Chapter 1
Introducing Krill

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Krill, a term originally applied to 'fish fry', is now taken to refer to euphausiids, a group comprising over 80 species most of which are planktonic. They are widespread with examples to be found in all the oceans of the world. Their size and, in places high numerical density, makes them of particular importance in some marine ecosystems. That importance is enhanced in the case of the few species that are commercially harvested.

Commercial harvesting and economic importance are the two criteria which, when applied to euphausiids, provide the focus for this volume. This immediately reduces the area of interest from all the oceans and seas of the world to the consideration of a few geographical regions. In the Pacific Ocean there is the area in the north-west around Japan and in the north-east the coast of British Columbia. In the North Atlantic, interest is concentrated on the Nova Scotian shelf and in the Southern Ocean interest has been greatest in the Atlantic sector with lesser interest in the Indian and Pacific Ocean sectors. Commercial interest in harvesting krill has been reported from other regions such as the Mediterranean Sea and coastal Tasmania, although currently this appears to be of very limited extent. Several species of krill aggregate into swarms and it is this swarming behaviour which makes them attractive to commercial harvesting.

Focussing attention towards those species likely to be present in areas where fishing is taking place invites a further restriction to the surface waters down to approximately 500 m. Thus although there are different species present in deep water they have little impact on or interaction with those that are found closer to the surface. Applying these restrictions we are left with a small number of key species and others whose ranges overlap with them geographically and vertically.

1.1 Euphausiid Identification

Accurate identification is central to many ecological investigations and is a topic worthy of careful study. Convergent evolution in pelagic crustacea has resulted in a variety of species that have similar superficial appearances but different phylogenies. Thus the first step must be to ensure that the specimen under consideration is a Euphausiid and not, for example, a Decapod or Mysid. All Euphausiids have

gills clearly visible below the carapace on thoracic segments seven and eight. The morphology of a typical euphausiid is shown in Fig. 1.1. There are photophores or luminous organs at the base of the abdominal pleopods, at the genital segment of the cephalothorax and also near to the mouth parts. The photophores produce a blue light which can often be seen in fresh caught live specimens while still in the net.

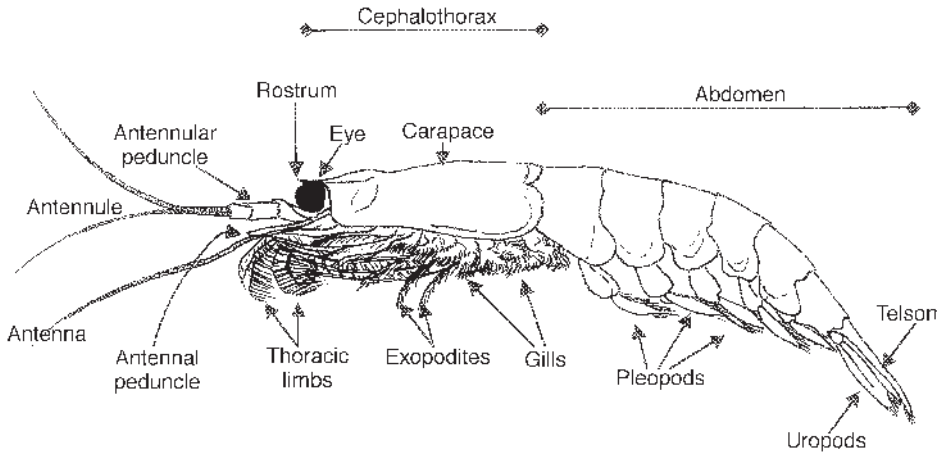

Fig. 1.1 Generalised view of a euphausiid to show the main morphological features mentioned in the text and also that are relevant to identification.

There are good dichotomous keys to be found in Baker *et al*. (1990) and Mauchline & Fisher (1969). Both of these are comprehensive and include euphausiids world-wide, the former having a very good set of clear drawings. In addition, for the north Atlantic and Southern Ocean Mauchline (1984, 1980a respectively) provide good illustrated keys both of which are a truncated version of the Mauchline & Fisher (1969) key. Although there is much commonality between these keys it is worth consulting more than one, and also source literature, when there is any doubt over the identity of a particular specimen. This is because there are differences in the way individual features are illustrated and as an added bonus many of the engraved plates of the early expedition reports, as well as possessing considerable scientific merit, are also an art form frequently to be admired.

1.2 Broad-scale distribution

The following is a brief summary by way of general introduction to describe the broad-scale distribution of euphausiids in the main areas of interest. More detailed information on the key species of commercial interest and species that are likely to be found associated with them will be found in Chapter 3. Further general information on distribution can be found in Mauchline & Fisher (1969) and Mauchline

(1980b); most of the following information has been summarised from these two publications.

North Pacific Ocean

Several species are found on both eastern and western seaboards of the North Pacific Ocean. The species of greatest commercial interest in the North Pacific Ocean is undoubtedly *Euphausia pacifica* which is found across the Bering Sea, through the Southern part of the Sea of Okhotsk and the Sea of Japan extending southwards to about 30° N. The densest concentrations are generally found in the North Pacific Drift and Aleutian Current extending southwards off the Californian Coast and within the Californian Current. The southern limit for *E. pacifica* is at the 9.5°C isotherm at a depth of 200 m. The only similar species with which it might be confused is the much smaller *E. nana* whose distribution is restricted to Southern Japan and the East China Sea.

Although rarely present in great numbers, *Nematobrachion flexipes* is found in deep oceanic water of the North Pacific Ocean south of latitude 40° N. In addition, between latitudes 35° and 55° N, *Thysanopoda acutifrons* is likely to be present although its distribution appears to be limited by the 4°C and 10°C isotherm at 100 m depth. With a latitudinal span slightly further towards the equator, *E. gibboides* is found between 30° and 45° N across the Pacific Ocean and in the eastern end of this range it extends down the Californian Current. Closer to the equator the closely related *E. hemigibba* is probably restricted to deep oceanic waters between latitudes 18° and 42° N and in the equatorial zone from 160° E to 110° W *E. paragibba* is likely to occur.

Tessarabrachion oculatum is a mesopelagic species found between latitudes 35° and 53° N. It is absent from the oceanic region south-east of Kamchatka and also from the Bering Sea although it is found around the Aleutian Islands. The genus *Thysanoessa* is characterised by species found in high latitudes. *T. longipes* is present in the North Pacific, Gulf of Alaska, Bering Sea, eastern region of the Beaufort Sea and north of the Bering Strait. *T. raschi*, a neritic species, is found as far north as 80° N in the Arctic Ocean. In the Gulf of Alaska is *T. spinifera* another neritic species whose distribution extends down to the Californian coast although it is not found in the western Pacific. *T. inermis* has a latitudinal range extending from 63° N in the Bering Sea south to latitude 43º N and although it is present in the Arctic it is not known whether there is continuity with Atlantic populations.

In the western Pacific region *Pseudeuphausia sinica* is neritic and confined to the coastal regions of the East China and Southern Yellow Seas while *Euphausia similis* extends northwards through the South and East China Seas and extends eastwards of Japan in the Kuroshio Extension.

The final genus, *Nematoscelis*, is represented by three species. *Nematobrachion gracilis* is found in the western Pacific in the Kuroshio Current and its extension east of Japan. *N. difficilis* occurs across the Pacific Ocean between latitudes 35°

and 45° North and extends southwards to 20° N in the Californian Current. *N. microps* is found north as far as 40° N in the western Pacific but is absent from the eastern Pacific.

North Atlantic

The most important species is undoubtedly *Meganyctiphanes norvegica* which in the west Atlantic is found northwards from Cape Hatteras at 35° North along the edge of the continental slope to 70° North where it is found along the coasts of Labrador, Baffin Island and West Greenland. It is also present around south and east Greenland as far as 80° North. On the eastern side of the north Atlantic it extends from the western end of the Barents Sea, and is found throughout the Norwegian Sea, North Sea and Skagerrak. It is not however to be found in the Kattegat or eastern English Channel. The main breeding areas are thought to be off the Gulf of Maine, Gulf of St Lawrence, southwestern and southern Iceland and in the Norwegian Sea northwards to about 70° North.

Several other species are found on both sides of the Atlantic Ocean. On the western Atlantic seaboard *Thysanopoda acutifrons* is found from the Gulf of Maine to 70° North in the region of south-west Iceland and the Davis Strait while on the eastern seaboard it is found from Gibraltar northwards to 70° North. In the western Atlantic *Thysanoessa longicaudata* occurs from around the Gulf of Maine at 35° North and extends as far as 70° North off West Greenland. On the eastern side, although most common between latitudes 55° and 70° North, its range overall extends from the Bay of Biscay to 83° North off north-east Greenland.

Nyctiphanes couchii is a neritic species which occurs in the eastern seaboard above the slope and shelf of the north Atlantic between Gibraltar and 60° North. Although present in the Irish Sea it does not appear to breed there or north of the Skagerrak. It occurs in the Kattegat and is the only euphausiid to penetrate the western Baltic although it does not breed there.

Thysanoessa raschi, another neritic species, is the commonest euphausiid off West Greenland and extends northwards to about 70° and in extreme cases to 78° North. It is present in the Gulf of St Lawrence and Gulf of Maine but is not found further south than 40° North. On the eastern side of the Atlantic it is found around Iceland and is common around Scotland as far as 55° North. It is also found along the Norwegian coastline north to the Barents, White and Kara Seas. *Thysanoessa inermis* occurs from the Gulf of Maine north as far as west Greenland at around 70° North. Off East Greenland it occurs as far north as 75° to 80° North although, except in the Norwegian and Barents Seas, it does not breed north of 65° to 70° North. On the eastern Atlantic seaboard it is not found south of about 50° North.

The only bottom dwelling euphausiid is *Bentheuphausia amblyops* which appears to be widespread but is confined to water deeper than 1000 m from the equator to latitude 46° 15′ North on both eastern and western sides of the Atlantic.

Southern Ocean

All the Southern Ocean euphausiids have a circumpolar distribution and are broadly separated by their latitudinal ranges. The species commonly referred to as the Antarctic Krill is *Euphausia superba*, a widespread species which frequently swarms and is the subject of significant commercial fishing (Plate 1, facing p. 182). *Euphausia vallentini* and *E. longirostris* are restricted to the subantarctic zone, the former with a southern limit of the Antarctic Polar Front while the latter is found only between latitudes 40° and 55° South. The southern limit of *E. vallentini* approximates to the northern limit of *E. triacantha* a species having a circumpolar distribution between latitudes 50° and 60° South. The southern limit of *E. triacantha* overlaps the northern limit of *E. superba* and *E. frigida* both of which are only found south of the Antarctic Polar Frontal Zone (APFZ). The most southerly species is *E. crystallorophias* which is generally neritic and is restricted to the Antarctic continental shelf although some swarms have been found in the Scotia Sea (Brierley & Brandon, 1999) and they are also present in the caldera of Deception Island.

Thysanoessa vicina and *T. macrura* are two species with a circumpolar distribution in the Southern Ocean south of about 50° to 55° South and extending into the pack-ice zone. Although they are difficult to distinguish reliably without a binocular microscope, these two species can be recognised from all others in the Southern Ocean because their eyes are clearly in two parts with a constriction between. All the other Southern Ocean euphausiids have circular eyes.

Other areas

There have been a few proposals to fish for krill in other areas. In a recent review Nicol & Endo (1997, 1999) noted that there had been interest in fishing for krill in the Mediterranean Sea, although it is not clear what the target species might be, and also a proposal to fish for *Nyctiphanes australis* off Tasmania. In preparing this chapter I was made aware of anecdotal information indicating that there was some local fishing for *Meganyctiphanes norvegica* in Norwegian waters to provide feed for the aquaculture industry; however, I have found nothing to substantiate these suggestions.

1.3 Synopsis of the book

This book has been written primarily for postgraduate students, professional scientists and administrators concerned with krill ecology and in particular fishery management. Krill was initially seen as a ready source of protein to satisfy an expanding world population although the expansion anticipated in the 1970s has only partly materialised. Arising from this the main areas of commercial fishery interest are relatively few as has already been mentioned.

In Chapter 2 the methods of sampling krill are considered. Nets provide a method of direct sampling from which information on the type and quality of the krill can be determined. That method does have the disadvantage that it is time consuming. Major improvement in the development of quantitative echo-sounders over the past 30 years has meant that this technique is the preferred method for covering large areas and also for obtaining information on the local distribution of krill. Allied to these sampling methods is the need to make biological observations on the krill and these are discussed at the end of the chapter.

Having considered sampling methods the distribution and abundance of krill in the main areas of commercial interest are discussed in Chapter 3. In the coastal waters of Japan and Western Canada there are local fisheries while in the Southern Ocean the fishery has a very much larger area over which it can be distributed. Turning from the larger-scale distribution of krill considerations of swarming and vertical migration are discussed in Chapter 4. It is these aggregation patterns which make the krill suitable for commercial fishing and at the same time affect the foraging behaviour of dependent species.

Keeping to a discussion of krill centred features in Chapter 5 we have a full consideration of population parameters that can be used in developing population models. The information in this chapter is wide ranging in order to provide the reader with a view of the range of values likely to be encountered for each parameter. This broader view is retained as the reproduction of krill is considered in Chapter 6. Here aspects of the development of germ cells are considered leading to a discussion of the reproductive biology of various members of the group.

Having set the scene with regard to krill on their own, consideration is then given in Chapter 7 to the role of krill in the ecosystems within which it is harvested. This highlights the position of krill in the food chain. Against that background Chapter 8 considers ecosystem dynamics involving krill and considers the different time and space scales that are of relevance in developing management advice. These range from the broad scale of precautionary total allowable catches down to the interactions with the dependent species alluded to earlier.

The scene having been set, the emphasis changes wholly towards the krill fisheries and their management. In Chapter 9 the krill fisheries are described in terms of fishing methods, catch rates and history of the fisheries. A natural progression from considerations of the capture of krill is discussion on the biochemical qualities that can be utilised in the development of marketable products; these are discussed in Chapter 10.

Moving from the fishery and its operation commercially Chapter 11 is the first to consider fishery management, in this case in Japanese waters. The management regime there takes account of market forces and environmental variation. Management of the krill fishery in the Southern Ocean is discussed in Chapter 12. The Convention for the Conservation of Antarctic Marine Living Resources, being the first international fishery agreement to require the management regime to take an ecosystem approach, has required the introduction of novel approaches. These have

been considered by the authorities in determining how to manage the fisheries in Canadian waters described in Chapter 13. The final chapter looks to the future by considering what has been happening in the krill fisheries world-wide and considering how this might be brought forward as we move into the twenty-first century.

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