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On the Sacculinization of the Hermit-Crab,
Pagurus ochotensis
II. On the Fat Content¹⁾

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(With 3 Tables)

As regards the fat content of the host in crustacean parasitism, since Smith ('11, '13) and Robson ('11) reported that, in *Carcinus moenas* and *Inachus mauritanicus* parasitized by *Sacculina neglecta*, parasitization brought about an increase of the fat content of the host, there have been several works on this subject (Pierre '35, Reinhard & von Brand '44, Frentz & Veillet '53, Rudloff & Veillet '54). The results, however, seem to be in conflict with each other. In this study, the fat content of *Pagurus*²⁾ *ochotensis* both in the normal condition and parasitized by *Peltogasterella socialis* was examined.

Before going further, the writer wishes to express his cordial thanks to Professor Tohrü Uchida for his kind guidance and improvement of the manuscript.

Material and method : Normal and parasitized animals of both sexes caught in 1957 and 1958 at Akkeshi served as material. The abdomen of the hermit-crabs, after measuring the several portions of the body, was cut off and weighed. When the parasitized specimens were the subject of the study, the external sacs of the parasite were completely removed before the abdomen was cut off. The isolated abdomen was placed in a glass container into which about 80 ml of 5N NaOH solution was poured. Then the solution was heated on a water bath and shaken. After cooling, about 60 ml of HCl was added to the solution. The mixture was transferred into a separatory funnel and the fatty substances were extracted by repeated immersion of ether. After the ether had completely evaporated, the residue was weighed. In this paper, the fat means the fatty substance thus obtained. In the following description, the fat content will be expressed as a percentage of the total weight of the abdomen.

1) Contributions from the Akkeshi Marine Biological Station, No. 99.

2) In the previous paper (Oguro '55), the genus name of this animal was described as *Eupagurus*, but it is appropriate to rectify to *Pagurus* according to Miyake (J. Fac. Sci. Hokkaido Univ., (VI) 13 : 85-92).

The article published in Annot. Zool. Japon., Vol. 28, No. 2 (1955) should be referred to as No. 1 of the series of studies 'On the sacculinization of the hermit-crab, *Pagurus ochotensis*'.

Results

I

The hermit-crabs used in this section of the study were caught in June, 1957. The fat content was estimated in each group of the animals, i.e. normal male, normal female (non-ovigerous), parasitized male and parasitized female, but not in each individual. As is shown in Table 1, it seems that in the normal animals there exists a difference in fat content between the two sexes, the male being richer in fat than the female. Moreover, it is obviously detected that more fat is contained in the parasitized animals than in the normal ones regardless of sex. The fat content of the normal male is 7.1 while that of the parasitized is 14.8 percent. The similar results were obtained in the female, 5.4 in the normal and 13.1 in the parasitized. Therefore, it may be said that the parasitized animals store more fatty substances than the normal ones.

The fat content of the ovigerous eggs was also measured, though the eggs in each animal showed various stages of development. The average value of the eggs from 4 mother hermit-crabs is 7.6 percent. The value is somewhat high in comparison with that of the mother.

Table 1. Fat content of the abdomen of *P. ochotensis* in percentage to the fresh weight.

	Sex	Number of specimen examined	% of fat
Normal	♂	6	7.12
	♀ 1)	7	5.39
Parasitized	♂	8	14.82
	♀	7	13.10

1) non-ovigerous

II

Although several studies have been undertaken on this subject, no attempt has been carried out to analyze the problem in connection with the degree of parasitism, so far as the writer is aware. Therefore, the present writer attempted to examine the correlation between the degree of external modifications caused by the parasite and the fat content in each individual, using the animals collected in July, 1958.

The detailed results are shown in Table 2. Considering the data presented, it may be concluded that the number and the size of the parasite and degree of external modifications have no correlation with the amount of fat in the host. The seriously affected specimens (no. 16 & no. 20) show no difference in fat content from the other hosts less affected, while the host no. 13 with heavy affection gives a marked high fat content. On the other hand, the moderately affected host no.

Table 2.

No.	Sex	Carapace length (mm)	Degree of effect in chelae	Degree of effect in pereopods	Weight of abdomen (gr)	Weight of fat (gr)	Fat/Abdomen × 100	Length of external sac of the parasite (mm)	Number of external sac of the parasite
1	♂	19.7			4.757	.267	5.61		
2	♂	23.7			8.138	.628	7.72		
3	♂	26.5			8.987	.640	7.12		
4	♂	26.5			8.129	.668	8.22		
5	♂ 1)	20.5			6.622	.339	5.12		
6	♂ 1)	24.0			6.742	.313	4.64		
7	♂ 2)	19.1			3.568	.271	7.60		
8	♂ 2)	19.8			3.961	.251	6.34		
9	♂ 2)	21.5			5.361	.350	6.54		
10	♂ 2)	22.4			6.270	.458	7.31		
11	♂ 2)	26.4			8.766	.490	5.59		
12	P ³⁾ ♂	19.3	++		2.713	.369	13.60	10.0	20
13	P ♂	20.0	+	++	1.348	.413	30.64	9.8	35
14	P ♂	21.4		++	4.271	.594	13.91	8.5	65
15	P ♂	24.0		+	3.730	.249	6.68	9.5	76
16	P ♂	26.5	++	+	3.220	.480	14.91	10.7	38
17	P ♀	21.5		+	4.371	.565	12.97	12.1	21
18	P ♀	21.9		+	4.858	.588	12.10	10.5	80
19	P ♀	27.7	+		4.674	.661	14.14	12.2	23
20	P ♀	30.0	++	++	11.224	1.170	10.42	14.1	32

1) non-ovigerous. 2) ovigerous. 3) parasitized.

15 is poorer in fat than the other hosts with slight modifications. Therefore, it is generally concluded that more fat is present in the parasitized animals than in the normal ones irrespective of the degree of the external modifications by the parasite. The average fat content of the normal male, normal ovigerous female, parasitized male and parasitized female is 7.16, 6.67, 15.94 and 12.40 percent respectively. These results are in agreement with those presented in the preceding section of the study. Statistical analysis indicates that regardless of sex there is a significant difference in the fat content between normal and parasitized groups of animals.

Discussion

The results reported in the literature on the fat content of the host in crustacean parasitism are rather in conflict with each other as represented in Table 3. For convenience's sake, the discussion will be restricted to the cases in which rhizocephalan parasites are concerned. Besides the early works of Smith ('11) and of Robson ('11), Rudloff & Veillet ('54) reported that an increase of the fat content occurs in both sexes of the host resulting from parasitism. On the other hand, Pierre ('35), Reinhard & von Bränd ('44) and Baffoni ('35) pointed out a decrease of the fat content in the host animals. According to Frenz & Veillet ('53), an increase of the fat content was observed in the male host while the reverse result was obtained in the female one.

For explaining the phenomena of parasitic castration, Smith ('13) proposed the following hypotheses, on the bases of the results obtained by him and by Robson ('11). (1) The normal female crab is richer in fat than the normal male. (2) In the parasitized male, the parasite takes fat from the host as ovaries do in the normal

Table 3. A review of the reported cases

	Writer	Host	Parasite
Fat increase	Robson '11 Smith '11, '13 Hughes '40 Baffoni '53 Frentz & Veillet '53 Rudloff & Veillet '54	<i>Inachus mauritanicus</i> <i>Carcinus moenas</i> <i>Upogebia major</i> <i>Callinassa laticauda</i> <i>Carcinus moenas</i> ♂ <i>Diogenes pugilator</i>	<i>Sacculina neglecta</i> <i>Sacculina neglecta</i> <i>Gyge branchialis</i> * <i>Ione thoracica</i> * <i>Sacculina carcini</i> <i>Septosaccus cuenoti</i>
No change	Reinhard et al '47	<i>Pagurus longicarpus</i>	<i>Stegophryxus hyptius</i> *
Fat decrease	Pierre '35 Reinhard & von Brand '44 Baffoni '53 Frentz & Veillet '53	<i>Diogenes pugilator</i> <i>Pagurus pubescens</i> <i>Callinassa laticauda</i> <i>Carcinus moenas</i> ♀	<i>Septosaccus cuenoti</i> <i>Pellogaster paguri</i> <i>Parthenopea subterranea</i> <i>Sacculina carcini</i>

* Parasite with an asterisk belongs to the Epicaridae.

female. (3) In consequence, the metabolic pattern of the male host becomes changed to the female type and enhancement of the fat deposition is induced. Then, the external sexual characters of the male host are also modified to the female direction. On the other hand, Reinhard & von Brand ('44) observed that fat was diminished in *Pagurus pubescens* parasitized by *Pellogaster paguri*, and, against Smith's hypotheses, they proposed the production of toxic substance by the parasite, by which the fat content of the host is compelled to decrease. Apart from the presence of that toxic substance, the result showing an reduction of the fat in the host may be apprehended with little objection because the parasite relies upon the host for nutrition. The present study, however, showed a marked increase of the fat content in the parasitized animals. Therefore, the hypotheses of Reinhard and von Brand may not be generalized. Meanwhile, no significant correlation was detected between the degree of the external modifications by the parasite and the amount of fat in the host, and, normal male contains fat as much or more than the normal female in *Pagurus ochotensis*. Thus, the explanation of Smith above referred can be hardly accepted in his original form.

The present writer is of opinion that research of the relation between the state of the affected gonads and the fat content may give the solution to the question why inconsistent results above adduced have been obtained. According to Takewaki & Nakamura ('44) and Takewaki ('44), the adipose tissue of *Armadillidium vulgare* was markedly increased in the artificially castrated animals of both sexes. Further, the similar result was reported in the same species by Yamamoto ('55).

On the observation of the present writer, the castrated animals of the marine isopod, *Tecticeps japonicus* were richer in fat than the normal ones (unpubl.). In this respect, it must be recalled that infection of *Peltogasterella* brought about a complete destruction of the gonads of *P. cchctensis* in both sexes (Oguro '55).

Considering the facts above described, it may be assumed that parasite causes the change of the fat content in the host not directly but indirectly; the destruction of the gonads of the host by the parasite brings about a commotion of the fat metabolism which is under the control of the gonads for some mechanisms. If this assumption be acceptable, the reason for the conflicting results above noted might be explained as the following. When the gonads of the host suffered a heavy effect, gonadal control which obstructs the accumulation of the fat was eliminated. Thus the fat deposition occurred. On the contrary, when the function of the gonads was preserved despite the parasitism, the fat content of the host decreased mainly due to the nutrient disturbance by the parasite. Unfortunately, as there has never been study that discusses in detail the change of fat content in relation to the state of the affected gonads, proof of this assumption will require further studies using abundant material.

Summary

In this study, the fat content of *Pagurus ochotensis* was estimated in both normal and parasitized specimens. In the normal animals, the male seems to be slightly richer in fat than the female. The parasitized hermit-crabs with *Peltogasterella socialis* have significantly high amount of fat in comparison with the normal ones in both sexes: it reaches about twofold for the normal condition. No correlation seems to exist between the amount of the fat and the degree of the external modifications.

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