)	PA (mm^2)	Museum ID	Locality	Collector	Date
111	circular	334.94	1.493	6.24	4881-4045			
112	circular	408.69	2.019	6.53	4881-4640	Primorsky Kraj, Sikhois-Alin, Kamonusake, USSR	O. Gorbunov & V. Sytchjov	1991
114	circular	431.51	2.192	5.34	4881-4171	Tomakomai	M. Mori	1986
115	circular	423.05	2.127	8.59	4881-4085	Ezy Eure, France	M. Monguillon	1959
221	circular	112.17	0.285	2.26	4881-1035	Ezy Eure, France	M. Monguillon	1959
222	circular	122.28	0.324	2.36	4881-1765	Futatsu-yama Shibecha Hokkaido	S. Ishida	1958/7/2
223	circular	64.59	0.123	0.91	4881-25779	Phuphing Palace 1400m, Doi Suthep-Pui, C. Chiang Mai	T. Yamasaki	1987/9/8
224	circular	55.03	0.097	1.18	4881-4163			
225	circular	64.32	0.123	1.20	1282-34071	Nau Danda (2100m)- Biletanti (1350m), Central Nepal	M. Sakai	1981/10/13
226	circular	45.82	0.073	0.53	4881-13654	Minsheng Road in Liukuei, Kaohsiung, Taiwan	K. Ushijima	1977/6/10
229	circular	77.95	0.164	1.18	4881-13603	豊富町稚内	M. Mori	1986/9/14
331	circular	109.17	0.273	1.99	446-626			
332	circular	106.17	0.262	1.69	447-677			
333	circular	86.65	0.193	1.28	4881-13711	Ohara Iriomote I. (Ryukyus)	Y. Hori	1977/3/20
334	circular	106.60	0.264	1.23	4881-13753	Ishikari-cho Hokkaido	M. Mori	1986/10/10
335	circular	39.97	0.060	0.40	4463-128			
337	circular	30.88	0.040	0.49	4881-13536			
339	circular	43.34	0.067	0.49	4881-26157	Masuda City, Shimane Pref.		
340	circular	39.29	0.058	0.55	4881-11839	Shikamatazawa Niigate Pref.	Y. Hori	1982/10/12
342	circular	44.86	0.071	0.65	4881-13549	Okinawa Hegina, Maesato Ishigaki Is.		1975/6/16
344	circular	42.58	0.066	0.48	4463-178			
345	circular	39.96	0.060	0.52	4463-941			
346	circular	39.15	0.058	0.69	4463-218			
441	circular	63.77	0.121	0.36	4881-5237	Nau Danda (2100m)- Biletanti (1350m), Central Nepal	M. Sakai	1981/10/13
445	circular	79.72	0.170	0.61	1282-34177			
446	circular	95.73	0.224	0.96	4881-11832	Ceylon	G. Lewis	1881/12-1882/4
449	circular	32.42	0.043	0.47	4881-1706			
117	spatula	454.77	2.374	7.50	1282-34139	楊梅,高山頂	B.-S. Chang	1974/7/20
118	spatula	239.59	0.899	1.80	4463-1481			
119	spatula	201.83	0.693	0.93	4881-4160	Tarumai Marsh Yonaguni-jima	M. Sato	2000/3/29
120	spatula	183.41	0.600	1.21	4881-13622	Ikema-jima Ryukyus	M. Sato	1997/12/25
227	spatula	17.52	0.017	0.13	4881-12864	Jumla (2340 m), west Nepal	M. Sakai	1981/9/20
228	spatula	52.79	0.091	0.23	4881-13217	Yashagaiki Fukui	Y. Hori	1983/8/28
230	spatula	74.11	0.152	0.38	4881-13634	Gufa, 2950m, Terhathum, Nepal	M. Sato	1979/10/28
336	spatula	48.51	0.080	0.30	4881-4153			
343	spatula	43.88	0.069	0.06	4881-26132	Phaplu, 2380m, Solukhumbu, Nepal	M. Sato	1979/10/13
447	spatula	42.73	0.066	0.13	4881-12861	Jumla (2340 m), west Nepal	M. Sakai	1981/9/20
448	spatula	45.08	0.072	0.21	4881-25811			
451	spatula	27.90	0.035	0.05	4881-25920			
453	spatula	24.69	0.029	0.02	4881-5190	Midoridani Gifu, Japan	M. Sato	1972/4/30
456	spatula	8.60	0.006	0.05	4881-25966	Todai, S. Alps, Nagano	M. Sato	1978/8/13

*Only two specimens were identified: ID#225: *Hydaticus vittatus*; ID#446: *Hydaticus luczonicus* Aube

Table S2.

Summary and comparison of relationships among variables as shown in Figure 3.

Y vs. X	sample	*n*	slope *b*	intercept *a*	r^2	scaling results	Data
A_B vs. M_B	all live subjects	4[a]	0.66	2.41	0.99	$b \sim 0.67$, isometry	Fig. 3*a*
A_P vs. M_B	circular	27	0.72	0.60	0.89	$b = 0.72 > 0.67$, positive allometry	Fig. 3*b*[c]
	spatula	14	0.87	0.25	0.84	$b = 0.87 > 0.67$, positive allometry	
Fa vs. A_{ST}	*H. pacificus* (circular)	9[b]	0.85	1.50	0.94	$b = 0.82 < 1$, stress decreases w/ A_{ST}	Fig. 3*c*[d]
	C. rugosus (spatula, whole)	12[b]	1.20	2.00	0.24	$b \sim 0$ ($p = 0.1287$); stress unrelated to A_{ST}	

Scaling form: $Y = X^b + a$ (or $\log Y = b \log X + a$).

A_B: body area from top view; M_B: body mass; A_P: palette area; Fa: adhesive force; A_{ST}: seta area.

[a] For interspecific scaling, means from each species were used.

[b] We considered individual hairs of different sizes as independent samples. Circular samples were collected from two subjects and spatula samples were collected from six subjects.

[c] ANCOVA suggests significantly different OLS regression lines for circular and spatula setae. The slopes are similar ($F_{1,37} = 1.93$, $p = 0.17$; pooled slope = 0.78) but the intercepts are significantly different ($F_{1,38} = 51.45$, $p < 0.0001$).

[d] ANCOVA suggests a non-significant difference between OLS regression lines for circular and spatula setae (slopes: $F_{1,16} = 0.31$, $p = 0.58$; intercepts: $F_{1,17} = 3.12$; $p = 0.10$). A common regression line, $\log Fa = 0.86 \log A_{ST} + 1.57$, can be used to describe data from both types of setae.

Table S3.

Summary and comparison of attachment performance metrics between circular and spatula setae under different preloads as shown in Figure 4.

Y vs. X	sample	load type	# *trials*	slope *b*	intercept *a*	r^2	*p*	ANCOVA results	Data
Fa/A_{ST} vs. preload	circular	compression	35	19.33	35.17	0.67	< 0.0001	slopes: $F_{1, 70} = 8.53$, $p = 0.0047$	Fig. 4*a*
	spatula	compression	39	51.19	24.63	0.31	0.0002	OLS regressions significantly different	
Fs/A_{ST} vs. preload	circular	shear #1	7	8.89	23.09	0.16	0.38	slopes: $F_{1, 9} = 0.55$, $p = 0.48$	Fig. 4*c*
		shear #2	4	-1.22	32.80	0.004	0.90	intercepts: $F_{1, 10} = 0.68$, $p = 0.43$	
								common line: log Y = 5.04 log X + 26.67	
	spatula	proximal	20	8.22	-0.93	0.53	0.0003	slopes: $F_{2, 56} = 4.71$, $p = 0.0128$	
		distal	20	13.67	-0.93	0.46	0.001	OLS regressions significantly different	
		lateral	22	-0.77	10.57	0.0002	0.840		

Scaling form: $Y = X^b + a$ (or $\log Y = b \log X + a$).

Fa/A_{ST}: adhesive force of a single seta per seta area; Fs/A_{ST}: shear resistance of a single seta per seta area.

Captions for Supplementary Movies

Movie S1. Attachment-detachment process of a circular seta from male *H. pacificus* at a preload of 0.45 mN and pull-off velocity of 75 μm/s (~0.25 seta length per second, L_{ST}/s). This event was filmed laterally at 24 fps and played back at its original speed. Still images at different stages are presented in Fig. 5*a*.

Movie S2. Attachment-detachment processes of a spatula seta from male *C. rugosus* at a preload of 0.35 mN and pull-off velocity of 150 μm/s (~0.5 L_{ST}/s). This event was filmed laterally at 24 fps and played back at its original speed. Still images at different stages are presented in Fig. 5*b*.

Movie S3. Attachment-detachment process of a spatula seta from male *C. rugosus* at a preload of 0.76 mN and pull-off velocity of 75 μm/s (~0.25 L_{ST}/s). This event was filmed proximally from the stalk side at 24 fps and played back at its original speed. Before the seta touches down, the oval sucker and parallel channels can be seen from its ventral surface. Prior to sucker-substrate separation, stalk extension and slight deformation in the sucker can be observed.

Movie S4. Lateral shearing of a spatula seta from male *C. rugosus* at a preload of 0.24 mN and shearing velocity of 75 μm/s (~0.25 L_{ST}/s). This event was filmed proximally from the stalk side at 24 fps and played back at its original speed. Shortly after the sliding motion begins, the contact surface rotates until its long axis becomes parallel to the sliding direction; during pull-off, the contact surface re-orients to its initial direction.