

## Regular occurrence of *Thysanoessa inspinata* (Crustacea: Euphausiacea) in the Gulf of Alaska

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Over a period of five years (1997–2002) the euphausiid *Thysanoessa inspinata* has been recorded in plankton samples from the eastern Gulf of Alaska, as far north as 59°N. Until recently the northern limit of distribution of the species was assumed to be little further north than 50°N but the species is present in oceanic samples off the Alaskan continental shelf throughout the year and occurs regularly in the waters of the eastern Gulf.

### INTRODUCTION

*Thysanoessa inspinata* was considered to be a morphological variant of *T. longipes* Brandt, 1851 until Nemoto (1963) established its specific status. Brinton (1962) defined the northern limit of the distribution of *T. inspinata* in the eastern Pacific at about 50°N. The division of the eastward flowing North Pacific Current into the Alaska Current north of 50°N and the southward flowing California Current (e.g. Francis et al., 1998) provides a mechanism for maintaining this division in the eastern North Pacific.

Mauchline & Fisher (1969) suggested that the species may reach the Aleutian Islands, but the accompanying distribution chart showed the northern limit near to 50°N in the eastern Pacific. Motoda & Minoda (1974), Gorbatenko (2001) and Mackas & Galbraith (2002) have recorded the species to the north of this.

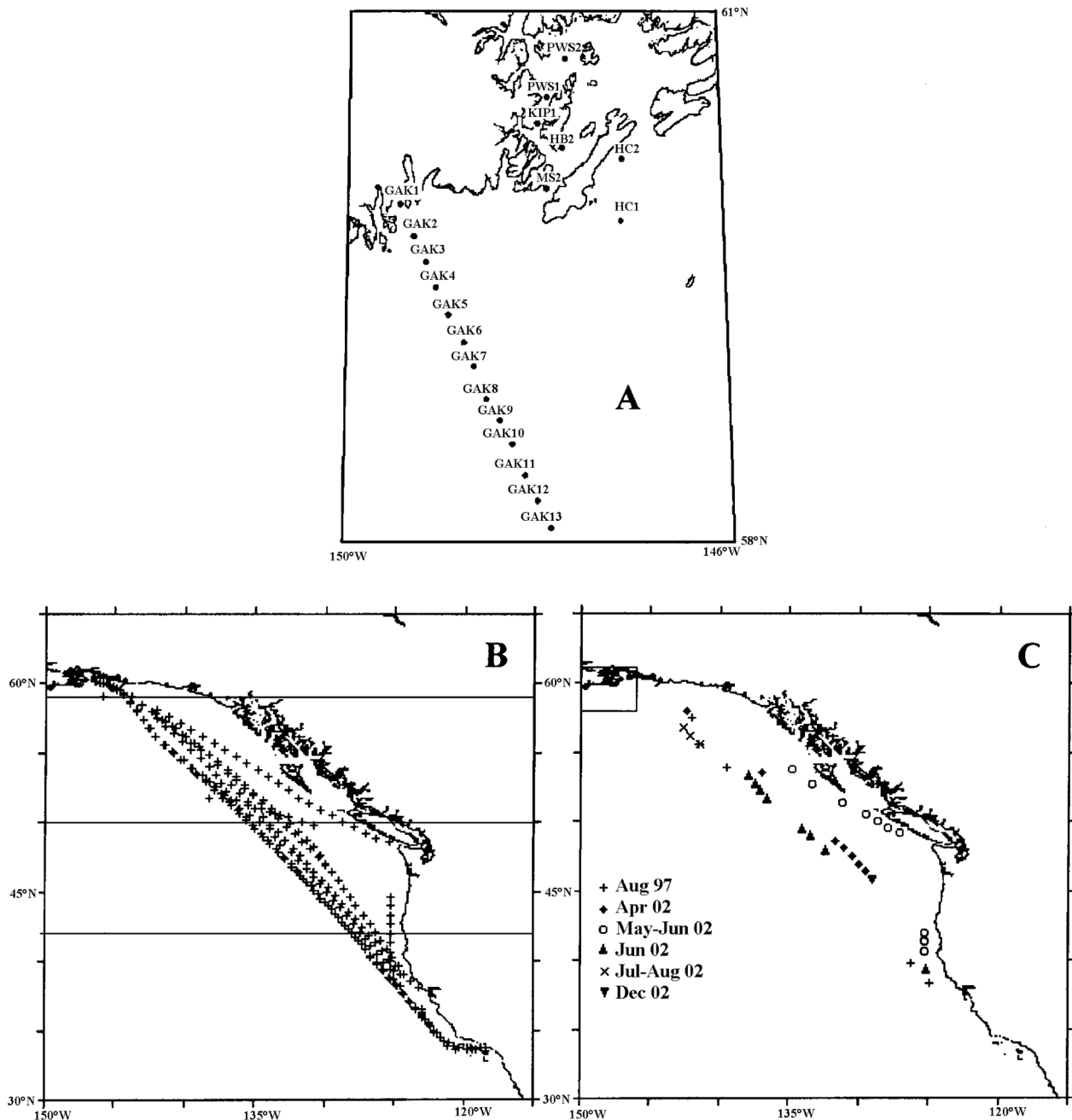
Coyle & Pinchuk (2003) noted occurrence of *T. inspinata* in samples taken in the Gulf of Alaska (GOA) north of 58°N. Examination of euphausiids from Continuous Plankton Recorder (CPR) tows taken between California and Alaska in 1997 and 2002 have shown regular occurrence of the species north of 50°N. Here the geographical distributions of the species in these samples and the seasonal and annual timing of the records are described.

### MATERIALS AND METHODS

*Thysanoessa inspinata* were collected during the North Pacific GLOBEC long-term observation programme (LTOP) in the northern GOA (Weingartner et al., 2002). Sample collection and analysis procedures are presented in detail in Coyle & Pinchuk (2003), and we describe them briefly here. Zooplankton samples were taken along the Seward Line and in Prince William Sound (PWS) (Figure 1A) from March 1998 through to October 2001 (Table 1A). Euphausiids were collected with a 1-m<sup>2</sup> MOCNESS (Wiebe et al., 1976) with 500- $\mu$ m mesh black nets. The MOCNESS was equipped with a flowmeter positioned outside the mouth of the net, conductivity and temperature probes. The net was fished at night and five

oblique samples were collected in 20 m increments from 100 m depth to the surface. The samples were preserved in a 10% formalin–seawater solution. Subsamples taken using a Folsom splitter were examined to identify, sex, stage and count euphausiids. The proportion of the total sample in the subsample varied according to the abundance of zooplankton. Due to uneven spatial distribution of euphausiids, the abundance data were transformed using a power of 0.15.

Continuous Plankton Recorders (Hardy, 1939) were towed between Long Beach, California and Valdez, Alaska in July 1997 and several times each year from 2000 to 2002. The CPRs are towed at a constant depth of  $\sim$ 7 m at speeds of  $\sim$ 15 kn. The plankton is retained on a band of gauze with a mesh aperture of 270  $\mu$ m which is wound into a storage tank where it is preserved with formalin. The gauze is divided into sections, each containing the plankton retained from 3 m<sup>3</sup> of water during ten nautical miles of tow (Batten et al., 2003). Every fourth sample was analysed, except over the Alaskan continental shelf where every sample was analysed. In routine analysis total numbers of furciliars and later stages of euphausiid are recorded and counted but not identified to species. An extreme El Niño event occurred in 1997–1998 with associated high temperatures in the north-western Pacific (Hare & Mantua, 2000), but subsequently temperatures have been lower. The samples taken in 1997 and in 2002, the year for which there was the most extensive sampling when the work was initiated, were selected for re-examination to provide data for contrasting years. The samples in which euphausiids were recorded have been re-examined and the furciliars and later stages have been identified, where possible, to species. As the furciliars of *T. inspinata* have not been described, only the post-larval stages have been counted, but 110 specimens (5% of total) were referred to '*Thysanoessa* spp. furcilia'. The distribution of analysed samples taken in 1997 and 2002 is shown in Figure 1B. The samples were allocated to four geographical regions, the Alaskan shelf (north of 59°N), the Californian slope region (south of 42°N) and northern and southern oceanic areas with a boundary at 50°N, an approximation



**Figure 1.** (A) Station locations for the northern Gulf of Alaska GLOBEC project; (B) positions of CPR samples taken between California and Alaska in 1997 and 2002 and the latitudinal subdivisions of the tows; and (C) occurrences of *Thysanoessa inspinata* in CPR samples shown in Figure 1B. The box, top left, shows the boundaries of Figure 1A.

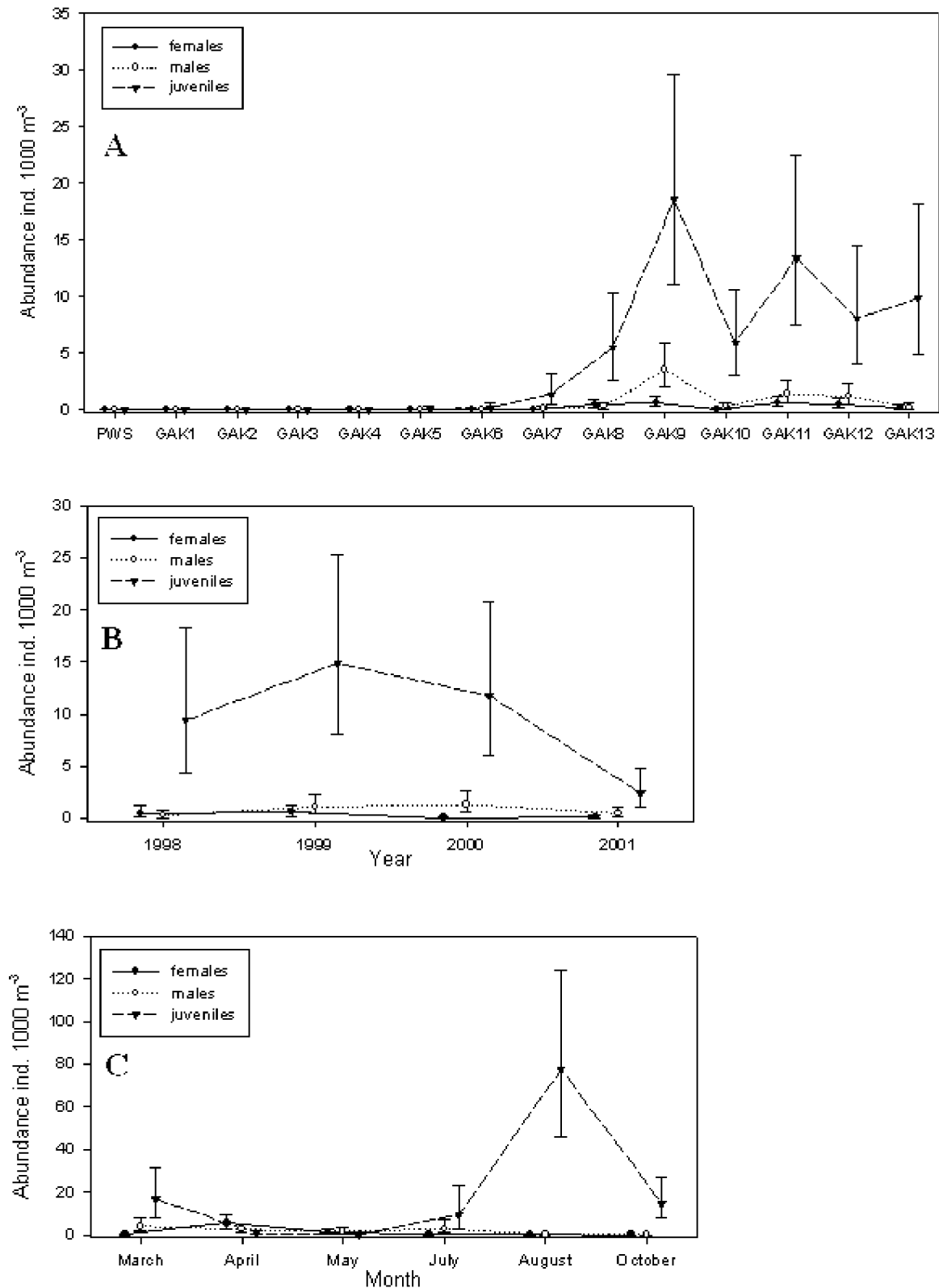
to the latitude of the division between the northward flowing Alaska current and the southward flowing California current. The dates of sampling and numbers of samples taken in these areas are given in Table 1B.

## RESULTS

*Thysanoessa inspinata* were usually not abundant in the GLOBEC monitoring stations, but were found consistently in samples from stations located near the shelf break and seaward in the Alaska Current (Figure 2A). Occasionally they were observed up to 59°N (Station GAK7) but they

were virtually absent from the inner shelf stations. There was no evidence of significant interannual variability of abundance of adults, but abundance of juveniles was significantly lower in 2001 than in previous years (Figure 2B). Females with attached spermatophores and males occurred only in March through May, suggesting spawning during this period. In contrast, few juveniles were recorded in March, but they occurred in substantial numbers from July through October (Figure 2C).

In the CPR samples, *Euphausia pacifica* Hansen, 1911 was the dominant euphausiid, (67.2% of specimens) with *Thysanoessa spinifera* Holmes, 1900 next (14.7%). *Thysanoessa*



**Figure 2.** *Thysanoessa inspinata* sample means and 95% confidence intervals: (A) distribution of along the Seward Line and in PWS in 1998–2001; (B) interannual variability of *T. inspinata* abundance on the outer shelf in the northern Gulf of Alaska (Stations GAK7–GAK13); and (C) seasonal variability of *T. inspinata* abundance on the outer shelf in the northern Gulf of Alaska.

*inspinata* was the third most abundant species at 11.3% of the total. *Thysanoessa longipes* occurred only in the 50–59°N zone where it accounted for 2.6% of euphausiids. The percentage composition of the counts in each of four latitudinal zones is listed in Table 2. The records of *Nyctiphanes simplex* include one in December 2002 at

49°50'N 132°31'W, slightly further north of the range described by Tanasichuk & Cooper (2002). The distribution of records of *T. inspinata* in the samples is shown in Figure 1C. Only small numbers of this species were taken in July 1997, the most northerly at 55°34'N. In April 2002, most of the records of *T. inspinata* were between

**Table 1.** Sampling in the GLOBEC long-term observation programme (LTOP) and Continuous Plankton Recorder (CPR) tows between California and Alaska.

A. GLOBEC LTOP cruises.							
Year	Mar	Apr	May	July	Aug	Oct	
1998	HX203	HX205	HX208	HX211		HX213	
1999	HX217	HX218	HX219		HX223	HX225	
2000	HX228	HX230	HX231		HX234	HX237	
2001	HX239	HX241	HX243	HX246	HX248	HX252	

B. CPR samples analysed in four bands of latitude.								
	1997	2002						
	21 Jul– 6 Aug	7–10 April	28 May– 6 Jun	16–24 Jun	29 Jul– 2 Aug	21–23 Oct	31 Oct– 2 Nov	7–9 Dec
> 59°N	3	7			3	7		
50–59°N	16	16	18	14	16	14	6	15
42–50°N	16	14	8	14	14	1	14	11
< 42°N	17	7	17	13	13		5	

**Table 2.** Euphausiacea in Continuous Plankton Recorder samples (1997 and 2002) in four latitudinal zones shown in Figure 1B (Area). Percentages of *Euphausia pacifica*, *Thysanoessa inspinata*, *T. longipes*, *T. spinifera* and 'Others' in each region, the total numbers and the numbers of samples are given.

Area	<i>E. pacifica</i>	<i>T. inspinata</i>	<i>T. longipes</i>	<i>T. spinifera</i>	Others	Total	Samples
> 59°N	50.0	0.0	0.0	40.0	10.0	10	20
50–59°N	41.9	18.6	2.6	29.3	9.8	883	122
42–50°N	52.9	19.1	0.0	14.0	14.0	388	78
< 42°N	96.8	1.2	0.0	1.0	1.1	936	68

'Others' includes *Nematoscelis difficilis* Hansen, 1911, *Nyctiphanes simplex*, *Thysanoessa inermis* (Krøyer, 1846) and furciliars of *Thysanoessa* spp. that could not be referred to species.

46°N and 49°N but the most northerly occurred in a sample at 57°56'N, the highest latitude at which the species has been recorded in CPR samples. In succeeding months the main concentrations of *T. inspinata* were progressively further north than in April occurring from 55° to 57°N between 29 July and 2 August. There were no records of the species in the October and November tows and only one in December 2002.

## DISCUSSION

In the GOA shelf waters there are two major currents, the Alaska Current which flows at or near the shelf break and is transformed into the swifter and narrower Alaskan Stream in the north-western GOA (Weingartner et al., 2002), and the Alaska Coastal Current, a buoyancy driven low-salinity current generated by freshwater discharge and cyclonic wind stress (Royer, 1981; Johnson et al., 1988; Stabeno et al., 1995) within 20 to 50 km of shore (Royer, 1998). In addition to the main currents, the rugged topography and strong semidiurnal tides generate numerous eddies and meanders including large Haida eddies. These influence the shelf-slope exchange of water mass properties and biota including the distribution of zooplankton along the shelf (Okkonen et al., 2001) and provide a mechanism for transport of *Thysanoessa inspinata* (Mackas & Galbraith, 2002).

Our data shows that *T. inspinata* in the GOA inhabits the Alaska Current and avoids the Alaska Coastal Current. It is also transported into the southern Bering Sea by the northward flowing branches of the Alaskan Stream (Motoda & Minoda, 1974). Gorbatenko (2001) recorded *T. inspinata* in 1998 from the north-western Bering Sea. Apparently, the species has been transported by the Aleutian North Slope Current and the Bering Slope Current, which originates in the eastern Aleutians (Stabeno et al., 1995; Hermann et al., 2002). Nemoto & Kamada (1980) and Taki & Kotani (1994) recorded *Thysanoessa inspinata* in cold waters underlying the Kuroshio but not in the warmer northward flowing Kuroshio. Thus, the records of *T. inspinata* listed above, in addition to those from our work suggest that the species routinely occurs in the Alaska Current/Alaskan Stream/Oyashio current system, by which it can be transported across the North Pacific from the American coast to Japan and into the Bering Sea. Therefore the actual range of *T. inspinata* extensively overlaps that of its sibling *T. longipes*, and its northern limits resemble those of *Euphausia pacifica* (Brinton et al., 2000).

In the waters off Vancouver Island there was a cumulative shift to more 'southerly' zooplankton through the 1990s (Mackas et al., 2001). Hollowed et al. (2001) show that prolonged periods of warm conditions at high latitudes have been associated with periods of highly

frequent El Niño events. Numbers of *T. inspinata* in the LTOP samples have been declining, which may be related to lower temperature since the end of the El Niño event in 1997–1998 (Hare & Mantua, 2000). If the temperatures remain at the lower level it will be interesting to see whether the species will persist in the area. It will also be interesting to compare the future records of the oceanic *T. inspinata* with those of *Nyctiphanes simplex*, which occurs mainly in coastal waters, the northward spread of which has been linked to the El Niño southern oscillation, particularly the 1998 event (Tanasichuk & Cooper, 2002).

Kuznetsova (1980, 1994) concluded that *T. inspinata* has a two-year life span and spawns once a year in late spring. In the northern GOA our results are consistent with a discrete spring spawning event in the GOA. It is unclear if *T. inspinata* breeds in the northernmost areas of its range in the Bering Sea.

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