

## NAUPLIAR DEVELOPMENT OF *METRIDIA PACIFICA* (COPEPODA: CALANOIDA) REARED IN THE LABORATORY

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### ABSTRACT

All 6 naupliar stages of *Metridia pacifica* are described. Naupliar development is compared within the genus *Metridia* and external morphological characters are discussed with respect to previous studies on co-occurring nauplii of *Calanus*, *Neocalanus*, and *Pseudocalanus*. A key to the identification of the naupliar stages is provided.

Knowledge of naupliar morphology is very important for studies of stage-dependent biological and ecological phenomena. Larval walleye pollock (*Theragra chalcogramma* Pallas) in the southeastern Bering Sea are very selective in the species of copepods and developmental stages that they eat. They prefer nauplii of *Metridia*, although these nauplii are relatively rare (Hillgruber *et al.*, 1995). As part of a study of biological and physical variability that influences recruitment of walleye pollock in the southeastern Bering Sea, I describe the naupliar stages of *Metridia pacifica* Brodsky, 1950, and those diagnostic features that facilitate their identification.

### MATERIALS AND METHODS

Adult copepods were sorted from samples collected in the Aleutian Basin of the southeastern Bering Sea and shipped to the Seward Marine Center Laboratory. Females were maintained in separate containers with fresh sea water in a temperature controlled room at 3°C. The copepods were fed ad libitum a mixture of autotrophic flagellates (*Isochrysis galbana* Parke and *Tetraselmis suecica* (Kylin) Butcher) and the diatom *Chaetoceros calcitrans* (Paulsen) Takano. *Artemia* sp. reared for 2 weeks with the above flagellates were added to the mixture. During the fall of 1995 and the winter of 1995-1996, a few females were caught in Resurrection Bay, Gulf of Alaska. They were kept under the same conditions.

When the eggs hatched, some nauplii were immediately preserved in 10% Formalin for later examination. The remaining nauplii were moved into new containers with freshly filtered sea water every fifth day. Specimens and molts of each developmental stage were preserved in 10% Formalin. Since it was not possible to rear beyond stage N IV, specimens of the last 2 naupliar stages were separated from preserved Bering Sea samples (Paul *et al.*, 1996).

Drawings were made using a camera lucida. Two or 3 specimens per stage were checked for variability. Since no asymmetry of segmentation or setation was observed

between sides of paired appendages, only 1 side of each pair is shown. The lengths of the nauplii were measured from the anterior to the posterior end excluding the caudal setae or spines; body width is given for the widest part of the naupliar shield. Body measurements were taken from the specimen that is illustrated in the drawings. A light microscope with maximal 1,000× magnification was employed. The abbreviations used are: N I-VI = naupliar stages I-VI.

### NAUPLIAR STAGES OF *METRIDIA PACIFICA*

The body (N I-VI) is illustrated in ventral view (Fig. 1). The nauplii are oval, becoming more elongate in the course of development. From stage N III onward the hind body gradually protrudes caudally from the dorsal shield. There is no visible segmentation of the body through stages N I-IV. The description of each naupliar stage includes only the changes from morphology of the previous stage.

#### Nauplius I Figs. 1-4

Body length 150 µm, width 100 µm. Body broadly oval, rounded at anterior end, tapering slightly toward posterior end. Hind body bearing pair of long caudal setae (Fig. 1). Labrum conspicuous ventrally, 3 pairs of appendages (antennules, antennae, and mandibles) well developed.

Antennule (Fig. 2) consisting of 3 segments. Proximal 2 segments devoid of conspicuous armature. Distal third segment bearing 3 terminal setae. Coxa of antenna partially separate from basis, neither coxa nor basis armed (Fig. 3). Endopod 2-segmented, partially separate from basis, bearing 2 terminal setae. Exopod consisting of 5 segments partially separate from basis; first to fourth segments each bearing 1 long seta on inner mar-

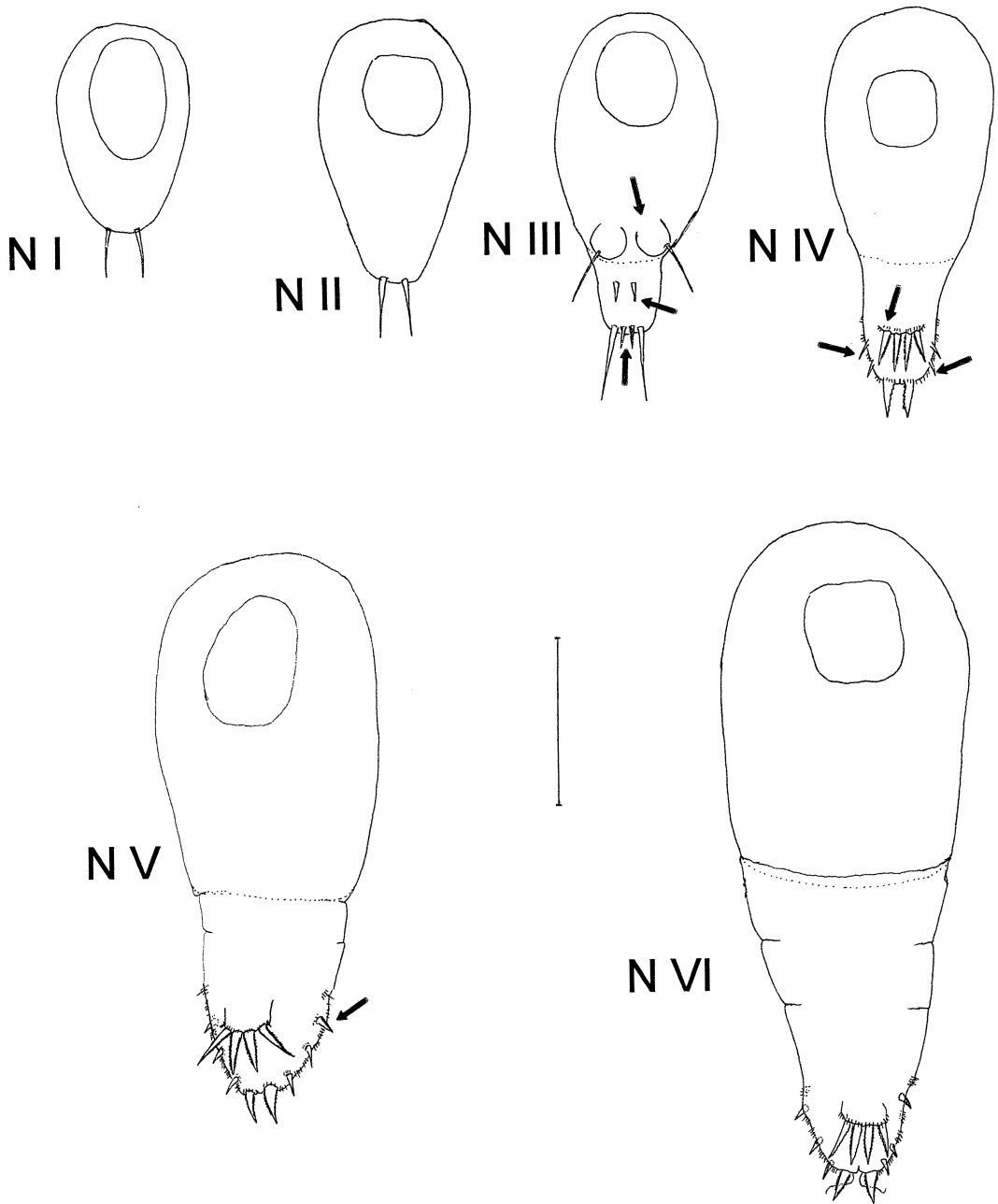


Fig. 1. *Metridia pacifica*. First to sixth naupliar stages (N I–VI) in ventral view. Appendages omitted for clarity. Arrows indicate new structures as compared with preceding stage. Scale bar = 100  $\mu$ m.

gin. Distal segment with 2 terminal setae. Coxa and basis of mandible unarmed (Fig. 4). Endopod 1-segmented, bearing 2 terminal setae. Exopod 4-segmented; segments 1–3 each with 1 seta on inner margin; distal segment with 2 terminal setae.

#### Nauplius II Figs. 1–4

Body length 175  $\mu$ m, width 100  $\mu$ m. N II differs from N I as follows:

Body more tapered posteriorly (Fig. 1).

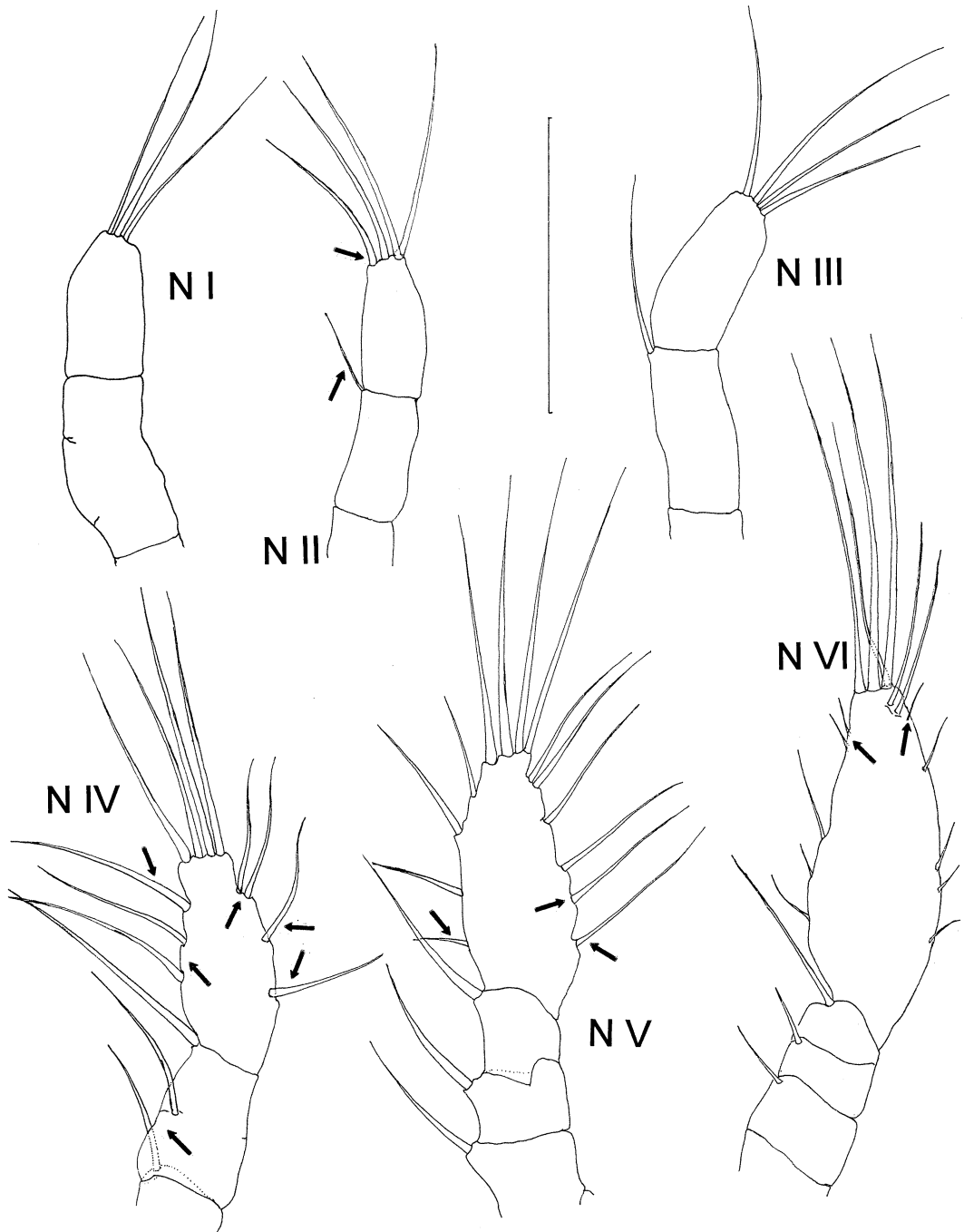


Fig. 2. *Metridia pacifica*. Development of naupliar right antennules in N I-VI stages. Arrows indicate new structures as compared with preceding stage. Scale bar = 100  $\mu$ m.

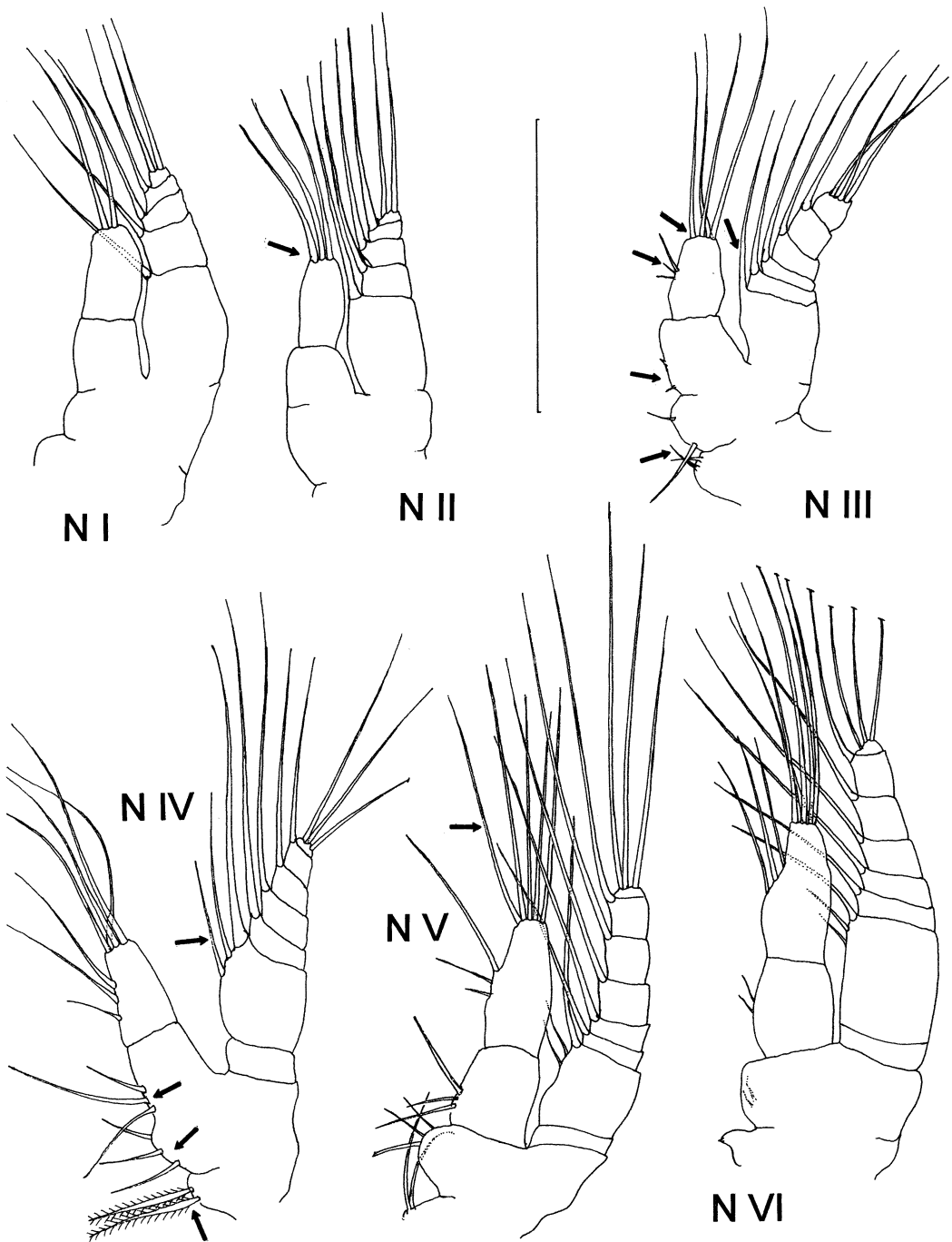


Fig. 3. *Metridia pacifica*. Development of naupliar right antennae in N I–VI stages. Arrows indicate new structures as compared with preceding stage. Scale bar = 100  $\mu$ m.

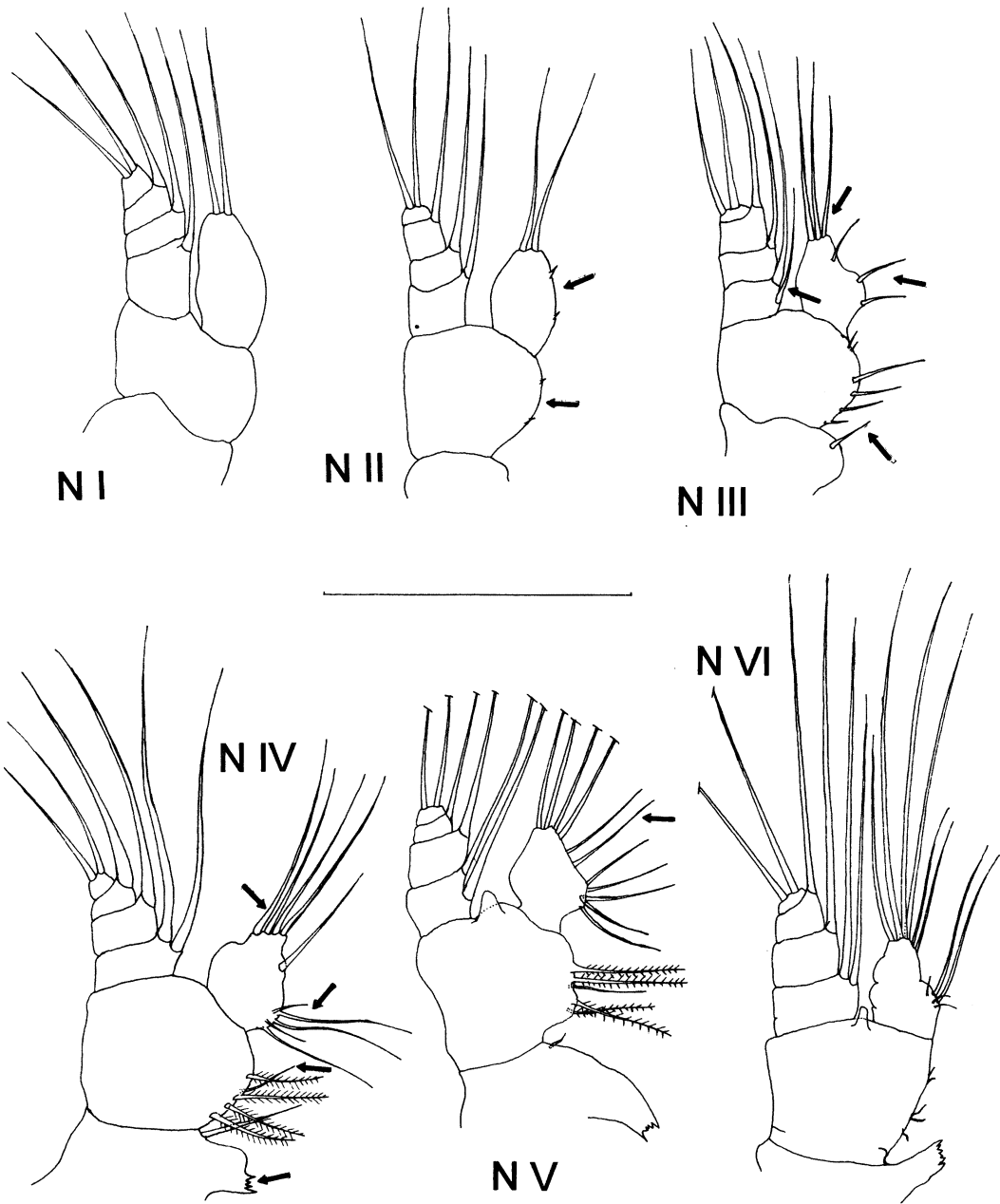


Fig. 4. *Metridia pacifica*. Development of naupliar left mandibles in N I-VI stages. Arrows indicate new structures as compared with preceding stage. Scale bar = 100  $\mu$ m.

Antennule (Fig. 2) adding fourth terminal seta and 1 seta on ventral margin of second segment (Fig. 2). Endopod of antenna (Fig. 3) with 3 terminal setae. Mandible (Fig. 4) acquiring 2 spines on inner margin of basis and 2 on inner margin of endopod.

Nauplius III  
Figs. 1-4

Body length 200  $\mu$ m, width 125  $\mu$ m. N III differs from N II as follows:  
Anterior part of body distinct from poste-

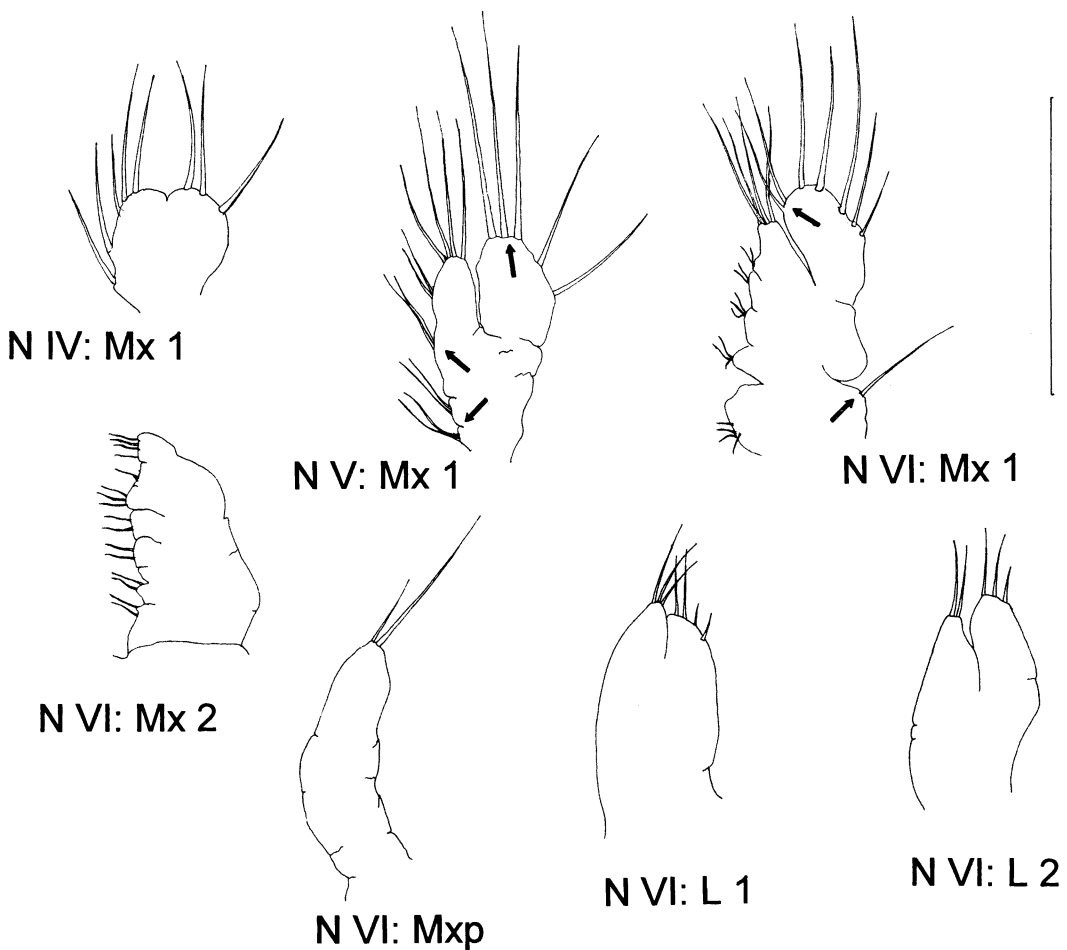


Fig. 5. *Metridia pacifica*. Development of naupliar right maxillule (Mx 1) and maxilla (Mx 2), maxilliped (Mxp), swimming legs 1 (L 1) and 2 (L 2). Arrows indicate new structures as compared with preceding stage. Scale bar = 100  $\mu$ m.

rior part, beginning posterior to bud of maxillule. Hind body bearing pair of caudal setae, pair of caudal spines, and pair of smaller ventral spines (Fig. 1). Coxa of antenna (Fig. 3) bearing 2 spines on inner margin, appearing not articulated with appendage segment; basis with 1 long and 1 short setae. Endopod adding 2 spines on inner margin of proximal segment, and 1 terminal seta and 3 setae on inner margin of distal segment. Exopod consisting of 6 segments; proximal segment not separated from basis; third to fifth segments each armed with 1 seta on inner margin; third seta added to distal segment. Coxa of mandible (Fig. 4) adding spine on inner margin. Inner margin of basis adding 4 setae and

2 spines. Endopod armed with 3 setae on inner margin and 3 terminal setae. First segment of exopod adding 1 seta on inner margin. Bud of maxillule as medial folds armed with 1 long seta each (Fig. 1).

#### Nauplius IV Figs. 1–5

Body length 275  $\mu$ m, width 113  $\mu$ m. N IV differs from N III as follows:

Caudal margin of hind body with pair of spines added and second pair of spines added ventrally (Fig. 1). Antennule consisting of 3 segments; second segment with 2 setae added on ventral margin; distal segment with 3 setae added on ventral margin and 4 setae added

on dorsal margin; anteriormost setae on dorsal margin originating from same notch. Setae on inner margin of coxa of antenna (Fig. 3) transformed into 2 long plumose setae; basis bearing 3 setae on inner margin; proximal segment of endopod fused to basis and with 3 setae added on inner margin; second segment of 7-segmented exopod with 2 fine setae added on inner margin. Coxa of mandible (Fig. 4) with endite developed as masticatory gnathobase; basis with fifth seta added on inner margin. Endopod with setae added, 3 grouped proximally, and 1 terminal. Maxillule (Fig. 5) bilobed, with 5 setae on endopod and 3 setae on exopod.

#### Nauplius V Figs. 1–5

Body length 330  $\mu\text{m}$ , width 130  $\mu\text{m}$ . N V differs from N IV as follows:

Body with 1 segment added. Hind body with fourth pair of well-developed caudal spines added (Fig. 1). Antennule 4-segmented; distal segment armed with 2 additional setae on dorsal margin and 1 additional seta on ventral margin (Fig. 2). Exopod of antenna 8-segmented, with 1 segment added, armed with 1 long seta; endopod 2-segmented, separated from basis, bearing 5 setae terminally (Fig. 3). Coxa of mandible bearing small seta instead of long coxal seta of N IV; endopod with 1 seta added on inner margin (Fig. 4). Exopod of maxillule with 2 additional setae; endopod with 4 setae terminally and 2 slender setae laterally, pair of setae added to each of 2 syncoxal lobes (Fig. 5).

#### Nauplius VI Figs. 1–5

Body size 385  $\mu\text{m}$ , width 150  $\mu\text{m}$ . N VI differs from N V as follows:

Body with 1 additional segment. Antennule 5-segmented; distal segment elongate, with 1 seta added on ventral margin and 1 seta on dorsal margin (Fig. 2). On inner margin of coxa of antenna, 1 seta lost, other seta represented by small spine; both basis and first segment of endopod with 1 seta on inner margins lost (Fig. 3). Maxillular syncoxa bearing long plumose setae on outer margin; exopod with 2 additional slender setae; 1 or 2 setae added to inner lobes of syncoxa and basis (Fig. 5). Maxilla uniramous, with 5 inner lobes of syncoxa and basis bearing 2 se-

Table 1. Differences of developmental patterns within the naupliar phase of *Metridia pacifica* (original data), *Metridia lucens* (\*—after Gibbons (1938); \*\*—after Ogilvie (1953)), and *Neocalanus plumchrus* (after Campbell (1934)).

	<i>M. pacifica</i>	<i>M. lucens*</i>	<i>M. lucens**</i>	<i>N. plumchrus</i>
Antennular lateral setae on 2 proximal segments at N I	absent	3	3	1
Hind body caudal armature at N II	2	2	2(4)	2
Hind body caudal armature at N III	4	n/a	4	4
Hind body caudal spines at N IV	6	6	6(8)	6(10)
Hind body caudal spines at N V	8	8	8(12)	8(10)

tae and 1 seta distal to fifth lobe; maxilliped elongated bearing 2 setae terminally (Fig. 5). Swimming legs 1 and 2 present as bilobed folds (Fig. 5). Exopod of leg 1 bearing 2 setae and 2 spines, endopod with 3 setae terminally. Exopod of leg 2 bearing 3 setae, endopod with 2 setae.

#### KEY TO THE NAUPLIAR STAGES OF *METRIDIA PACIFICA*

1. Nauplius bearing 3 pairs of appendages . . . . . 2
- Nauplius bearing more than 3 pairs of appendages . . . . . 3
2. Antennular distal segment with 3 setae . . . . . N I
- Antennular distal segment with 4 setae . . . . . N II
3. Maxillule precursors present as medial folds armed with 1 long seta each; hind body armed with 2 caudal setae, 1 pair of caudal spines, and 1 pair of smaller ventral spines . . . . . N III
- Maxillule well developed, bearing more than 1 seta; hind body armed with 2 pairs of long ventral spines, 1 pair of denticulate caudal spines, and 2 or 3 pairs of smaller lateral spines . . . . . 4
4. Exopod of maxillule bearing 3 setae; distal segment of endopod of antenna bearing 4 terminal setae . . . . . N IV
- Exopod of maxillule bearing more than 3 setae; distal segment of endopod of antenna bearing 5 terminal setae . . . . . 5
5. Exopod of maxillule bearing 5 setae . . . . . N V
- Exopod of maxillule bearing 7 setae; nauplius bearing 8 pairs of appendages; swimming legs 1 and 2 with buds present as armed medial bilobed folds . . . . . N VI

#### DISCUSSION

A few publications provide descriptions of the naupliar stages of *Metridia* (Gibbons,

Table 2. Comparative length measurements ( $\mu\text{m}$ ) of nauplii of *Metridia* ( $\dagger$ —original data;  $\star$ —from Paul *et al.* (1996); \*—from Gibbons (1938); \*\*—from Ogilvie (1953)) and *Neocalanus plumchrus* (from Campbell (1934)).

Stage	<i>M. pacifica</i> $\dagger$	<i>Metridia sp.</i> $\star$	<i>M. lucens</i> *	<i>M. lucens</i> **	<i>N. plumchrus</i>
N I	150–175 ( $N = 8$ )	—	170–180	190	280–300
N II	175–200 ( $N = 11$ )	—	210–230	210	300
N III	200–225 ( $N = 17$ )	190–260	270–280	270	350
N IV	250–290 ( $N = 8$ )	270–320	320–340	340	460
N V	—	350–430	400–420	410	560
N VI	—	400–500	—	460	700

1938; Ogilvie, 1953; Lapota *et al.*, 1988). Both Gibbons (1938) and Ogilvie (1953) described the closely related species *Metridia lucens* Boeck from the North Atlantic. Gibbons (1938) drew only the posterior body parts and the distal antennular segment for N IV, but gave short written descriptions of N I through N V. Ogilvie (1953) drew the antennules and the posterior end of the body for all six stages without further detailed descriptions. *Metridia lucens* and *M. pacifica* have similar naupliar morphology (Table 1). There are differences in the hind body armature at N III and in the number of setae on the antennular proximal segments at N I. Since the hind body of N IV–VI of both species has both larger lateral spines and smaller lateral spinules, the armature differs from the original descriptions (Table 1). In Table 1 the numbers in parentheses refer to total caudal armature, including spinules.

Lapota *et al.* (1988) illustrated only N IV of *Metridia longa* (Lubbock) from the Norwegian Sea. However, the presence of such remarkable characters as three pairs of caudal lateral spines on the hind body and well-developed exopod and endopod of the maxillule suggests that stage N V may have been described instead. On the other hand, the antennule, which is illustrated separately, seems to share its characters with N IV of *Metridia pacifica*.

Campbell (1934) described the nauplii of *Neocalanus plumchrus* Marukawa (named *Calanus tonsus* Brady), and the comparison of those drawings with my results reveals no significant differences. It may be that the nauplii described by Campbell (1934) as "*C. tonsus*" actually were *Metridia pacifica* (see Miller *et al.*, 1984), because of the following unique characters common to stages N III–VI of Campbell's description and *M. pacifica*: the ventral spines located a substantial

distance from the caudal spines; the two anteriormost setules on the dorsal margin of the distal segment of the antennules are very close together and originate from the same notch. Both characters can be used to distinguish the nauplii of *Metridia* from those of *Calanus*, *Neocalanus* (see Gibbons, 1938; Ogilvie, 1953; Batchelder, personal communication), and *Pseudocalanus* (see Ogilvie, 1953).

However, the size for the naupliar stages described by Campbell (1934) is much larger than for nauplii from both the previous works on *Metridia* and my study (Table 2). Campbell (1934) may have described the nauplii of *Metridia okhotensis* Brodsky instead of *Neocalanus plumchrus*. *Metridia okhotensis* can be found in British Columbia waters (Gardner and Szabo, 1982). Since *N. plumchrus* and *M. okhotensis* are similar in size as adults (Brodsky, 1950; Brodsky *et al.*, 1983), it is plausible that the nauplii have similar size ranges as well. Since there is no other description of nauplii of *N. plumchrus* (Sazhina (1985) reproduced Campbell's drawings), a laboratory study of the development of *N. plumchrus* is needed.

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