BIOLOGY AND BIOCHEMICAL COMPOSITION OF THE
DEEP-WATER SHRIMP HETEROCARPUS VICARIUS FAXON
(CRUSTACEA: DECAPODA: CARIDEA: PANDALIDAE) FROM
THE SOUTHEASTERN GULF OF CALIFORNIA, MEXICO

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ABSTRACT

Juvenile and adult specimens of the deep water shrimp Heterocarpus vicarius Faxon (Crustacea: Decapoda: Caridea: Pandalidae) were obtained from sampling operations in the southeast Gulf of California, Mexico. The catch (10.36 kg ha⁻¹) represents the most important reported so far for this species. Fixed specimens were used for taxonomical and morphological analyses. Variation in rostrum:carapace length ratio was found to be related to size of individuals. Number of spines on rostrum also varies considerably, from 5–14 dorsally and 8–12 ventrally. Fresh specimens were kept frozen and used to determine growth curve and biochemical composition of peeled tail (protein, lipid and trace metals). Protein (83.8–84.4%) and lipid (8.2–9.1%) content were independent from body size. Concentrations of trace metals (μg g⁻¹ dry weight: Cu 17–20; Co 0.41–0.42; Cd 0.74–0.89; Cr 0.63–0.91; Mn 0.4–0.6; Fe 17–24; Ni 0.9–1.1; and Zn 26–33) were not significantly related to body size, except for Fe and Zn. On average, values were much lower than what has been reported for trace metals in whole individuals of other species of shrimps, but were similar to values obtained in peeled tails of penaeid shrimp from the area.

Shrimps of the family Pandalidae (s.l.) are important for fisheries. Recent exploratory surveys in tropical and subtropical waters have contributed to a notable increase of known species (Gouding, 1984; King, 1987; Crosnier, 1986, 1988; Hendrickx, 1990). According to Holthuis (1980), some 34 species have generally been considered of commercial importance worldwide. Among these, nine species belong to the genus Heterocarpus, including only one species (H. vicarius Faxon) endemic from the eastern tropical Pacific and commercially fished for in Costa Rica and Panama (Holthuis, 1980). Recently published data related to abundance and distribution of the eastern Pacific pandalids, however, clearly indicate that some other species might also represent a fishing potential, in particular below 200 m depth (Hendrickx and Wicksten, 1989; Hendrickx, 1995a).

Because they live in much deeper water than the commercially important penaeid shrimps (e.g., Penaeus, Trachypenaeus, Xiphopenaeus, Solenocera), tropical pandalids are caught only during exploratory surveys or experimental fishing activities. Information related to occurrence and biology of these species are therefore limited to occasional captures. On the contrary, in selected temperate fishing areas, a highly efficient fishery has sometimes been developed for these shrimps (e.g., Heterocarpus reedi Bahamonde, Peru and Chile; Pandalus jordani Rathbun, from California to Washington; P. borealis Kroyer, North Atlantic and North Pacific) (Holthuis, 1980).

When compared to temperate areas, little is known about abundance and distribution of trace metals in tropical and subtropical marine environments. Fundamentally, these environments differ from those of temperate regions for three main reasons. First, marine tropics are characterized by the presence of complex ecological systems which are probably more sensitive to contamination. Second, most countries bordering tropical and sub-
tropical oceans and seas are still underdeveloped, yet their rapid population growth has lead to an increase in the frequency and intensity of anthropogenic damage. Third, local populations depend heavily on marine systems as a source for food or revenues linked to tourism and sport-fishing (Hatcher et al., 1989; Phillips, 1991).

Although about 230 species of marine and brackish water shrimps occur in the eastern tropical Pacific region (Wicksten and Hendrickx, 1992), biochemical composition and trace metals concentrations of species have seldom been reported (see Páez-Osuna and Ruiz-Fernández, 1995a; Páez-Osuna and Ruiz-Fernández, 1995b; Páez-Osuna and Trón-Mayen, 1995), and never for caridean shrimps. Such data, however, are essential to evaluate the importance of organisms as natural or exploited food sources, and to detect the possible bioaccumulation of metals in marine species. Furthermore, open-oceans or deep-waters can be considered to provide baseline levels for the assessment of metal contamination in polluted coastal waters (Ridgway et al., 1985).

Heterocarpus vicarius is a relatively common species of pandalid shrimp known from the Gulf of California to the coast of Peru. It has been trawled from 73–760 m depth and captured in traps even deeper (to 1454 m) (Hendrickx, 1995a). Recent captures in the southeastern Gulf of California allow for examination of a large series of specimens of different sizes. In this study, data related to growth, abundance and distribution are presented together with values of protein and lipid composition. Concentrations of nine metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) were also measured in order to establish baseline levels in this species.

**Material and Methods**

Specimens were collected during one cruise, August 1991, as part of the TALUD (Benthic Macrofauna of the SE Gulf of California Continental Slope) project. Samples of benthic macrofauna were obtained with a modified Agassiz dredge operated at depths between 216 and 1380 m. A large series of specimens of *H. vicarius* were obtained at one sampling station, and separated from the rest of the catch. Abundance was estimated using the swept area method. On board, selected specimens of different sizes were rinsed, blotted dry, and kept separately in plastic trays. Trays were sealed in plastic bags, covered with aluminum foil, and kept frozen at -15 to -25°C until chemically analyzed in the laboratory. The remainder was fixed with a formaldehyde solution. Fixed specimens were later washed with fresh water and preserved in 70% ethanol for further examination at the laboratory, including identification, counting and measurement (total length, rostrum length, and carapace length to the nearest 0.1 mm). Defrosted specimens were measured to the nearest 0.1 mm (carapace length = CL) and weighed to the nearest 0.1 g. Because our prime interest was to estimate the protein and lipid composition of the flesh, the abdomen (=-tail) of each specimen was separated from the cephalothorax and the exoskeleton was removed using plastic implements. Prior to removing the exoskeleton, tails were weighed to the nearest 0.1 g. *H. vicarius* is not a very large pandalid shrimp. Peeled tails were pooled in two batches as needed to provide sufficient material for protein, lipid, and trace-metals analysis: Batch A with 44 specimens ranging from 2.0 to 3.8 g fresh tail weight, and batch B with 20 specimens ranging from 4.0 to 6.2 g fresh tail weight. Another series of defrosted specimens was used to complete data (carapace length, total weight and tail weight). The tails were oven-dried at 80°C for 48 h, ground in a teflon grinder, and passed through a 200 μm mesh size nylon net. Lipid was determined using the soxhlet extraction method with ethyl ether (Páez-Osuna et al., 1993), and protein levels by the standard Kjeldahl method calibrated with urea using the value of 6.25 as a conversion factor between nitrogen content and protein (Páez-Osuna et al., 1993). Ash content was determined by ashing the homogenized material in a muffle furnace (550°C 12 h) (Páez-Osuna et al., 1991). The precision of the different determi-
nations expressed as coefficient of variation, was estimated to be: Lipids, 6%, proteins, 5%, and ash content 3%. For the trace metal analysis, triplicate aliquots of 1 g of homogenized tissue (tails) and blanks were treated with 50 ml of concentrated and quartz-distilled nitric acid in silica beakers. The digests were slowly evaporated to dryness (100°C) and the remainder dissolved in 1 M HNO₃. After centrifugation (1400 rpm), the solutions were diluted to a final volume of 20 ml with distilled water and placed in acid-washed polyethylene bottles (Moodie and Lindstrom, 1977). They were then aspirated in a Shimadzu (model AA-630) atomic-absorption spectrophotometer using standard flame conditions for each metal. The amount of each metal was determined quantitatively by the method of internal standard additions (Páez-Osuna and Tron-Mayen, 1995). All glassware and plastic utensils used during this study were thoroughly washed with acid (Moodie and Lindstrom, 1977). Those used for manipulating samples were washed with water and detergent, rinsed with distilled water, kept for 3 d in a solution of HCl (2M), rinsed 3 d in 2M solution of HNO₃, 2M, and rinsed with water distilled for another 3 d. Acid solutions were prepared with quartz-distilled HCl and HNO₃ (Baker) (Hamilton, 1980). Quality control was provided by analytical checks on blanks and by means of an intercalibration sample (material of shrimp homogenate, MA-A-3TM) supplied by the International Laboratory of Marine Radioactivity (IAEA, 1987), Monaco. This sample was also used to estimate the accuracy of the method employed. The recoveries and coefficients of variation in parentheses were as follows: Cd, 105% (6.2%); Cu, 93% (4.7%); Ni, 110% (8.4%); Mn, 67% (2.4%); Fe, 98% (3.8%); and Zn, 97% (11.8%). All metal concentrations are expressed as µg g⁻¹ dry wt. Abbreviations used herein are: CL, carapace length; TW, total fresh weight; TL, total length; Tfw, tail fresh weight.

RESULTS AND DISCUSSION

SIZE, SEX AND ABUNDANCE.—The maximum known size of H. vicarius is 115 mm total length (ca. 35 mm CL). Specimens collected during this survey range from 10.5 to 33.0 mm CL. Total catch at station 28 was 7.5 kg fresh weight (22.2 kg ha⁻¹), including 3.5 kg (10.36 kg ha⁻¹) of H. vicarius. The rest corresponds to the red crab Pleuroncodes planipes Stimpson (3.6 kg), Cancer johnsgarti Carvacho, Squalia biformis Bigelow, and a single specimen of Plesionika trigonata Squires and Barragáin (0.4 kg for all three species). For each of the species for which little is known, all by-catch species (including P. planipes in its benthic phase) are known to occur in deep water with low oxygen content (Hendrickx and Salgado-Barragáin, 1991; Hendrickx, 1995b; Hendrickx, 1995c). Sampling depth (221–244 m) is within the known bathymetric distribution range of H. vicarius.

Carapace length-frequency distribution indicates that most specimens belong to the 16–26 mm (CL) size classes. The collection contains a number of individuals as large as 30.0 mm CL and a few even larger (Fig. 1). Together with the presence of individuals smaller than 16.0 mm CL, these data are interpreted as co-occurrence of juveniles and adults in a relatively small area. Low frequency of larger (>26 mm CL) specimens in sample (Fig. 1) could be attributed either to failure of the fishing device to catch the larger, fast moving animals, or else to migration to deeper or shallower water. Although the histogram may merely represent the population structure at the site sampled. Captures of large specimens of H. vicarius (158 individuals, 81.0–108.0 mm TL) have been reported at a depth of 75 m, off the coast of Sinaloa. Adult specimens have also been caught at several deep water localities (475–1454 m depth) throughout the Gulf of California (Wicksten and Hendrickx, 1985; Hendrickx and Wicksten, 1989), thus indicating that there is no clear bathymetric distribution pattern for the species.
Only four ovigerous females were found in the samples. Their sizes ranged from 23.3 to 23.9 mm CL, and fresh weight was approximately 10% higher than in males and non-ovigerous females of similar size. Sex ratio among adults (>20.0 mm CL) was estimated (n = 110) at 11%. Egg number per female was ca. 3100; average diameter of eggs was 305 μm.

MORPHOLOGY AND BIOMETRIC RELATIONSHIPS.—The different sizes obtained represent the first large series of growth stages available for this species. Largest specimens were compared to conotype material of *H. vicarius* of similar size collected in the Gulf of Panama (USNM 21113, 8 March 1891) (Faxon, 1893) (Fig. 2A). Except for a stronger calcification of integument in conotype material, no significant morphological differences were detected among specimens. A more membranous integument has been previously reported by Chace (1937:118), who studied smaller specimens (CL: 7.5 mm) from the Gulf of California. Growth pattern observed from juveniles (ca. 10.0 mm CL) to largest adults (ca. 30.0 mm CL) indicates that *H. vicarius* exhibits a notable decrease of rostrum relative to carapace length with increase of size. On the average, rostrum:carapace length ratio is greater than one in specimens smaller than 18.0 mm CL, but allometric growth leads to a reverse pattern (ratio <1) in larger specimens (Fig. 4). While comparing his material to the smallest of Faxon's types, Chace (1937) also attributed the presence of a lesser upturned rostrum in young specimens to age; our material, however, indicates that there is no clear pattern that sinuosity of rostrum strongly varies in specimens, independently from size (Figs. 2, 3). Number of rostral and postrostral teeth also show a notable variation during growth and among specimens of similar size. This has been observed in other species of *Heterocarpus*, in particular in *H. gibbosus* Bate (Chace, 1985). Overall variation in *H. vicarius* is 5–14 dorsal (usually 9–12) and 8–12 ventral teeth (usually 10–12). A few specimens show no dorsal teeth in the anterior half (Figs. 2B, 3B). Specimens with no dorsal teeth in anterior half of the rostrum, generally feature much smaller ventral teeth.

Tail weight/total weight relationship was assessed for 51 specimens (CL: 8.9–30.2 mm). The relationship was $T:\bar{W} = 0.3251 \times TW + 0.0904$ ($r = 0.973$). Carapace length/total weight
relationship was also assessed for 84 specimens. The relationship was $TW = 0.0016 \cdot CL^{2.4234}$ ($r = 0.963$) (Fig. 5).

Protein and lipid content.—Protein content of smallest (batch A) and largest shrimps (batch B) did not show differences (84.4% and 83.8% dry weight respectively). Corresponding figures obtained for lipid content were 8.2% and 9.1% (dry weight). Ash contents were 9.1 and 8.5% (dry weight) (Table 1). Comparative values for caridean shrimps are rare. Moreover, available data are often presented as percentage of whole individuals mass (Teshima et al., 1977; Torres et al., 1994) and are therefore difficult to compare. Available data for species of penaeid shrimps, however, compare well with those obtained during this study. Protein content of tails of adult of Penaeus monodon Fabricius, ranges from 89.4% to 92.6% (De-Peteflorida and Millamena, 1990). Similar figures were ob-
Figure 3. Variation in the carapace and rostrum outline according to body size in smaller specimens (CL <25 mm) in a sample of *Heterocarpus vicarius*, lateral view (scale bar = 5 mm).

Lipid level and composition in penaeid shrimps are known to depend upon the source and proportion of lipids in diet (Sick and Andrews, 1973), the molting cycle (Teshima et al., 1975), and the season (Guary et al., 1974). Teshima et al. (1977) found that total lipid in *Penaeus japonicus* Bate (whole individuals) fluctuated with the molting cycle (1.04–1.3%, fresh weight), and Guary et al. (1974) observed slight variation of lipid content among sexes of the same species (2.8% in males and 2.7% in females, fresh weight). Values observed with *H. vicarius* are much higher than these (3.3–3.6%, fresh weight), due to the fact that only tail muscle was used in the analysis.

TRACE METALS.—Trace-metal concentrations in peeled tail of shrimps is of particular importance for it is this part of the product which is generally used as food. Eight metals were detected in *H. vicarius* samples. The concentrations of Pb were too low to be mea-
Figure 4. Relationship between rostrum:carapace length ratio and size (CL) in a sample of *Heterocarpus vicarius*. Arrow indicates values for ectype material.

Figure 5. Comparative analyses of weights and lengths in a sample of *Heterocarpus vicarius*. (A) Relationship between total weight and tail weight; (B) relationship between carapace length and total weight.
Table 1. Concentration of lipids, proteins and ash in specimens of *Heterocarpus vicarius* as a percent of dry weight and fresh weight ( ).

<table>
<thead>
<tr>
<th>Size class</th>
<th>Lipids</th>
<th>Proteins</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0–3.8</td>
<td>8.2</td>
<td>84.4</td>
<td>9.1</td>
</tr>
<tr>
<td>(n = 44)</td>
<td>(3.3)</td>
<td>(33.8)</td>
<td>(3.6)</td>
</tr>
<tr>
<td>4.0–6.2</td>
<td>9.1</td>
<td>83.8</td>
<td>8.5</td>
</tr>
<tr>
<td>(n = 20)</td>
<td>(3.6)</td>
<td>(33.5)</td>
<td>(3.5)</td>
</tr>
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</table>

sured (<1.1 ppm), thus indicating that this metal does not represent a problem in the sampling zone or that it does not bioaccumulate in the abdominal tissues of this species. Highest concentrations were obtained for Zn, Fe and Cu (Table 2). Concentrations were slightly higher in larger specimens (batch B, n = 20), except for Cr, Mn and Ni where a reverse pattern is observed. A Student t-test reveals that only in the case of Fe and Zn were the differences significant. Garcia and Fowler (1972) concluded that concentrations of four trace metals (Cu, Co, Mn and Zn) were higher in smaller specimens of *Penaeus californiensis* Holmes than in older, larger individuals. On the contrary, Páez-Osuna and Ruiz-Fernández (1995a) found a higher level of Zn in larger specimens of *P. stylophoros* Stimpson, while Martin (1974) found manganese concentrations to be higher in larger specimens of *Cancer irroratus* Say.

Published data are scarce and difficult to compare as they often result from the analysis of whole organisms. Ridout et al. (1985) reported values (μg g⁻¹ dry wt) about 4–7 times higher than ours for Mn (2.3–2.9) and up to 43 times higher for Cd (11.1–31.8) in *Systellaspis debils*, a mesopelagic caridean shrimp. Comparatively, values for Fe (31.2–77.8), Cu (25.9–66.6), and Zn (41.9–92.9) provided by these authors were only 2–3 times higher than in this study. Because they are involved in enzymatic processes, Fe, Cu and Zn are considered essential metals for living organisms (Förstner and Wittmann, 1979) and their relatively high concentrations in the tail tissue of *H. vicarius* is not surprising. The concentrations of zinc obtained during our study, however, were lower than those reported for several species of penaeids (*Penaeus merguiensis* De Man and *P. monodon* Fabricius, from Australia; *P. monodon* and *Metapenaeus affinis* [Milne Edwards], from the Indian Ocean) and caridean (*Pandalopsis dispar* Rathbun, *P. borealis* Kroyer, and *P. platyceros* Brandt, from the Canadian Pacific) shrimps. Copper in *H. vicarius* was also lower than in these three penaeid species, but slightly higher than in the Canadian pandalids (Harding and Goyette, 1989). The concentrations of iron vary widely throughout marine crustaceans (Eisler, 1981). Whenever whole organisms are analyzed, the iron content of the hepatopancreas increases the average concentration of this trace metal in tissues. Values found in *H. vicarius* were much lower than those reported for other species of shrimps.

Table 2. Concentration of trace metals (μg g⁻¹ dry wt) in different size specimens of *Heterocarpus vicarius*.

<table>
<thead>
<tr>
<th>Size class (g fresh wt)</th>
<th>Cu</th>
<th>Co</th>
<th>Cd</th>
<th>Cr</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>2–3.8</td>
<td>17</td>
<td>0.41</td>
<td>0.74</td>
<td>0.91</td>
<td>0.60</td>
<td>17</td>
<td>1.1</td>
<td>26</td>
</tr>
<tr>
<td>4–6.2</td>
<td>20</td>
<td>0.42</td>
<td>0.89</td>
<td>0.63</td>
<td>0.40</td>
<td>24</td>
<td>0.9</td>
<td>33</td>
</tr>
</tbody>
</table>
but higher than in the tail muscle of *P. merguiensis* and *P. monodon* (Darmon and Denton, 1990).

Cadmium is known to accumulate in some oceanic decapods (Leatherland et al., 1973). The very low levels observed in *H. vicarius* tails would indicate that Cd does not represent an environmental hazard in the area, although concentrations were slightly higher than in the above-mentioned species of penaeids and carideans (Won, 1973; Harding and Goyette, 1989; Darmon and Denton, 1990) or in species captured off the coast of Texas (Horowitz and Presley, 1977). The concentrations of manganese were much lower than the majority of data available for coastal crustaceans like *Peneaus monodon* (Zingde et al., 1976; Darmon and Denton, 1990) and *P. japonicus* Bate (Ishii et al., 1978), as well as for lobsters and crabs (Eisler, 1981).

The concentrations of chromium, cobalt and nickel in decapod crustaceans are not well documented. Values found in *H. vicarius* are similar (Cr, Co and Ni) or in some cases even lower (Cr and Ni) than what has been reported in other crustaceans by Eisler (1981) and Harding and Goyette (1989).

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**LITERATURE CITED**


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