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THE SOUTHERN OCEAN

the living resources of the Southern Ocean



UNITED NATIONS DEVELOPMENT PROGRAMME

FOOD AND AGRICULTURE ORGANIZATION OF
THE UNITED NATIONS ROME



THE LIVING RESOURCES OF THE SOUTHERN OCEAN

by

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Southern Ocean Fisheries Survey Programme

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

UNITED NATIONS DEVELOPMENT PROGRAMME

Rome, September 1977

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THE SOUTHERN OCEAN FISHERIES SURVEY PROGRAMME

In view of the potential importance of the living resources of the Southern Ocean, the United Nations Development Programme (UNDP) Governing Council approved in January 1976 a preparatory phase of a Southern Ocean Fisheries Survey Programme, to be executed by the Food and Agriculture Organization of the United Nations (FAO). The long-term objective of the Programme is to improve the knowledge of the nature, magnitude and distribution of the living resources of the Southern Ocean (South of latitude 45°S), with a view to assisting in their eventual rational utilization. The immediate activities of the preparatory phase (to continue until the end of 1977) include a review of the present information on the distribution and magnitude of the living resources of the Southern Ocean; a review and evaluation of the present state of exploitation and utilization of these resources; and the establishment of a system for regular compilation of statistical and other information about them.

This report is one of a series prepared by FAO under the preparatory phase of the Programme. It gathers together current knowledge on the magnitude and distribution of the living resources of the Southern Ocean. Other reports in this series assemble current knowledge on the technology of harvesting and on the utilization of krill.

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Programme Co-ordinator

M-43

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TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| 1. INTRODUCTION | 1 |
| 2. THE PHYSICAL ENVIRONMENT | 2 |
| 2.1 Topography | 2 |
| 2.2 The Major Water Masses | 3 |
| 2.3 Meridional Circulation | 3 |
| 2.4 Longitudinal Circulation | 6 |
| 2.5 Detailed Circulation Patterns | 8 |
| 2.6 Ice | 9 |
| 2.7 Long-Term Variation in the Physical Environment | 10 |
| 3. PRIMARY PRODUCTION | 12 |
| 3.1 Controlling Factors | 12 |
| 3.2 Production Rates and Total Production | 17 |
| 4. ZOOPLANKTON | 19 |
| 4.1 Introduction | 19 |
| 4.2 Distribution | 19 |
| 4.3 Biomass and Production | 25 |
| 5. BENTHOS | 27 |
| 5.1 Introduction | 27 |
| 5.2 The Habitat | 27 |
| 5.3 Faunal Associations and Zonation | 27 |
| 5.4 Biomass and Production | 30 |
| 6. KRILL | 33 |
| 6.1 Introduction and General Biology | 33 |
| 6.2 Distribution | 35 |
| 6.3 Growth and Life Span | 42 |
| 6.4 Reproduction | 48 |
| 6.5 Swarming | 50 |
| 6.6 Food and Feeding | 54 |
| 6.7 Production and Biomass | 55 |
| 6.8 Exploitation | 58 |
| 6.9 Stock Assessment | 60 |
| 6.10 Harvesting at Higher Trophic Levels | 65 |
| 7. CEPHALOPODS | 69 |
| 7.1 Introduction | 69 |
| 7.2 Biology | 70 |
| 7.3 Production and Biomass | 72 |
| 7.4 Exploitation | 72 |
| 7.5 Stock Assessment | 74 |

| | <u>Page</u> |
|---|-------------|
| 8. FISH | 75 |
| 8.1 Introduction | 75 |
| 8.2 Species | 75 |
| 8.3 Distribution | 75 |
| 8.4 Size and Growth | 90 |
| 8.5 Reproduction | 97 |
| 8.6 Feeding | 103 |
| 8.7 Exploitation | 103 |
| 8.8 Biomass, Production and Yield | 109 |
| 9. WHALES, SEALS AND BIRDS | 113 |
| 9.1 Whales | 113 |
| 9.2 Seals | 117 |
| 9.3 Birds | 120 |
| 10. TROPHIC RELATIONS | 123 |
| 11. DISCUSSION | 129 |
| 11.1 Past and Present Exploitation | 129 |
| 11.2 Management Arrangements | 130 |
| 11.3 State of Stocks | 136 |
| 12. NOTE ON STANDARDIZATION OF MEASUREMENTS | 139 |
| 13. ACKNOWLEDGEMENTS | 139 |
| 14. REFERENCES | 140 |

1. INTRODUCTION

Until quite recently the name Antarctica conjured up images to the layman on the one hand of heroic exploration and on the other of the ruthless slaughter of whales. Over the past few years an additional dimension has been introduced, that of krill. In addition to being the staple food of many whale, seal and bird species in the Southern Ocean, it is also being considered as a raw material for producing fishmeal and also for direct human consumption.

When the potential of a new resource is recognized several very important questions immediately arise. These may be summarized as follows:

- (i) Where does the resource occur?
- (ii) How can it be found and caught?
- (iii) How much may be taken?
- (iv) What marketable products can be produced and where can they be marketed?

This report is largely concerned with questions (i) and (iii).

The reliance of whales upon krill indicates that neither should be considered in isolation since changes in one could produce changes in the other. Various conservation groups, well aware of the vast reduction brought about to the whale stocks by over-exploitation, have realized that over-fishing of krill could prolong the period of recovery or even reverse the increase of the whale stocks.

Krill and whales are not the only living resources of the Southern Ocean. Fish and squid occur in quantities which could be of commercial importance and all have some link with krill in the ecosystem context. In this paper, information on the living resources of the Southern Ocean has been brought together initially for review with each resource considered in isolation and then in terms of the ecosystem. In this way it is hoped that the paper will be useful not only for the factual information it contains but also for highlighting those research areas where more information is required for wise management of the resources.

In spite of the fact that to many people "little is known of the living resources of the Antarctic", the greatest problem in preparing this review has been in deciding what information to omit rather than what to include. At the start of most sections reference is made to major reviews. There are in addition several other bibliographic sources available which include references to material outside the scope of this paper. For information prior to 1970 the following are recommended:

- (a) Arnaud, P., F. Arnaud et J.-C. Hureau, 1967
Bibliographie Générale de Biologie Antarctique et Subantarctique
(Cétacés exceptés)
CNFRA No.18, 180 pp.
- (b) Polar Record - Issues up to and including September 1972 (16 (102))

Citations to up-to-date information in scientific journals will be found in the Aquatic Sciences and Fisheries Abstracts and also in the Antarctic Bibliography, published by the Library of Congress of the USA.

2. THE PHYSICAL ENVIRONMENT

2.1 Topography

In contrast to the Arctic which is an ocean basin, the Antarctic is a vast land mass that is surrounded by ocean. In spite of this, twenty per cent more of the Southern Hemisphere surface than the Northern Hemisphere surface is covered by water. The size of the Antarctic continent means that almost all the earth surface between latitudes 75°S and 90°S is either exposed land or ice cap (Fig. 2.1) although, by contrast, between 60°S and 65°S , 99.7% of the earth's surface is covered by sea (Ostapoff 1965). This ring of ocean is contiguous to the three major ocean basins to the north (Atlantic, Indian and Pacific) and the bottom topography of the Southern Ocean is closely related to the major morphological features of these ocean basins. Thus the Atlantic-Indian rise which occurs south of Africa between latitudes 50° and 55°S is an extension of the mid-Atlantic ridge. Further east in order are the elevations in the sea floor on which Prince Edward Island and Crozet are situated and the Kerguelen Gaussberg ridge, the latter extending over almost twenty degrees of latitude. Immediately south of New Zealand is the Campbell plateau whilst further south between approximately the same longitudinal limits is a series of marine elevations and islands extending to the continent. The narrowest constriction of the Southern Ocean occurs between South America and the Antarctic Peninsula. In this region the Antarctic is connected geologically to the South American continent by the Scotia Arc. Within this system of islands and submarine elevations three major seas are identifiable, the Ross, Bellingshausen and Weddell Seas each of which plays an important part within the overall Southern Ocean circulation.

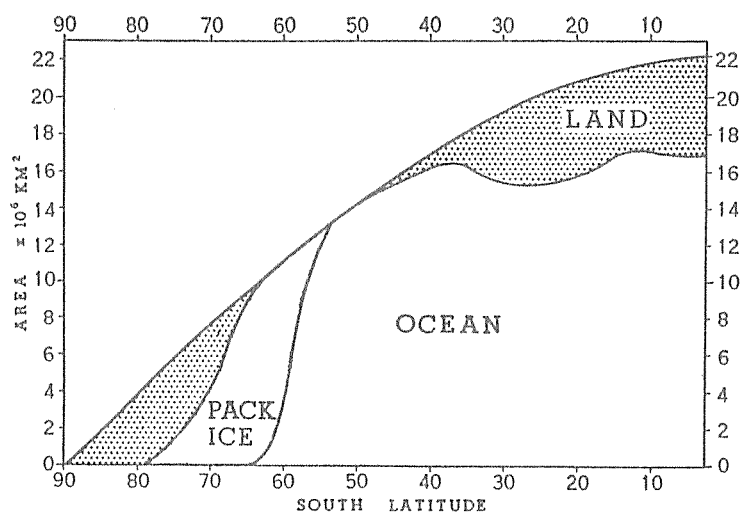


Fig.2.1 Distribution of land and water areas in the Southern Hemisphere for 5° zones (after KOSSINA, as quoted by Wüst *et al.*, 1954) and pack-ice cover in September (according U.S. Hydr. Office, 1957)

2.2 The Major Water Masses

In his description of the hydrology of the Southern Ocean, Deacon (1937) identifies five major water masses. These are Antarctic surface water, a warm deep layer, Antarctic bottom water, sub-Antarctic water and sub-tropical water. The three major water masses surrounding Antarctica, the surface water, warm deep water and bottom water each contain core layers which reflect the characteristics of their respective source regions. The relative positions of these layers are indicated in the meridional vertical section shown in Fig. 2.2. Core layers are identified by either maximum or minimum values of salinity, or temperature or oxygen (extrema values). The extrema layers identified by Gordon (1967) are:

| <u>Core layer</u> | <u>Water mass</u> |
|------------------------------------|--------------------------------|
| Temperature minimum | Antarctic surface water |
| Temperature maximum | Circumpolar deep water (upper) |
| Oxygen minimum | Circumpolar deep water (upper) |
| Salinity maximum | Circumpolar deep water (lower) |
| Deep potential temperature minimum | Antarctic bottom water |
| Deep oxygen maximum | Antarctic bottom water |

The temperature minimum layer (which occurs in the Antarctic surface water) is not identifiable in all months of the year since from about June to September the surface water is mixed and fairly homogeneous. At this time the surface water has characteristics similar to the temperature minimum layer, when it is discernable, a similarity which prompted Mosby (1934) to refer to the latter as "Antarctic winter water". At the Polar Front or Antarctic Convergence the surface water sinks below the more buoyant southward flowing sub-Antarctic water but due to mixing with this warmer water the temperature minimum characteristic is no longer identifiable although it is still identifiable as Antarctic surface water because of its low salinity. This northerly flowing water mass beneath the sub-Antarctic surface water was called sub-Antarctic intermediate water by Wüst (1935).

Analysis of data on the temperature maximum layer by plotting temperature/salinity diagrams indicates the presence of two distinct types. One, characterized by generally high temperature ($+1.5$ to 2.5°C) is typical of the Southeast Pacific sector whilst the other, characterized by lower temperature (0 to $+1^{\circ}\text{C}$) and a narrower salinity range over the area, is typical of the Weddell Sea water, (Gordon 1967). The confluence of these two water masses, often referred to as the "Bellingshausen front" (Model 1958), is of particular importance to an understanding of the way the krill stocks are maintained and will therefore be considered in more detail later.

The characteristics of the water masses of greatest importance to Antarctic living resources are summarized in Table 2.1.

2.3 Meridional Circulation

Although both meridional and longitudinal circulation are very important components of the Southern Ocean water movements, they will be considered separately in order to simplify the descriptions.

The Antarctic surface water, which has its origin near to the continent, has a slight northerly component which takes it over several degrees of latitude until at around latitude $55 - 60^{\circ}\text{S}$ it sinks beneath the sub-Antarctic surface water. This occurs in a fairly well defined and identifiable zone often referred to as the Polar Front or, since this is an area of convergence, the Antarctic Convergence. This area is of great importance ecologically since it coincides with the limit of distribution of many marine species. Because of this it is a suitable boundary to use to define the northern limit of most of the Antarctic living resources covered in this paper.

Table 2.1 The Major Water Masses of the Southern Ocean

| WATER MASS | CHARACTERISTICS | ORIGIN | CROSS DISTRIBUTION |
|--------------------------------|--|---|---|
| <u>Antarctic Surface Water</u> | Shallow layer of cold water 100 to 250 m in thickness. In winter practically homogeneous. In summer, owing to the greater effect on the surface water of solar radiation and meltwater there is often a warmer surface stratum of low salinity | Mixture of fresh water from melting ice and snow with highly saline water from a warm deep current | Circumpolar from the continent to the Antarctic Convergence |
| <u>Warm Deep Layer</u> | High temperature and salinity | The high temperature and salinity indicate origins in the major oceans well to the north | Circumpolar extending from well north of the Antarctic into the Pacific, Indian and Atlantic Oceans |
| <u>Antarctic Bottom Water</u> | Low temperature, high salinity, high oxygen content | Cold highly oxygenated shelf or slope water in areas of shelf with very low temperature and ice formation. Also from warmer water with a lower oxygen content such as deep waters from neighbouring oceans. The major area of formation is in the Weddell Sea | The only area where this water mass has much influence outside the Antarctic zone is in the Atlantic sector |

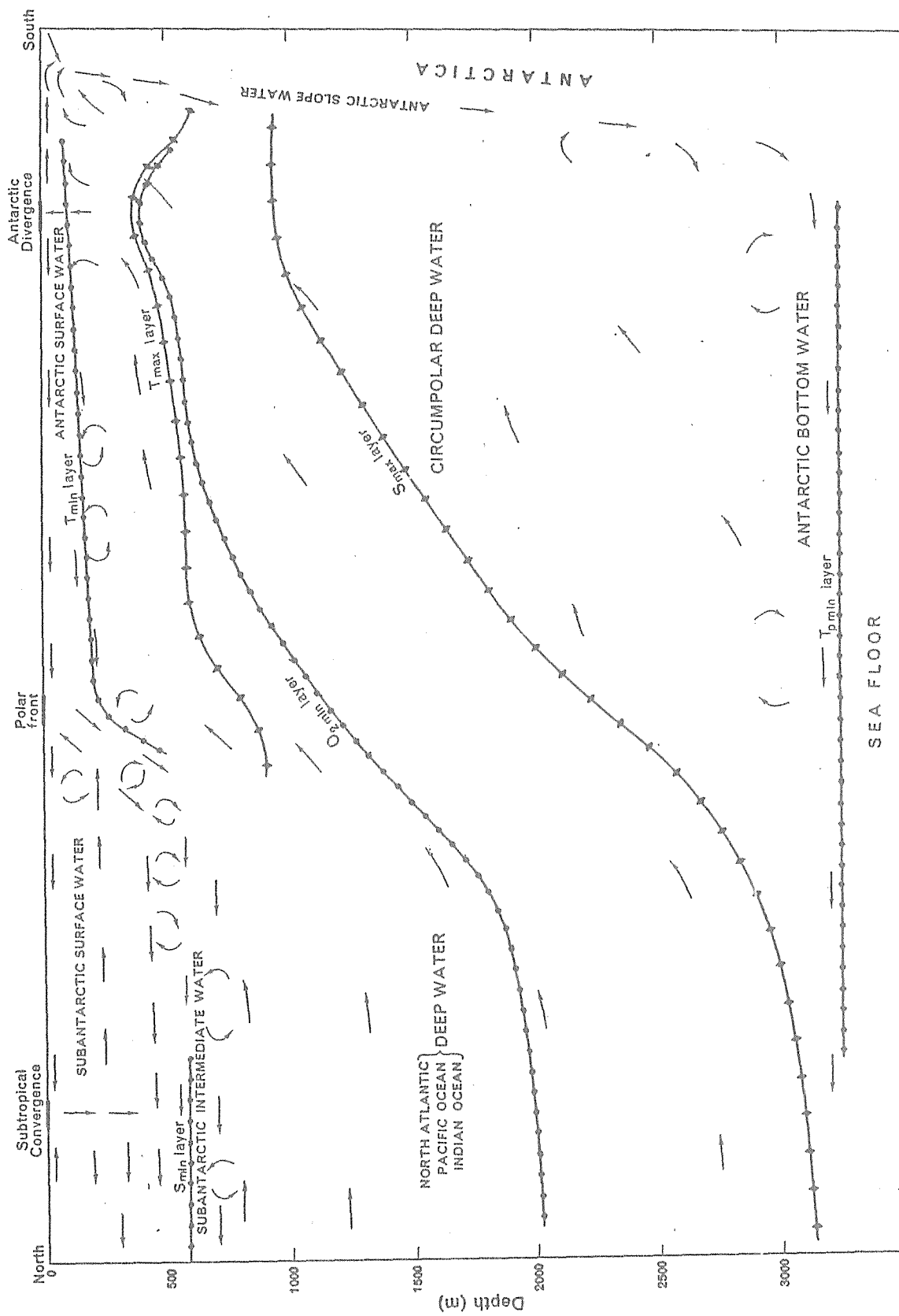


Fig. 2.2 Schematic representation of water masses and core layers in the Southern Ocean in a meridional section

The warm deep layer, which has its origins well to the north, has a southerly component which brings it to the Antarctic beneath the surface water. Near to the continent it arrives at the surface and spreads out mainly to the north although a much smaller proportion has a southerly movement. This divergence zone, which can be recognized around most of the continent, is often called the Antarctic divergence.

Near to the Antarctic continent the cold bottom water is formed. This, since it is the densest of all the Southern Ocean water masses, flows down the continental slope and spreads out northwards on the bottom.

2.4 Longitudinal Circulation

The major driving force for the surface currents of the Southern Ocean is the atmosphere. The atmospheric pressure in the Southern Hemisphere is characterized by relatively high pressure over the Antarctic Continent, a belt of low pressure at about 65°S and a belt of high pressure at about 30°S . The winds are thus predominantly easterly near the continent and westerly north of about 60°S . (Foster, in press). The major water movements follow this same general pattern, being towards the west near to the continent (the Antarctic Coastal Current or East Wind Drift) and towards the east, north of about 60°S (the West Wind Drift). The deeper water masses also follow the same general longitudinal circulation although they are influenced to a much greater extent by other factors such as the earth's rotation and bottom topography. The general patterns of circulation are indicated diagrammatically in Figs. 2.3 and 2.4.

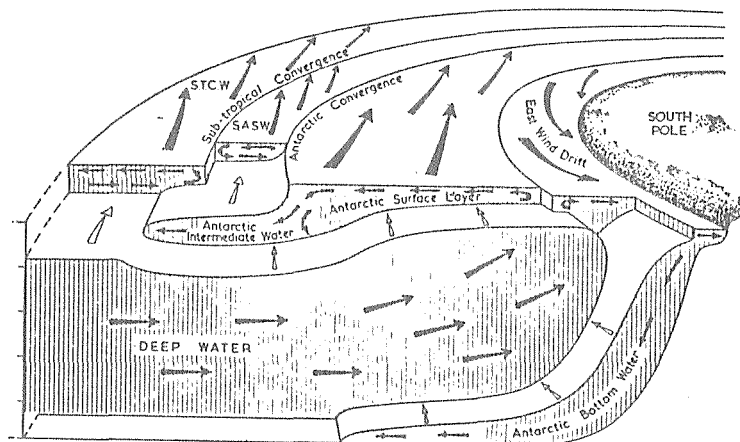


Fig.2.3 A three dimensional diagrammatic representation of the water masses and circulation of the Southern Ocean. S.A.S.W. = Subantarctic surface water. S.T.C.W. = Sub-tropical central water (David 1965)

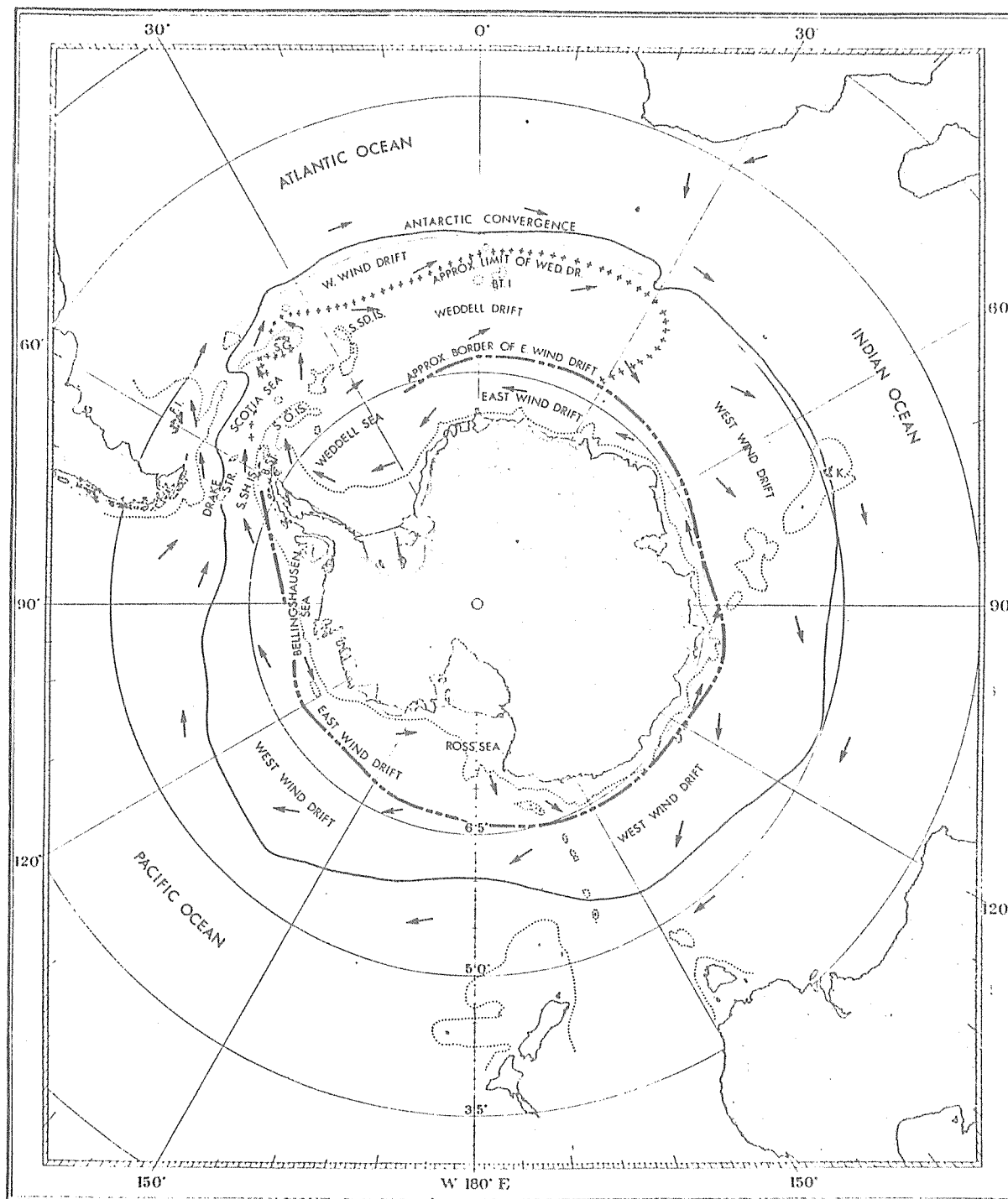


Fig. 2.4 Antarctic regions. Arrows indicate direction of surface currents. Dotted line: 2 000 m contour. B.S.T: Bransfield Strait. BT.I: Bouvet I. F.I: Falkland Is. K: Kerguelen. S.G.: South Georgia. S.O.IS: South Orkney Is. S.SD.IS: South Sandwich Is. S.SH.IS: South Shetland Is. (Mackintosh 1972).

2.5 Detailed Circulation Patterns

Although the general pattern of circulation described above can be recognized over most of the Southern Ocean, there are deviations from this circulation in localized areas which are of particular importance to the living resources.

In his description of the hydrology of the Southern Ocean, Deacon (1937) describes the cold Antarctic bottom water as having its origin for the most part in the shelf area of the Weddell Sea and to a lesser extent in the Ross Sea. Recent Russian research (Treshnikov 1968) has indicated that the bottom water is formed over a much greater area of the Continental Shelf although Foster (in press) as a result of several seasons' observations tends to agree with the more limited area of formation described by Deacon. Because of the importance of deep water in the early life history of krill, it is clearly necessary to resolve this difference whether it be due to method, interpretation of results or seasonal or long term natural variation.

The influence of atmospheric circulation on the surface water can be seen by the formation of gyres in areas of atmospheric cyclones. These result in local deviations from the general East and West Wind Drifts described above. Beklemishev (1960) identified an association between the tracks of southern atmospheric cyclones and the whale feeding grounds (and therefore of krill). The coincidence between these observations is very close for the major areas of krill distribution around the continent. The largest and most clearly defined of these gyres is that of the Weddell Sea and this can be identified from the Antarctic Peninsula as far east as about 30°E . This gyre, often referred to as the Weddell Drift, is almost certainly a result of a combination of the effects of the atmospheric circulation with a strong influence from the bottom topography. For some years now there has been some uncertainty as to whether there was a complete circulation in the surface water. Deacon (1937) found no evidence for a southerly movement of surface water at around 30°E to complete the gyre although subsequent research has shown that there is almost certainly a southerly movement in that region (Kumagori and Yanagawa (1958)). This point is further discussed by Deacon (1976) who brings together further information on ice movements and atmospheric circulation whilst emphasizing the importance of this circulation pattern to the maintenance of the krill stocks in the Atlantic sector.

Another feature that has been the subject of some controversy recently has been location of the frontal zone between Weddell Drift and West Wind Drift, since this is of great importance in understanding the origins of the krill at South Georgia. In the past it has been generally agreed that krill caught in the vicinity of South Georgia had their origins in the Weddell Sea and were carried there in the Weddell Drift. The accepted circulation pattern described the frontal zone between Weddell Drift and West Wind Drift as being on a line approximately from the Antarctic Peninsula to the southeast end of South Georgia. This description by Deacon (1937) is based on data from a detailed analysis of water masses in relation to bottom topography and prevailing wind coupled with direct evidence of surface water movement as indicated by the drift of ice and ships beset in it. As a result of recent investigation, Bogdanov et al., (1969) have suggested that the frontal zone lies more or less on a line from the northern end of the Antarctic Peninsula to the South Sandwich Islands (Fig.2.5). Their conclusions are based largely on the distribution of silicate in the area - Weddell Drift water having a concentration generally of over 3 000 $\mu\text{g/L}$ whilst West Wind Drift water has a concentration generally less than 2 000 $\mu\text{g/L}$ in the area. Although silicate concentration obviously varies with primary production the differences in concentration are almost certainly greater than would be caused by this factor alone. It is theoretically possible for circulation patterns in this area to change quite markedly as a result of small changes in the strength of the atmospheric circulation (Takeshi 1966) which suggests that the difference between the two conclusions based as they are on series of observations thirty years apart may well be due to long-term climatic change (this is discussed in a later section).

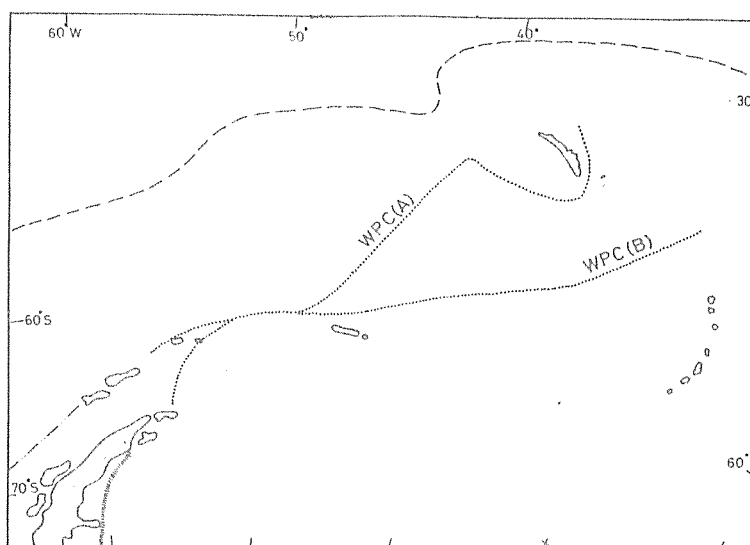


Fig.2.5 The approximate location of the confluence between Weddell and Pacific surface water, as described by Deacon (A) and Bogdanov (B). WPC, Weddell and Pacific confluence (After Everson 1976)

2.6 Ice

One of the well known characteristics of the Southern Ocean is the presence of large amounts of ice over much of the region. Ice in the sea has its origins either as a result of the direct freezing of the sea, in which case because of the nature of the freezing process the ice contains a significant concentration of sea salts, or from precipitation on the continent forming glaciers and ice shelves, both of which have very low salt concentrations. Both these forms of ice have an important effect on the marine environment. For example, on 22 February 1927 RRS DISCOVERY sighted an iceberg measuring about 35 miles by 90 miles long showing 130 to 150 feet above the water. In the process of melting, Heap (1962) estimated that this berg alone could have lowered the temperature of a layer of water 10 metres thick and about 1 000 000 km² in extent by one centigrade degree. Although this particular iceberg was well over the average size, the large numbers of icebergs present in the Southern Ocean must amount to a considerable volume and thus have a considerable effect on the heat budget.

The effect of sea ice is no less dramatic in several other important ways. The pack ice and, to a greater extent, fast ice almost totally eliminate wave action and therefore turbulence whilst at the same time acting as a light and thermal barrier. The result of this is that the already marked seasonality in the aerial environment is even further accentuated in the sea. One of the results of this is the enormous difference between winter and summer rates of primary production (see later section).

The extent of sea ice cover varies throughout the year from a maximum in September when it covers about 25.5×10^6 km² of the Southern Ocean to a minimum of about 13×10^6 km² during the summer (Mackintosh and Brown 1956, Lewis and Weeks 1971). The enormous difference between the sea ice cover in winter and summer indicates that much of each winter's sea ice formation melts during the following summer (Heap 1962). In addition to this, very little pack ice drifts as far north even as the Antarctic Convergence (Mackintosh and Herdman 1940, Heap 1962).

The extent of sea ice cover has been mapped by Mackintosh and Herdman (1940) based on shipborne observations and briefly reviewed by Hean (1965) and French (1974). The recent introduction of reconnaissance satellites covering the Southern Ocean daily by the United States National Oceanic and Atmospheric Administration (NOAA) has enabled the United States Fleet Weather Facility, Suitland, Maryland, U.S.A., to produce weekly ice charts of the whole of the earth's surface south of 60°S which are broadcast for facsimile reception by ships.

2.7 Long Term Variation in the Physical Environment

The relatively long natural lifespan of many of the major Southern Ocean living resources means that their population dynamics in addition to being strongly affected by seasonal variation are almost certainly affected by long term variations in the physical environment. Unfortunately, much of the Antarctic has only recently been discovered which means that long term monitoring has been undertaken only in a few localities.

In his description of South Georgia, Cook (1777) makes the observation:

"It is remarkable that we did not see a river, or stream of freshwater on the whole coast. I think it highly probable that there are no perennial springs in the country"

Those who have visited South Georgia in recent years are well aware of the presence of freshwater streams on the island and since Cook's observation was made during the Little Ice Age period of 1750 - 1800 (Clapperton 1971) it is highly likely that this observation does indicate major climatic change.

Another indication of long term climatic change is given by the advance and retreat of glaciers. The Ross Glacier at Royal Bay, South Georgia, advanced nearly a mile seawards between 1882 and 1902 but by 1930 had retreated almost to its former position (Mathews 1931).

With the setting up of permanent bases, and the realization that the Antarctic was an important component of Southern Hemisphere weather systems, has come the establishment of long term monitoring programmes. An example of such a series of observations is shown in Fig. 2.6 which clearly indicates that the late 1920's were an unusually cold period both in terms of the duration of fast ice and air temperature. Comparing notes for several localities indicates that the lower temperatures originated in the Antarctic rather than north of the convergence, since the magnitude of the change was much less in the Falkland Islands than in the South Orkneys (Fig. 2.7). In addition to this, it is known that a particular feature of the period 1927 - 1933 was the presence of large numbers of icebergs in the area between the Antarctic Peninsula, the South Orkneys and South Georgia (Wordie and Kemp 1933, Marr 1935). The close interaction between the circulation patterns in the atmosphere with those of the Southern Ocean has already been noted and this would suggest that there have been some major variations in oceanic circulation. One feature which is very likely to have been subject to some variation is the frontal zone between Weddell Sea and Bellingshausen Sea water. This was described by Deacon (1937)^{1/} as following a line more or less from the Antarctic Peninsula to South Georgia whereas Bogdanov *et al.* (1969) describe this frontal zone as occurring well south of South Georgia (Fig. 2.5). This change could well be a direct effect (or cause) of the lower air temperatures observed at the time of Deacon's observations relative to the warmer conditions prevailing now. The position of the frontal zone between Weddell Sea and Bellingshausen Sea water is likely to

^{1/} Confirmation of the circulation pattern described by Deacon (1937) may be inferred from the distribution of phytoplankton indicator species described by Hardy and Gunther (1935). A recent study by Vladimirovskaya *et al.* (1976), however, indicates that in the vicinity of the South Orkneys *Thalassiothrix*, *Corethron* and *Rhizosolenia* are indicators of different water masses to those described by Hardy and Gunther.

have a profound effect on the origins of the surface water around South Georgia and by implication the creatures carried in it (e.g. krill). Long term variations in the physical environment are, therefore, likely to affect not only the long lived species which live through the changes by altering their production characteristics, but also to short lived species by changing their environment.

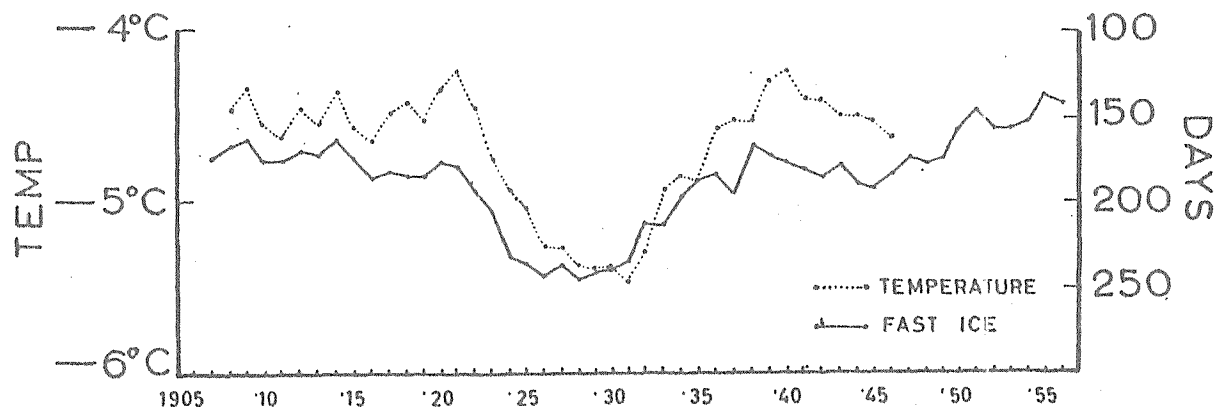


Fig.2.6 Ten-year running means of annual longevity of fast ice and of annual temperature at Laurie Island, South Orkney Islands (Heap 1962)

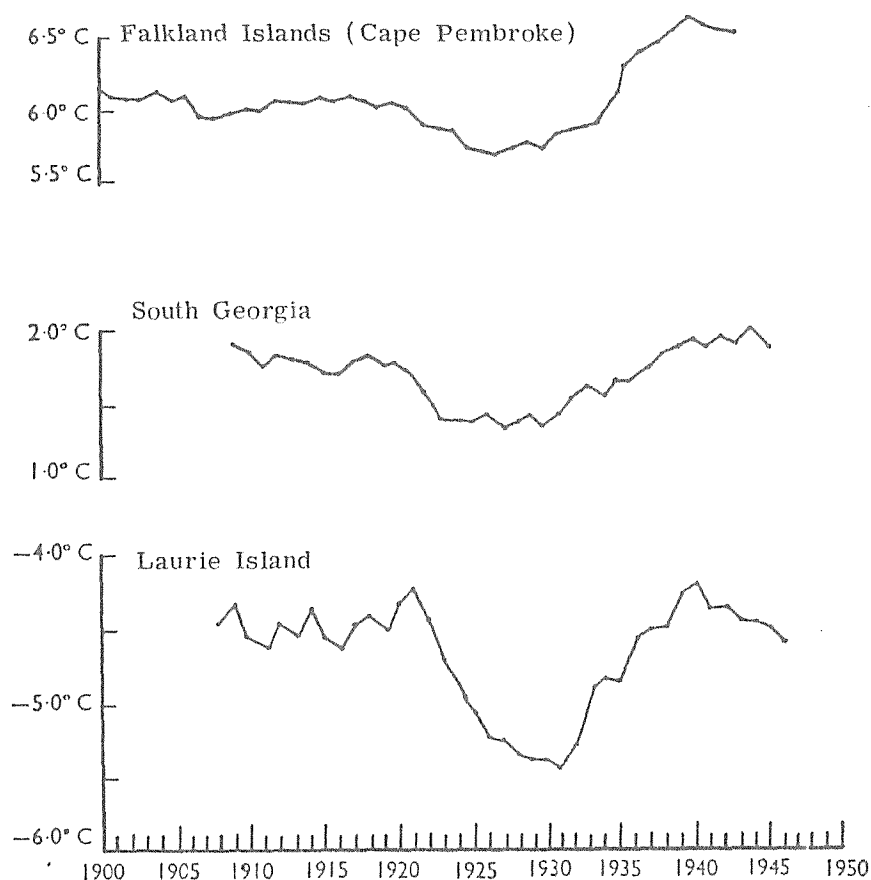


Fig.2.7 Ten-year running means of annual temperature at Laurie Island, South Georgia and the Falkland Islands (Heap 1964)

3. PRIMARY PRODUCTION

3.1 Controlling Factors

Studies of primary production in Antarctic waters have been made by members of several expeditions in the past fifty years. One of the earliest and by far one of the most extensive and thorough analyses is that of Hart (1934, 1942) whose work was based largely on cell counts and "settled volume" estimations. He divided the Southern Ocean into three major arbitrary regions, a Northern region extending for 530 km south of the Antarctic Convergence, an intermediate region which extended north from the Antarctic Circle and a Southern region south of the circle, but excluding the immediate coastal areas. He also designated certain special areas. The seasonal changes in standing stock of phytoplankton in the three major regions are shown in Fig. 3.1. Two important points are shown in this Figure; firstly that production is limited to the summer months and secondly that there is a delay in the initiation of the summer production in higher latitudes.

Other studies (e.g., El-Sayed 1967) have confirmed the fact that the production season is generally limited to one major peak during the summer months and highlight the enormous variability in values obtained (Figs. 3.2 and 3.3). Both Hart (1942) and Hardy and Gunther (1936) discussed this phenomenon and concluded that the continental shelf, by causing upwelling, and the frontal zones between major water masses were largely responsible for the locally higher productivity values, particularly around South Georgia (Fig. 3.4).

The results of El-Sayed (1967) clearly confirm that high productivity is often associated with the continental shelf since on lines of stations across Drakes Passage the highest values tended to be in the vicinity of Cape Horn or the South Shetland Islands (his Figs. 1 and 2). El-Sayed (1967) also found high productivity rates in some areas of open ocean (e.g., Scotia Sea) which would be in agreement with the frontal zone effect hypothesis. The large variation in the values obtained at a given time of year is therefore probably a result of the effects due to the different sampling locations and it would seem very likely that the variance would be reduced if repeated samples were taken from the same location. There is therefore a need for sampling in two forms; firstly a continuation of previous regimes aimed at a geographical analysis and secondly repeated sampling at given locations in order to determine more precisely changes in relation to water circulation and season.

One of the earliest studies around South Georgia (Hardy and Gunther 1936) showed that generally the "simpler" nutrients (e.g., Phosphate, Nitrate), which were thought to limit production in temperate regions, were generally present in quite large concentration and although the phytoplankton production did reduce the nutrient concentration locally they were rarely reduced to a level that would limit production. This conclusion has been confirmed by El-Sayed (in Balech et al. 1968).

Volkovinsky (1974) in an analysis of results from a meridional section along 19°W extending from north of the equator to the Antarctic continent has calculated the rate at which some of the nutrients are depleted (Table 3.1). The very long time required to theoretically use up nutrients suggests that some other factors control the onset time, rate of increase and subsequent decline in primary production during the brief summer season. In a recent review Fogg (1977) discussed the major factors affecting primary production and suggested that in addition to light and ice cover turbulence may well be a major factor but that other factors such as micro-nutrients, for which there is only very limited information, could also be important.

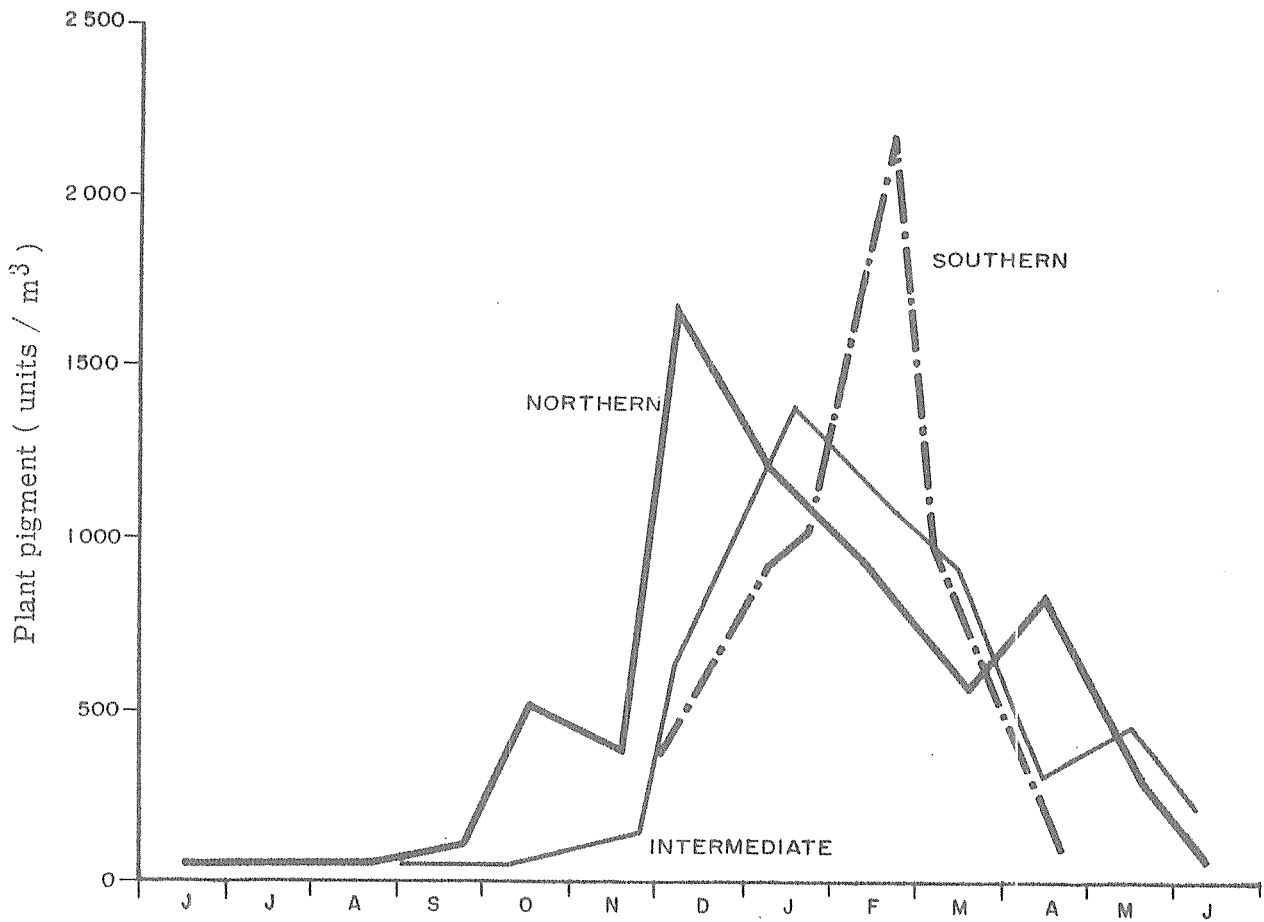


Fig.3.1 Seasonal changes in standing stock of phytoplankton in three major regions of the Southern Ocean (data from Hart (1942))

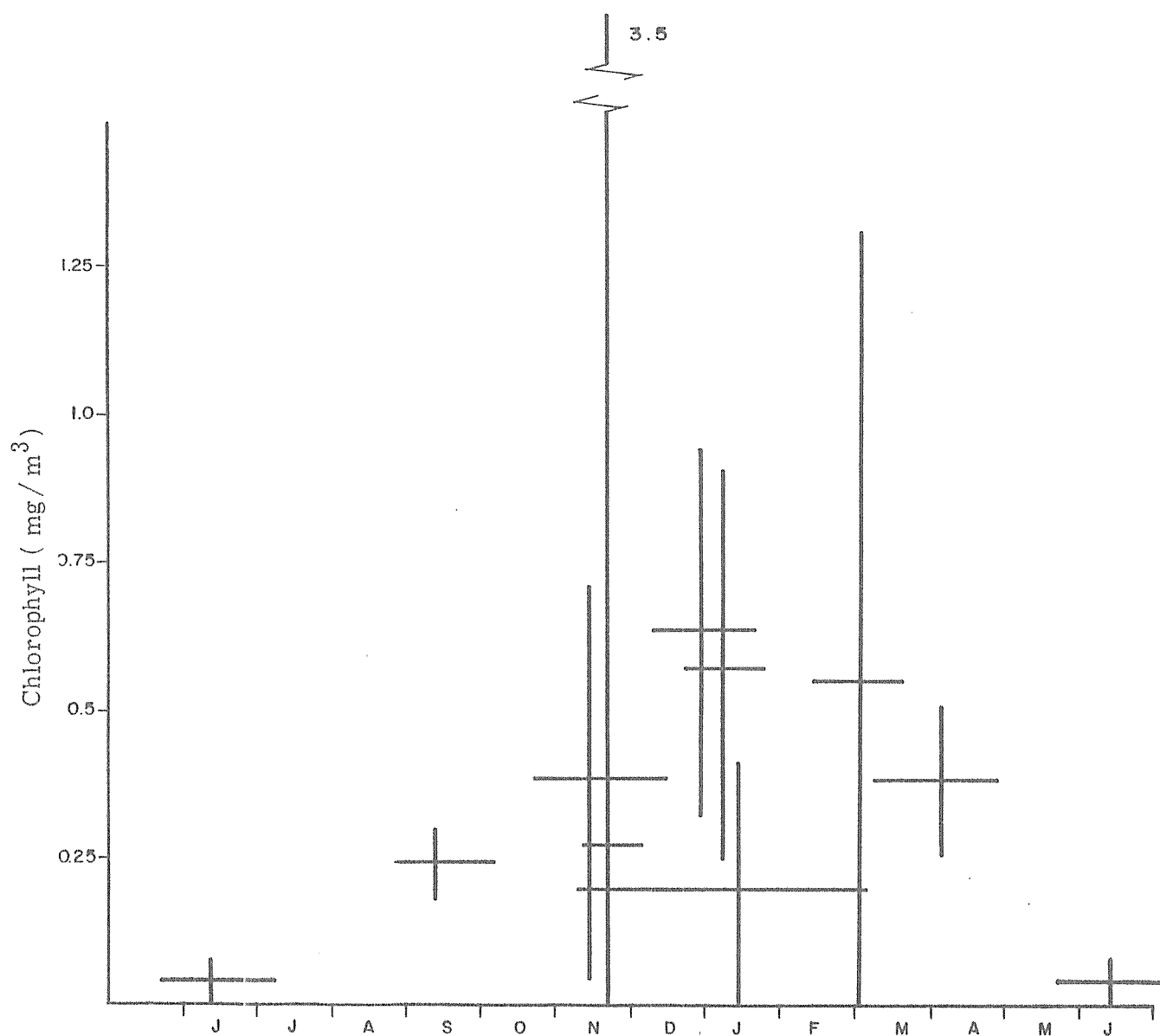


Fig.3.2 Variations in the standing stock of chlorophyll in the Drake Passage. Vertical bars show one standard deviation about the mean. Horizontal bars show the mean during the period of observations (data from El-Sayed (1968))

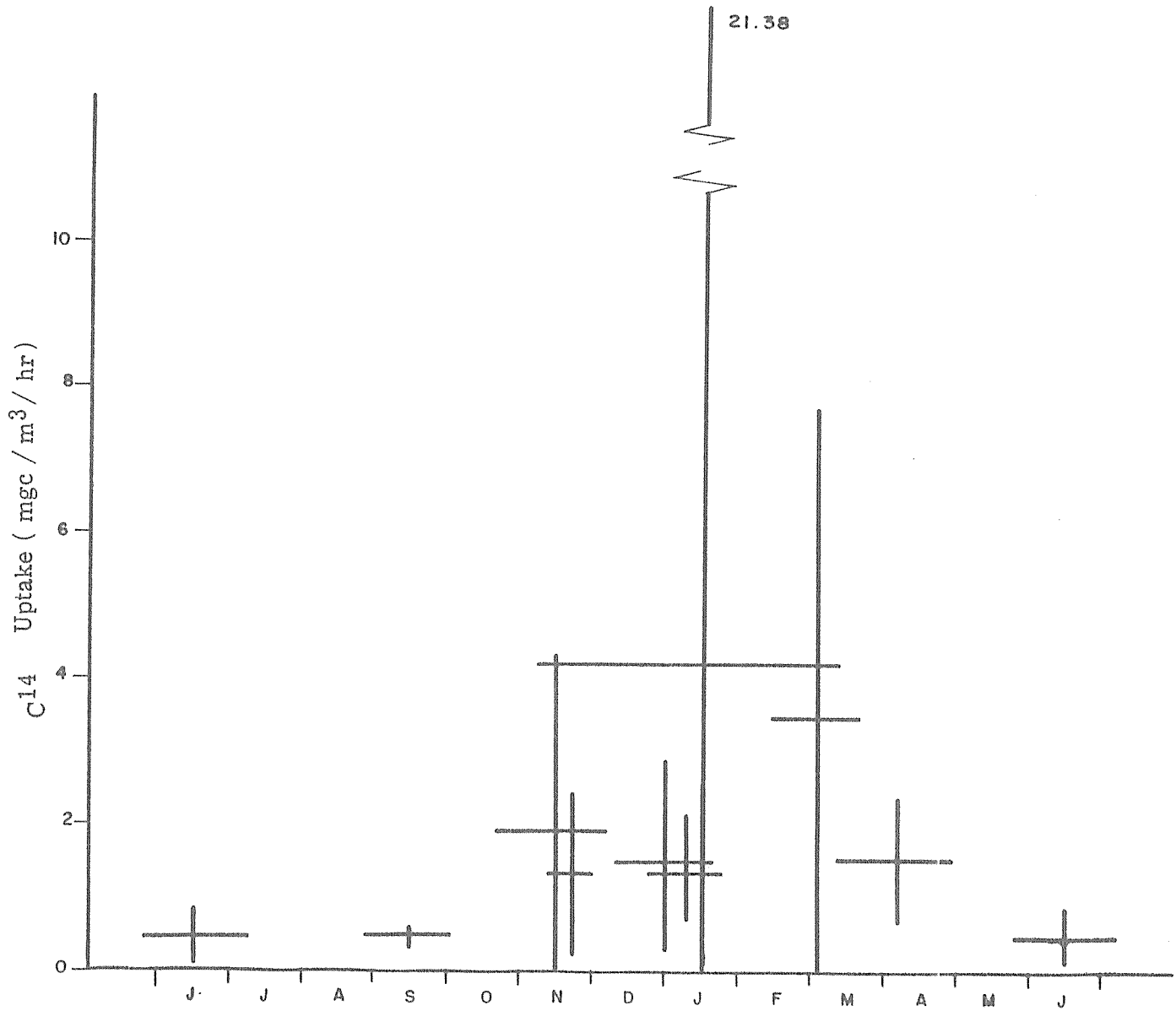


Fig.3.3 Variations in the production rate in the Drake Passage, as measured by C¹⁴ uptake. Vertical bars show one standard deviation about the mean. Horizontal bars show the mean during the period of observations. (data from El-Sayed 1968))

Table 3.1. Primary Production in relation to depletion rate of two nutrients.
Data from Volkovinsky 1974

| | | South Latitude | | | | | |
|---|---|----------------|----|-----|-----|-------|-----|
| | | 20 | 30 | 40 | 50 | 60 | 72 |
| Average Primary Production ($\text{mg}^{\text{C}}/\text{m}^2/\text{day}$) | | 70 | 70 | 70 | 140 | 200 | 340 |
| Time to deplete: (days) | P | 120 | 81 | 667 | 909 | 833 | 667 |
| | S | 82 | 90 | 312 | 769 | 1 250 | 730 |

The results of Volkovinsky (1974) also indicate an increasing rate of primary production in higher latitudes^{1/}. This result is at variance with that of, El-Sayed (1967) who found on balance a reduction in higher latitudes (Table 3.2).

Table 3.2. Standing crop and primary production in relation to latitude.
Data from El-Sayed 1967

| | South Latitude | | | | | | | | |
|---|----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | 35-40 | 40-45 | 45-50 | 50-55 | 55-60 | 60-65 | 65-70 | 70-75 | 75-80 |
| Chlorophyll (mg/m^3) | 0.62 | 1.05 | 0.53 | 0.71 | 0.61 | 1.67 | 1.02 | 0.44 | 0.30 |
| C^{14} Uptake ($\text{mg}^{\text{C}}/\text{m}^3/\text{hr}$) | 9.22 | 6.77 | 5.70 | 6.04 | 1.83 | 8.73 | 1.94 | 4.16 | 2.43 |

In fact most of the lower latitude values were obtained over the Argentine continental shelf whilst between latitudes 55° - 60° S and 65° - 70° S a fair proportion were in open ocean conditions which, as discussed previously, did produce lower results. The line of Volkovinsky's stations (19° W) is for the most part in the open ocean and it is possible that in the open ocean production rate increases with increasing latitude whilst in the shelf area it does not.

^{1/} These results appear to have come from one meridional section. Thus the delay in production peak with increasing latitude (Fig. 3.1) could affect the average rate determined.

In the Southern Ocean increasing latitude is accompanied by decreasing temperature and increasing ice cover and seasonal variability in light regime all of which would be expected to have some effect on primary production. Fogg (1977) in reviewing the information available on the effect of temperature discusses evidence of temperature affecting the physiology of primary producers, but concluded that there was insufficient evidence to decide whether the lower temperature in high latitudes produced any effect relative to other areas. Ice cover can be expected to affect production in two ways, by reducing the amount of light entering the water and also by reducing turbulence. The net effect of pack ice on primary production is only poorly understood and yet since in winter approximately two-thirds of the Southern Ocean is covered by pack and fast ice (Mackintosh and Brown 1956) and since *Euphausia superba*, one of the dominant herbivores of the zooplankton, has much of its range within the pack ice zone, further studies are clearly needed.

3.2 Production Rates and Total Production

In an area as large as the Southern Ocean (approx. $32 \times 10^6 \text{ km}^2$) where there is known to be enormous variability in production rate in both time and place, it is very difficult to produce an "average" figure. The importance of primary production in ecosystem studies has meant that several workers have produced overall figures with the limited information available. These are summarised in Table 3.3.

Table 3.3. Estimated production figures for the Southern Ocean

| Mean Production Rate $\text{g C/m}^2/\text{year}$ | Southern Ocean Summer ice free area $(23.4 \times 10^6 \text{ Km}^2)$ | | Authority |
|--|---|---|-------------------------------------|
| | Carbon $(\text{t} \times 10^8)$ | Fresh Wt. ^{1/} $(\text{t} \times 10^8)$ | |
| <u>100</u> | 23 | 230 | Ryther 1963 |
| <u>43</u> | 10 | 100 | Currie 1964 |
| <u>33</u> | | 330 | El-Sayed 1967 |
| <u>6.5</u> | | 65 | Holm-Hansen <u>et al</u> (in press) |

The figures refer to the summer ice free area since Bunt (1968) has indicated that production in the pack ice zone is almost certainly very low although El-Sayed (1971) working in the Weddell Sea has shown the presence of localised highly productive areas.

^{1/} Assumes Carbon is 10% of Fresh Weight

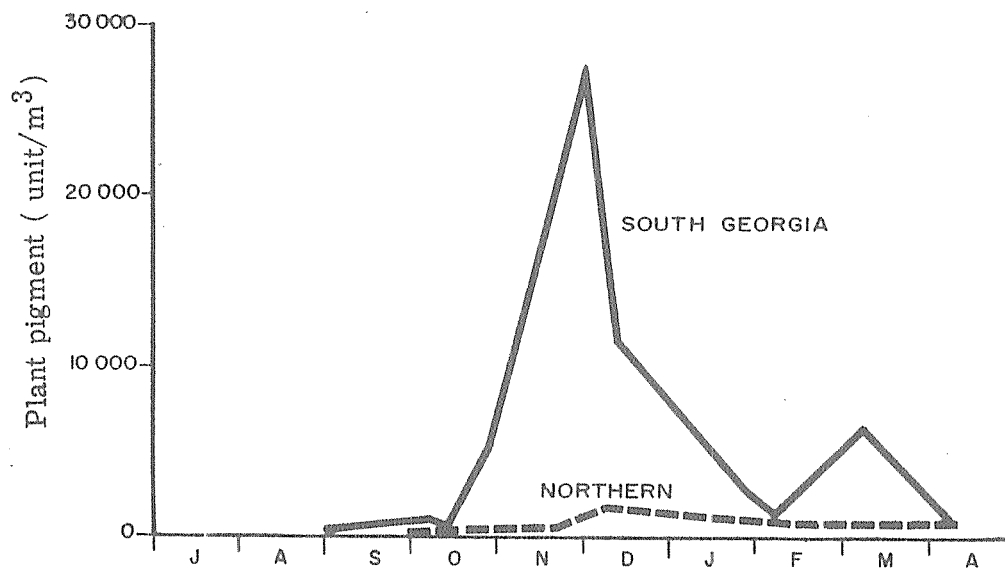


Fig. 3.4 Seasonal changes in standing stock of phytoplankton, showing the high values observed around South Georgia compared with the northern region of the Southern Ocean (data from Hart (1942))

4. ZOOPLANKTON

4.1 Introduction

The literature on Southern Ocean zooplankton is dominated by studies on a single species Euphausia superba which as well as being of enormous interest ecologically is also a resource of considerable commercial potential. This species is therefore discussed separately in Chapter 6. Information on the remaining zooplankters is, apart from systematic studies, far from complete although it is sufficiently comprehensive to permit some ecological generalisations to be made.

4.2 Distribution

The circumpolar nature of the Southern Ocean with the dominant West to East (and vice versa in high latitudes) water movement suggests that many planktonic species may be circumpolar in distribution. That this hypothesis is largely correct was shown by Baker (1954) studying the zooplankton and Hart (1942) the phytoplankton samples of "Discovery Investigations". They both found that species composition did not change markedly around the continent. It has also been found that there is little difference in the mean biomass throughout the year in the various sectors around the continent (Foxton 1956) (Fig. 4.1) a fact that when considered in conjunction with the general circulation pattern, has led to the suggestion that zooplankters are being carried continuously around the Southern Ocean (see Mackintosh 1937, Baker 1954). This theory indicates that however long it takes to complete one circuit, to all intents and purposes there is continuity over the breeding range. Although this point is of minor importance for zooplankton in general it is of great significance when considering Euphausia superba since the description of a breeding stock or stocks is essential for resource management. This is discussed more fully in the section on krill.

Variations in standing stock with season, depth and latitude have been discussed by several workers (general discussions are given by Mackintosh 1937, Foxton 1956, Voronina 1968 and 1970). In an analysis based for the most part on a series of samples taken in December, March, September, October and November at standard depths and positions along the 80°W meridian, Mackintosh (1937) divided the more frequently occurring zooplankters into several major groups. These are:

Group 1: No effective daily migration but a marked descent from the surface layers in summer to the warm deep water in winter.

| <u>Species</u> | <u>Further information</u> |
|---|--------------------------------|
| <u>Rhincalanus gigas</u> | Ommaney 1936, Voronina 1970 |
| <u>Eukrohnia hamata</u> | David 1958, 1965, Timonin 1968 |
| <u>Calanus acutus</u> = <u>Calanoides acutus</u> | Andrews 1966 |

Subsequent research has shown that the following species placed in Group 3 should be more correctly assigned to this group.

| | |
|----------------------------------|---------------|
| <u>Sagitta gazellae</u> | David 1955 |
| <u>Calanus propinquus</u> | Voronina 1972 |
| <u>Parathemisto gaudichaudii</u> | Kane 1966 |

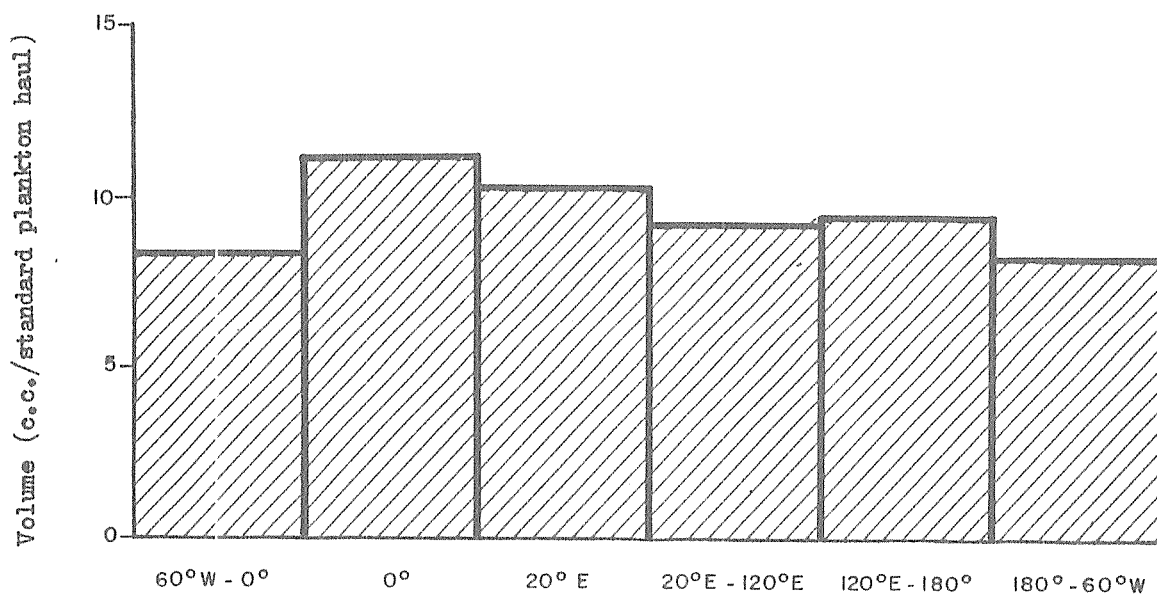


Fig.4.1 Longitudinal variations in the total volume of zooplankton (0 - 1 000 m depth) in the Southern Ocean (from Foxton (1956))

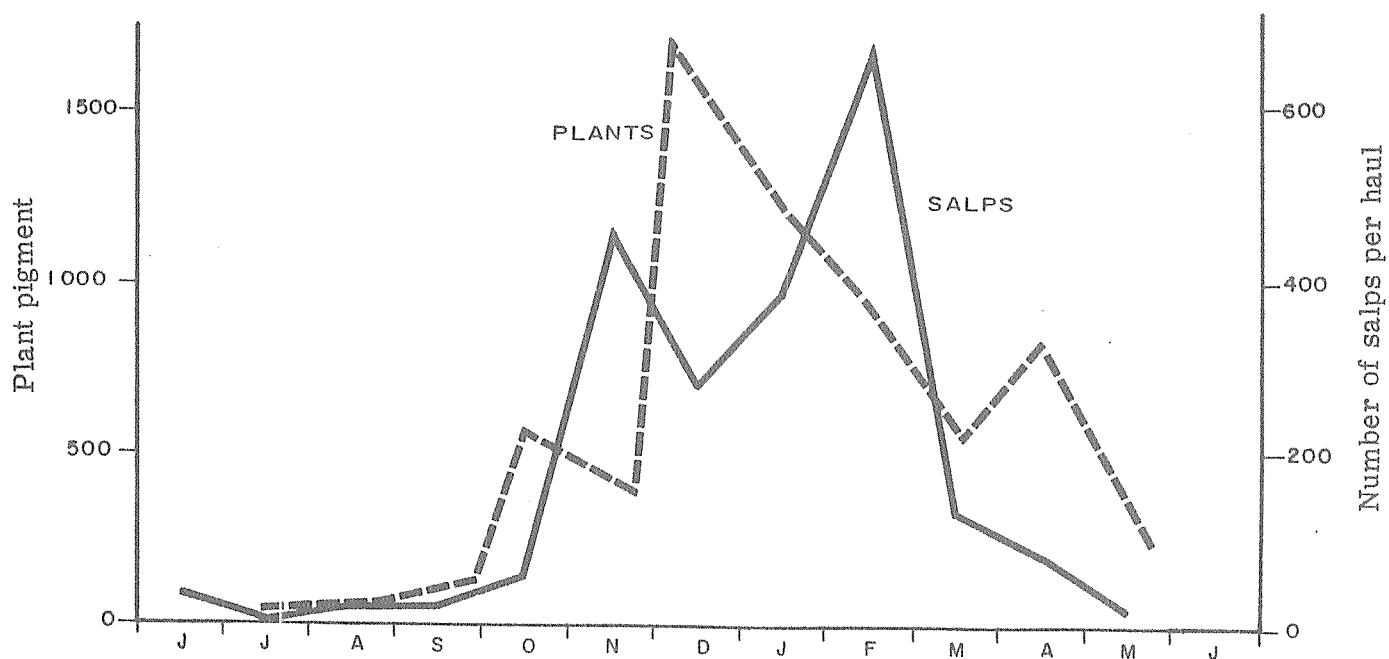


Fig.4.2 Seasonal changes in plants (as measured in plant pigment units) and herbivores (number of salps, *Salpa thompsoni*, caught per standard haul) (data from Hart (1942) and Foxton (1966))

Group 2: Energetic daily migration but no extensive annual migration.

Pleuromamma robusta

Euphausia triacantha

Baker 1959

Euphausia vallentini

Mauchline and Fisher 1969

Euphausia frigida

Mauchline and Fisher 1969

Group 3: Normally inhabiting the surface layers, but with no effective daily migration and no apparent annual migration. The three species originally designated as belonging to this group have now been placed in Group 1. Mackintosh originally suggested that Euphausia superba should be placed into this group which in general terms (neglecting the developmental ascent) may well be correct. Reference should be made to this topic in Section 6.2.

Group 4: Normally inhabiting the warm deep water with no effective daily migration but descending into slightly deeper water in winter.

Sagitta maxima, S. planktonis and Eukrohnia hamata and E. antarctica were placed in this (see David 1958, 1965, Timonin 1968).

Group 5: Scarce or irregularly occurring species whose distribution could not be definitely classified.

In general the vertical range of the migrations undertaken by species classified into groups 1 and 2 will mean that they will move either from the surface water with its slight northerly component to the warm deep water with its slight southerly component or vice versa. Movement between these two water masses will, as Mackintosh points out, providing the relative residence time in relation to water movement is right, maintain the zooplankters in approximately the same latitude but with some meridional shift. This meridional shift would theoretically eventually carry around through 360° of longitude as mentioned above. Vertical migration whether annually or diurnally is therefore a major factor in maintaining many zooplankters within their range.

Seasonal variation

In the section on primary production it was shown that the production peak is often of great magnitude but short duration. The standing stock of herbivorous zooplankton in the euphotic zone in many cases follows closely this build-up (Foxton 1964, 1966) (Fig. 4.2). Bearing in mind the difference in timing of the primary production peak in different latitudes, it is to be expected that the peaks of herbivore abundance should follow a similar trend. Such a trend has been described for the summer increase in zooplankton which would seem to fit the theory (Voronina 1966). The seasonal change in zooplankton volume (assumed equivalent to biomass) has been well documented by Foxton (1956) who showed that although there is a marked seasonal change in the top 100m there is very little change over the whole water column (Fig. 4.3). (In a recent paper Vladimirovskaya 1975 quotes values of 53 ml/m² for winter, 33 ml/m² for spring and 134 ml/m² for summer plankton biomass in the Scotia Sea. Although large organisms were excluded it is possible that phytoplankton is included which around South Georgia could be the cause of much of the variation). The implication of Foxton's results is that during the summer the period of rapid phytoplankton growth is associated with a fast overall grazing rate and thus high zooplankton production. During the winter when phytoplankton production is at a minimum and the bulk of the zooplankton is deep down below the depleted euphotic zone it is probable that zooplankton production is very low (Foxton 1956). A closer examination of Fig. 4.3 shows that the summer (February, March, April) increase in the uppermost layer is coincident with an increase in total biomass. The reason for this is probably due to the increase in production outweighing predation at this time. The marked seasonal vertical migration pattern demonstrated for Calanoides acutus

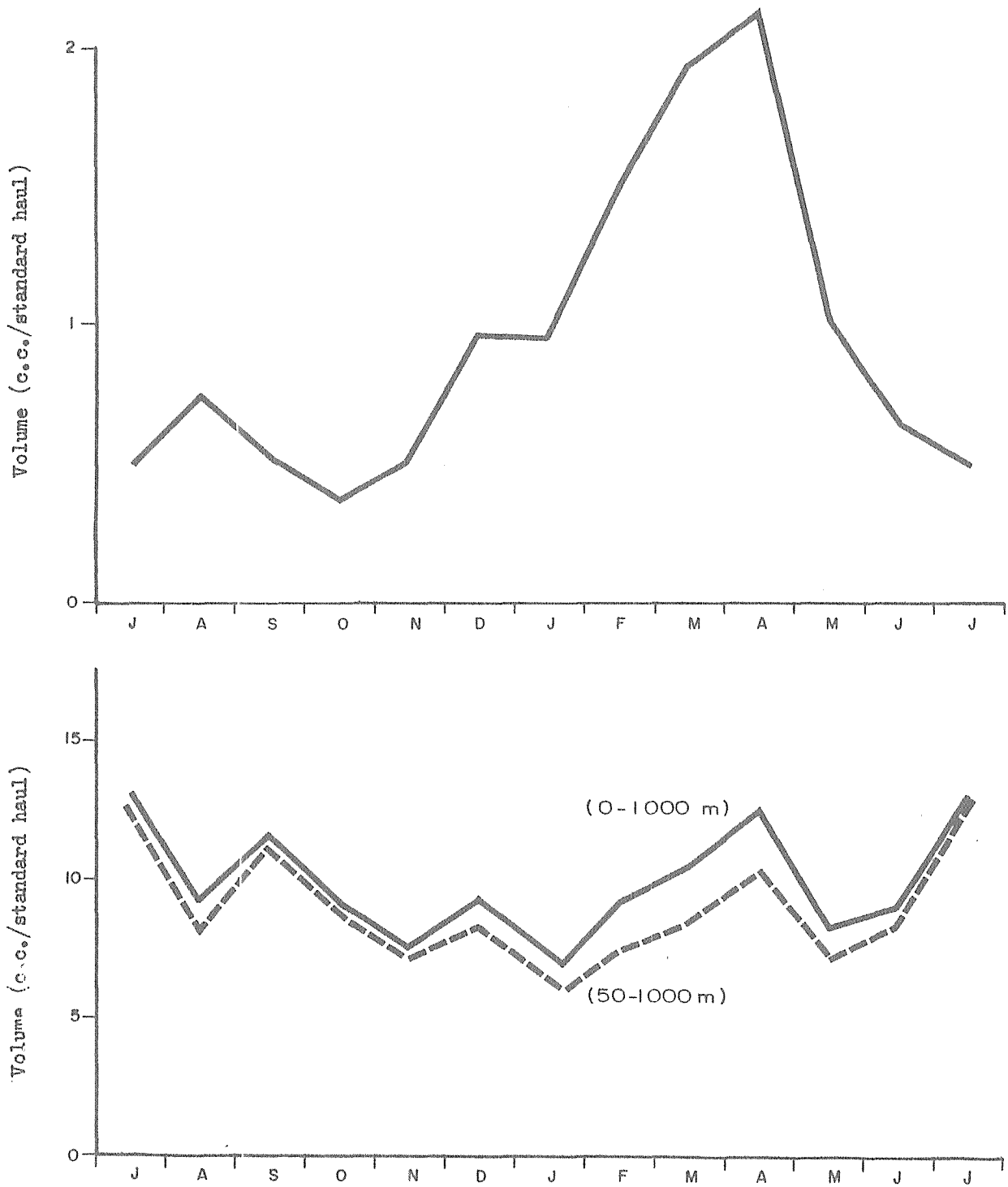


Fig.4.3 Seasonal variation in mean plankton biomass, (above), in the 0 - 50 m depth zone; (below) in the 0 - 1 000 m zone (data from Foxton (1956))

(Andrews 1966) (Fig. 4.4), one of the dominant herbivorous zooplankters, is almost certainly a major contributor to the high winter total biomass. The relatively high winter biomass values probably indicate that most of the zooplankters included in Foxton's analysis have a lifespan of at least one year. Although a species breakdown is not given, of those likely to be included Rhincalanus gigas, Calanoides acutus, Calanus propinquus (Copepoda) (Ommaney 1936, Voronina 1970, Andrews 1966) Sagitta gazellae (Cheatognatha) (David 1955) small euphausiids (Mauchline and Fisher 1969) and Parathemisto gaudichaudii (Amphipoda) (Kane 1966) have a normal lifespan of a year at least. Of the other members of the zooplankton one of the most important groups because of its potential influence on a krill fishery are the salps. Foxton (1966) has shown the enormous seasonal changes in biomass that one species, Salpa thompsoni, undergoes (Fig. 4.2). The enormous increase in abundance is almost entirely brought about by budding of the aggregate forms. This budding in conjunction with a growth rate of approximately 6-8 mm/month means that in a relatively short time a locally high biomass will result. Since salps were excluded from Foxton's (1956) analysis the probable enormous increase in summer biomass of this group is not reflected in those particular results.

Local distribution

The generalised picture of zooplankton distribution given above is derived as an average over very large areas. The restriction of high primary production to localised areas as for example frontal zones and shelf areas, has led to the suggestion that herbivorous zooplankton might be concentrated in a similar way. Around South Georgia, Hardy and Gunther (1936) found large concentrations of zooplankton although the distributions of phytoplankton and herbivore density showed a more or less inverse relationship (Table 4.1).

Table 4.1. Abundance of dominant zooplankters and phytoplankton from a series of hauls around South Georgia (Hardy 1967)

| Phytoplankton | <u>Euphausia</u> <u>superba</u> | <u>E. frigida</u> | <u>Thysanoëssa</u> | <u>Parathemisto</u> | <u>Salpa</u> <u>fusiformis</u> |
|---------------|------------------------------------|-------------------|--------------------|---------------------|-----------------------------------|
| 57 500 | 289 | 3 | 17 | 48 | 38 |
| 290 000 | 1 913 | 44 | 57 | 266 | 1 781 |
| 483 000 | 951 | 47 | 94 | 44 | 1 051 |
| 2 064 000 | 369 | 76 | 136 | 87 | 675 |
| 50 936 500 | 31 | 15 | 138 | 53 | 246 |
| 315 125 000 | 41 | 2 | 69 | 45 | 49 |

Although the South Georgia area (the location of the study summarised in Table 4.1) is known to be a region of high phytoplankton standing stock, the factor of 10 that Hart (1942) calculated in estimating the difference between South Georgia and Southern Ocean phytoplankton abundance generally would only result in the exclusion of the bottom line, or two lines, if considering this a picture of the Southern Ocean in general. On this basis the peak values for E. superba, Parathemisto and Salpa fusiformis, all of which are found in dense swarms, occur at relatively low phytoplankton values. Whether this result is due to a "grazing effect" (in this context excluding Parathemisto which is a carnivore) is not known although it is a reasonable hypothesis that swarms could have a major impact in local areas. It is important to bear in mind that the differences in abundance mentioned above are in limited areas. Thus South Georgia, a region of high summer phytoplankton standing stock, is also

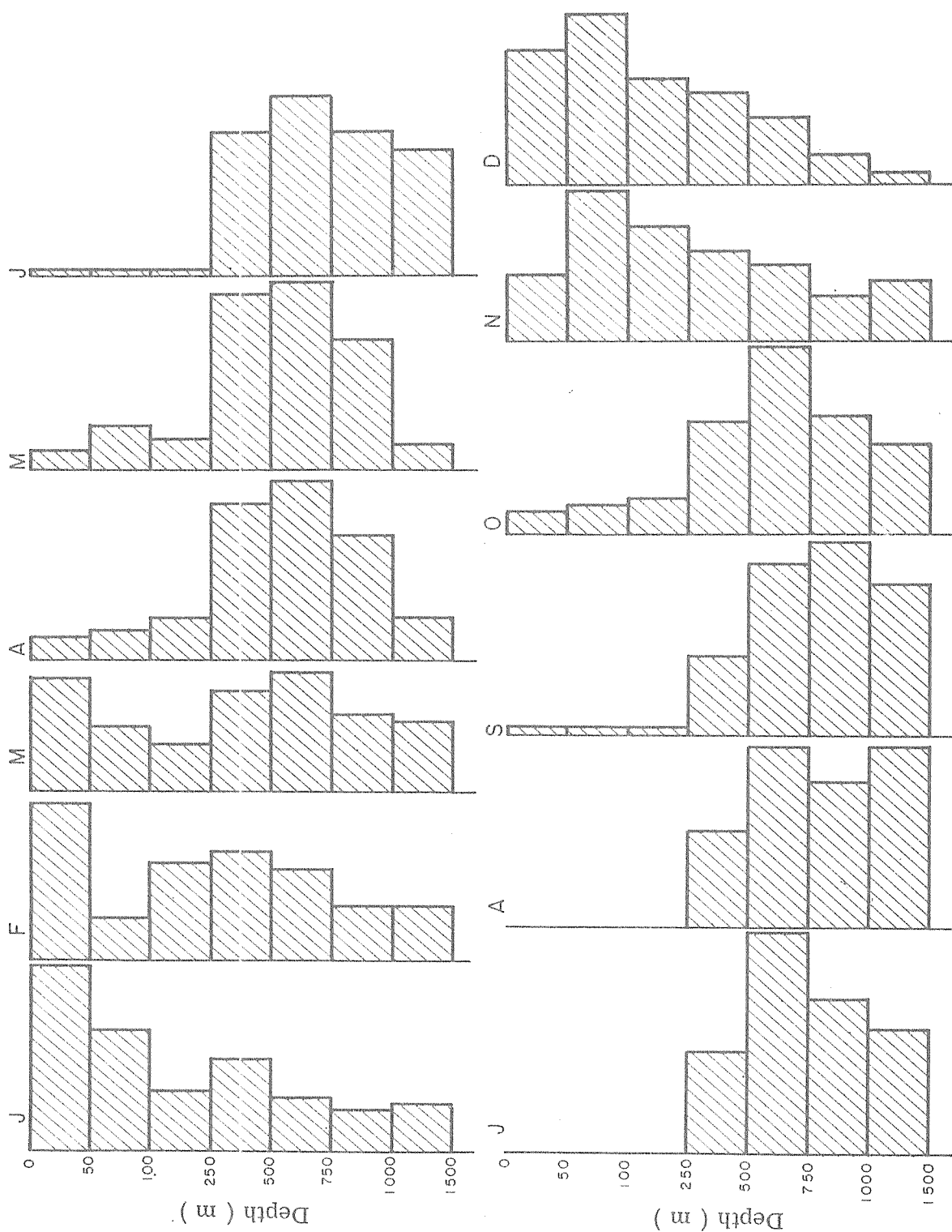


Fig.4.4 Seasonal variation in the vertical distribution of *Calanoides acutus* (data from Andrews (1966))

an area of high macroplankton density (Mackintosh 1934) the disparities mentioned above being largely due to the well known phenomenon of patchiness.

That individual plankters are distributed non-randomly has been well known for a long time. Parsons and Takahashi (1973) quoting Stavn (1971) describe the following as being the principle factors determining the non-random distributions of planktonic organisms.

1. Physical/chemical boundary conditions including light, temperature and salinity gradients
2. Advective effects as in wind or water transport, including small-scale variations due to turbulence
3. Reproduction rates within the population
4. Social behaviour with populations of the same species
5. Coactive factors determined by competition between species.

The factors in 1 and 2 have already been shown to apply to primary production concentrations and it is probably true to say that the same areas hold the higher zooplankton standing crops. (Mention has already been made of the South Georgia area and from the fragmentary evidence available this seems to be generally true throughout the Southern Ocean). Within these larger area patches there is for many species another form of patchiness superimposed. A simple example has already been given in the case of Salpa thompsoni which Foxton (1966) has shown to be generally distributed in the areas of higher primary production, but is also capable of reproducing at a fast rate to produce dense swarms. Similarly Euphausia superba is well known to exist in swarms over much of its distributional range. Once again the formation of swarms can probably be attributed to two factors; initially those resulting from, in the main, factors 1 and 2 above and secondarily factors such as 4 which lead to the formation of dense swarms. Thus within areas of high concentration there are very often small pockets of extremely dense concentration and also intermediate densities. Swarming in E. superba is discussed fully in section 6.5.

4.3 Biomass and Production

The enormous differences in physical size, activity and absolute density of the vast range of species making up the zooplankton has presented enormous problems in making realistic estimates of standing stock. For the most part the estimates that have been made exclude the physically large species (e.g., Medusae, Salps) mainly because their low frequency of occurrence in plankton hauls gives them an unrealistic weighting in statistical analysis. Species known to be quite active and therefore capable of avoiding nets (e.g., krill) are also generally excluded. The estimates which follow (Table 4.2) should therefore only be considered as minima and not representative of total zooplankton in the Southern Ocean.

The figures given in Table 4.2 refer in the main to copepod species which Voronina (1966a) found to represent 73% of the standing crop in the samples examined. The low figure of 7.6% for euphausiids is almost certainly a reflection of the way avoidance affects catches of zooplankton by small low speed nets. The euphausiid biomass is therefore almost certainly higher than this although whether it represents 50% (or more) of the total as Holdgate (1967) has suggested is unknown.

There are no direct figures available for zooplankton production although, because of the limited primary production season and the high winter zooplankton standing crop annual production is probably about equal to standing crop (Gulland 1970). The high carnivore/herbivore proportion found by Hopkins (1971) may indicate that herbivorous zooplankton production is several times the standing stock. However since the carnivores were almost certainly underestimated in his samples this may not necessarily be the case.

Table 4.2. Zooplankton standing crop estimates

| Standing stock | Depth range (m) | Notes | Reference |
|------------------------------------|--------------------|----------------------------------|---|
| 100 mg/m ³ | | Around 60°S | Bogorov <u>et al.</u> 1968 |
| 55 mg/m ³ | 0-50 | S. Ocean Mean. | Foxton 1956 |
| 1-20 g/m ³ | 0-50 | Feb. - Mar. near to shore ice | Vinogradov and Naumov 1958 |
| 100-150 mg/m ³ | 100-200 | " | " |
| 50 mg/m ³ | 200-500 | " | " |
| 25-6 mg/m ³ | 0-1000 | S. Ocean Mean. | Foxton 1956 |
| 5-10 mg/m ³ | 0-100 (?) | Pacific sector | Barkhtov <u>et al.</u> 1973 |
| 12 mg/m ³ | | Max. in Pacific sector | " |
| 50-500 cc/m ² | | (Based on Foxton 1956) | Beyer (unpublished) (Cited by Hempel 1970) |
| (8-10 to 80-100 g/m ²) | | Dry weight equivalent | " |
| 5 g/m ² | 0-1000 | Winter (dry wt. ?) | Hopkins 1966 |
| 3 g/m ² | 0-1000 | Summer (dry wt. ?) | " |
| 48 g/m ² | 0-2000 | Pacific sector | Hopkins 1971 |

5. BENTHOS

5.1 Introduction

The Antarctic marine benthic fauna contains very few species that are likely to be of potential commercial importance. In spite of this, it is still necessary to consider the benthic environment since it is the habitat in which many of the more important fish species occur for part of their lives. The crustacean fauna which in many other areas is dominated by crabs and lobsters is in the Southern Ocean mainly composed of Amphipoda and Isopoda, none of which are of commercial importance. Of the molluscs the only species likely to be taken commercially are the Octopoda although their standing stock is probably not large.

5.2 The Habitat

The Antarctic continental shelf is narrow with an average width of 60-240 km and covers an area of approximately 2.2×10^6 km² or about 7% of the area of the Southern Ocean south of the Antarctic Convergence. The outer edge of the continental shelf occurs at greater depth (400-500 m) than is typical of other seas of the world. The seabed itself is affected in a variety of ways by ice in various forms. When icebergs melt, rocks frozen into them are released to the seabed to form a hard substrate for sessile organisms. In addition there is a continual influx of glacial silt which provides a habitat for some infaunal components. In shallow regions icebergs also have an effect by abrading hard substrates and ploughing into mobile ones when they drift aground.

The effects of sea ice on the biota are no less profound than those of the icebergs. The exposed surfaces of the intertidal zone are rendered almost barren due to the scouring action of ice; the most conspicuous faunal component being the limpet (*Patinigera polaris*). In higher latitudes this barren zone extends down below low water mark to a depth of about 15 m (Dayton *et al.*, 1970). Sea ice also has an effect by reducing the amount of incident radiation that enters the water. Thus the marked seasonality in the incident light regime (Figure 5.1) is further accentuated by the winter formation of sea ice which can itself reduce the already low light level by well over 90%. The formation of sea ice as well as requiring some physiological compensation on the part of the fauna and flora is also an important habitat for certain species, e.g., Fish (Andriashev 1970), Amphipoda and Microalgae (Whitaker, in press).

The shallow water marine environment of the Antarctic zone is characterized by low temperature with only small seasonal variation in higher latitudes. (Figure 5.2). Thus at McMurdo Sound the yearly mean water temperature at 100 m depth is -1.36°C with a range of only 0.56°C (Tressler 1964), at Pointe Geologie ($66^{\circ}\text{O}'\text{S}$) the sea temperature varies from -1.9 to -0.5°C (Hureau 1970) and at Signy Island from -1.9 to $+0.4$ (Everson 1970).

5.3 Faunal Association and Zonation

In the main areas studied, several faunal associations have been recognized which have been related to depth and substrate, and although these areas are far apart geographically and have unique substrate qualities it is possible to make some generalizations.

Areas of rock and boulder are generally colonized by sessile plankton and detritus feeding species. In places these assemblages include several species growing on top of each other (Bullivant 1967). The dominant species represented are members of the Porifera, Tunicata and Hydrozoa, some of which grow to quite considerable size, e.g., the bowl-like sponge *Scolomastra joubini* which attains a height of 130 cm and width of 75 cm (Andriashev 1965). In lower latitudes in the euphotic zone, below the region of major ice scour, there is a dense growth of macroalgae. Living amongst these attached forms are a wide variety of motile species, predominantly Amphipoda, Isopoda, Gastropoda, Polychaeta, Nemertea and Echinodermata.

Zonation patterns of the main hard substrate forms are shown in Table 5.1.

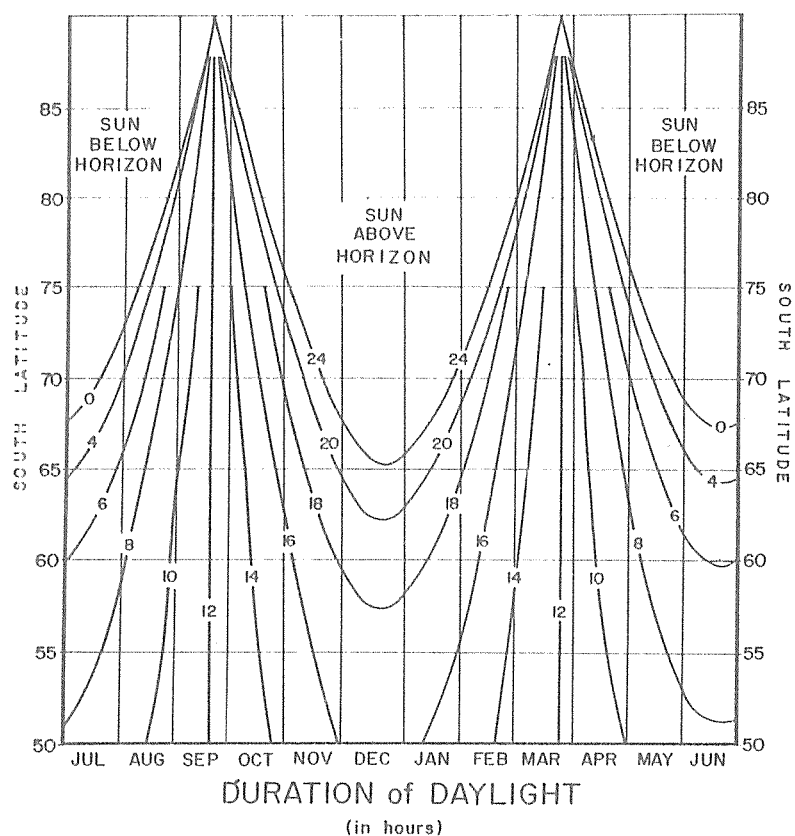


Fig.5.1 Duration of daylight, in hours for $50^{\circ} - 90^{\circ}\text{S}$ at sea level (Rubin 1965)

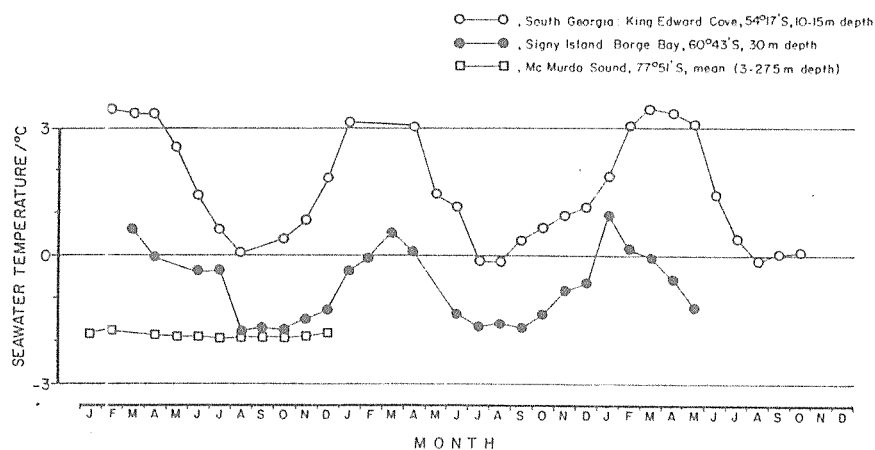


Fig.5.2 Seasonal variation in seawater temperature at three different Antarctic localities

Table 5.1 Benthic zonation patterns in the Antarctic

| ZONE | McMurdo (Dayton 1970) | Pointe Geologie (Arnaud 1974) | Signy Island (White and Robins 1972) | Kerguelen (Arnaud 1974) |
|------------------|--|--|--|---|
| Supralittoral | | | | |
| Littoral | | | Upper part of zone main alga is <u>Ulothrix</u> | |
| Sublittoral I | Temporarily colo- nized in summer by detritus feeders and scavengers | Not present | Not present | Not present |
| IIa | Few Algae(?) Sessile faunal forms, e.g., <u>Alcyonium Actinaria</u> Motile forms <u>Odontaster</u> , Fish, <u>Pycnogonida</u> | Annual Algae, e.g., <u>Leptosomia</u> and <u>Monostroma Lithothamnion</u> | | Dominant alga <u>Durvillea</u> <u>antarctica</u> . In deeper levels <u>Lithothamnion</u> <u>Patinigera</u> and <u>Mytilus</u> <u>edulis desolationis</u> |
| | | No sessile invertebrates | Sessile invertebrates | |
| IIb | | Perennial algae - <u>Himantothallus</u> <u>grandifolias</u> and <u>Desmarestia</u> Extensive fauna including some sessile invertebrates | | Dominant alga <u>Macrocystia</u> <u>pyrifera</u> |
| III | Substrate dominated by sponge spicules. Many Actinorians and Asteroids | Mat of sponge spicules. Algae mainly phyllo- phore. Exten- sive fauna of sessile invertebrates | Red algae. Extensive fauna, mainly sessile species | |

Sand and mud substrates in places contain large numbers of bivalves, amphipods and polychaetes (Table 5.2) (Lowry 1975, Hardy 1972). These can amount to a high biomass although in seas containing a high proportion of glacial silt the infauna is invariably very sparse.

Table 5.2 Infauna and Epifauna of mobile substrates in Borge Bay, Signy Island (Hardy 1972)

| Infauna | Epifauna |
|--|---|
| Amphipoda | Cumacea |
| Apoda (Echinodermata) | Echinodermata (excluding infaunal species) |
| Gastropoda (excluding Patinigera) | Isopoda |
| Nematoda | <u>Patingera polaris</u> |
| Polecypoda | Polychaeta: |
| Polychaeta (excluding three errant species) | <u>Lumbrineris kerguelensis</u> |
| Priapulida | <u>Neanthes kerguelensis</u> |
| | <u>Polynoidea</u> spp. |

5.4 Biomass and Production

5.4.1 General

Estimates of the standing stock of benthic organisms have been made using grabs, suction samplers, corers, and by divers picking specimens out of quadrats by hand. A large series of grab samples was obtained in East Antarctica by Russian investigators. Their results (Ushakov 1964) indicate a high biomass in coastal areas (1.3 kg/m^2) composed mainly of sponges and bryozoa whilst at depths of around 3 000 m the biomass is much smaller and composed largely of Vermes.

In shallower water higher biomasses have been found particularly on hard substrates. A comparison of the results from three sites is shown in Table 5.3. Although the sampling areas were far apart they do allow some tentative conclusions to be drawn about the changes in biomass with latitude. At the Haswell Islands, Propp (1970) found that the only major element of the macroalgal flora was the red alga Phyllophora antarctica. At Signy Island in comparative depths there is a high algal biomass made up mainly of Desmarestia sp and Himantothallus grandifolias^{1/} whilst at Kerguelen even higher biomasses (mainly Macrocystis) are common. It is very likely that ice by reducing light entering the water and by scouring the seabed is largely responsible for this very great difference.

^{1/} Previously called Phyllogigas grandifolias (Moe and Silva 1977)

Table 5.3 Comparison of Benthic Biomass from three Antarctic localities
(Data from Propp 1970, White and Robins 1972 and Grua 1971)

| Depth Range (m) | FLORA | | | FAUNA | | |
|-----------------|-------------------------------------|----------------------------------|-------------------------------|-------------------------------------|----------------------------------|-------------------------------|
| | Haswell Islands g/m ² | Signy Island g/m ² | Kerguelen g/m ² | Haswell Islands g/m ² | Signy Island g/m ² | Kerguelen g/m ² |
| 2-10 | * | 1040 1230 1723 | 4980 12000 15000 | 20-257 | 137 166 200 | 620 108000 135000 |
| 10-25 | * | — | 2540 3600 153600 | 550 | — | 10160 2400 38400 |
| 25-30 | 0 | 218 1487.5 | — | 1000 | 53 1347.5 | — |
| 30 | 0 | 0 | — | 3000 | 200 | — |

* Present in small quantity but not determined

The situation with regard to the faunal associations at all three sites is very similar in the shallow areas and below 25 m depth the biomass at the Haswell Islands and Signy Island are comparable. The fact that the biomass in the shallow depths at both the Haswell Islands and Signy Island are much lower than those at Kerguelen is almost certainly a result of the much reduced anchor ice and ice scour effects at the latter locality.

The limited information available for infaunal communities suggests that the faunal biomass is similar. Hardy (1972) estimated that in the depth range 6-7 m at Signy Island there was a mean biomass of 1.5 kg/m² and in 13-15 m depth the biomass was 2.6 kg/m² while at Arthur Harbour Lowry (1975) found a macrofaunal density of about 7 000 individuals/m².

There are no estimates available for the production by the benthic fauna although since growth rates tend to be slow (Everson 1977), with many species living for more than one year, the ratio of annual production to biomass is probably low. There are however certain species which do grow quite rapidly, for example Mycale, the only sponge species in which a measurable increase in size occurred after one year, which increased its mass by up to 67% (Dayton et al. 1974)

5.4.2 Macroalgae

For some years now there has been an industry extracting alginates from kelp. In California and the Falkland Islands alginates are extracted from Macrocystis and since the same species occurs at Kerguelen, South Georgia, Heard and Macquarie, as well as in the Falkland Islands, kelp is a resource of economic potential.

Studies on Macrocystis have been in progress now for several years at Kerguelen. Grua (1964) estimated that in Morbihan Bay the kelp canopy covered an area of 45 km² and had a biomass of 6.3 million tons. Delepine (in press) noted that total regeneration had occurred six months after an experimental cutting programme. The observed growth rate varies from about 2 cm/day in summer to 1 cm/day in winter (Delepine in press), and the mean length of the fronds in the sea is 11 m (Grua 1964). This growth rate is much less than that achieved by the Californian Macrocystis where growth can reach 20 cm/day. On the basis of the observed growth/regeneration rates relative to the frond length, it seems likely that a crop of about one quarter of the standing stock could be sustained. Bearing in mind that around Kerguelen alone the kelp beds cover over 200 km² with a biomass of 5-10 kg/m² (Delepine in press), the yield is potentially quite large. No figures are available for other areas south of the Antarctic Convergence although it is clear that based on the figure for Kerguelen the potential yield from Macquarie, Kerguelen, Crozet and Marion Islands could boost that from the Falkland Islands and Tasmania in what could be an expanding market (Shackleton 1976).

6. KRILL

6.1 Introduction and General Biology

There are in the Southern Ocean several commonly occurring species of euphausiid crustacean. These are listed below and their approximate latitudinal ranges shown in Fig. 6.1.

Euphausia superba
Euphausia vallentini
Euphausia triacantha
Euphausia frigida
Euphausia crystallarophias
Thysanoëssa macrura

The distribution of these species along with an identification key are described by Mauchline and Fisher (1969) and more detailed information is available in John (1937) and Baker (1965) (Euphausia species), in Baker (1959) and Marr (1962) (Euphausia triacantha), Marr (1962) (Euphausia superba) and in Nemoto and Nasu (1958) (Thysanoëssa).

Of these species E. superba (Fig. 6.2) is the largest and most abundant and is the species generally considered as being synonymous with the term "Antarctic Krill". It is this species which is of greatest interest from the fisheries point of view since its habit of congregating into dense swarms makes it an ideal target for modern midwater trawlers. The bulk of this section is therefore in the main restricted to information on E. superba although other species have been occasionally found to be more abundant in some areas of the Southern Ocean (Nemoto, Doi and Nasu, in press, found E. vallentini and Thysanoëssa macrura predominated in six out of 318 samples).

Before reviewing in detail the information on E. superba, a brief outline of some of the essential features of its general biology will be given in order to assist the reader in gaining a clear understanding of the processes which are described in the sections which follow.

The main part of the spawning season for E. superba occurs from January to March. The eggs, about 0.7 mm in diameter, are released at the surface and then sink to considerable depth, almost certainly to the lowest levels of the warm deep water. During the weeks which follow the eggs hatch into nauplii and, whilst rising through the water column, develop through a metanaupliar stage to arrive at the surface as first calyptopes. They then develop through two further calyptopis and six furcilia stages before being classed as adolescents. During the subsequent two or more years the krill increase in size to a maximum length of about 6 cm. and are to be found, for the most part, in the top 200 m of the water column. Any diurnal vertical migration that does occur is thought to be within the Antarctic surface water so that in the West Wind Drift the krill are in water masses having a slight northerly component.

The more or less total restriction of E. superba to the surface water may well be associated with the fact that it is the only species of euphausiid which at least during the summer feeds predominantly on phytoplankton. Other food types are however taken depending upon availability.

The habit of E. superba of congregating in dense swarms has been well known for a long time. The swarms themselves are often several hundred metres across and within them the krill may be as concentrated as several kilograms in a cubic metre of water. Thus, within a region of above average abundance the distribution is extremely patchy.

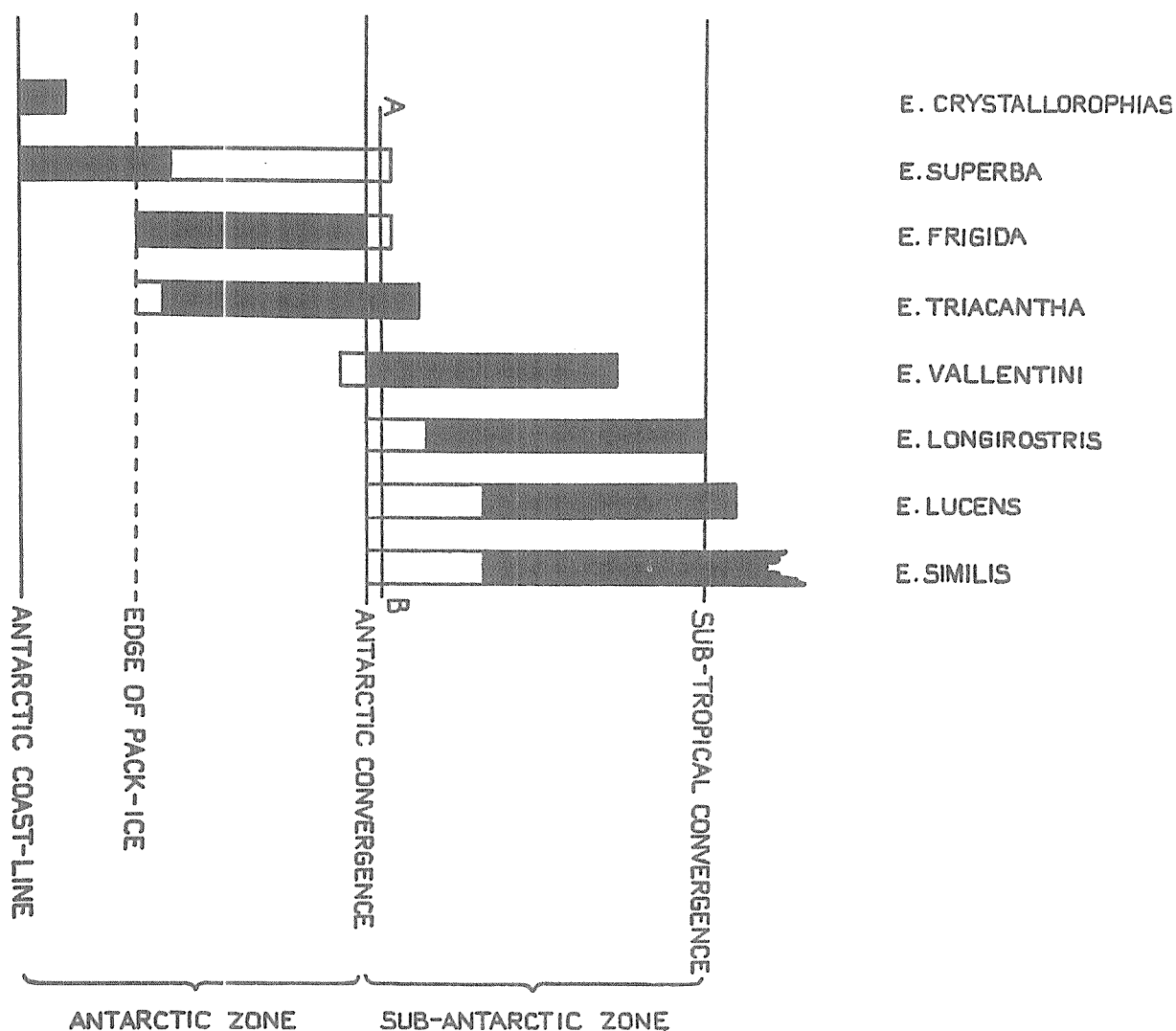


Fig. 6.1 Distribution of species of *Euphausia* in the surface waters of the Antarctic and sub-Antarctic zones (John 1937). The blacked-in portion of each column shows the normal range of that species, the entire column the possible range.

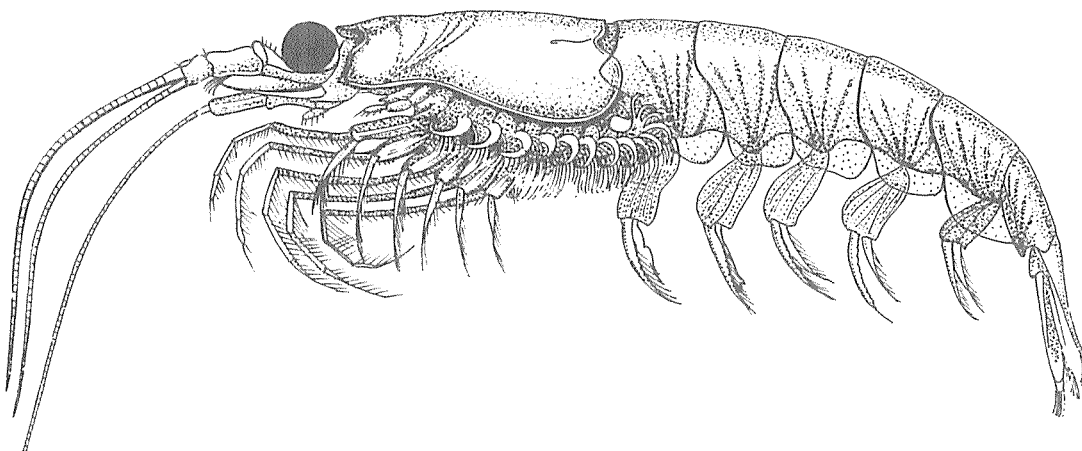


Fig. 6.2 The euphausiid *Euphausia superba* (5 cm), the krill of Antarctic waters (Clarke and Herring 1971)

6.2 Distribution

In broad terms the overall geographical distribution of E. superba may be taken as being circumpolar south of the Antarctic convergence (Marr 1962, Baker 1954) and is one of the dominant macroplankton organisms. (The dominant components of the macroplankton in the Pacific sector may be Salps and Coelenterates (Barkhatov et al. 1973) although Mackintosh (1973) thinks most of the krill there are in the East Wind Drift and therefore in the Pack Ice Zone). There are few records of E. superba occurring north of the convergence. Mackintosh (1973) described krill north of South Georgia in a tongue of cold water, Sasaki et al. (1968) described a concentration at 45°S 145°E and Dall and Dunstan (1957) found fresh krill in the stomach of a humpback whale caught off Queensland. Marr (1957) considers such occurrences of minor importance. Within these very broad limits the density of krill is extremely variable. Marr (1962) describes the major concentrations as occurring in the East Wind Drift, Scotia Sea, Weddell Drift and South Georgia areas although Mackintosh (1973) has shown the existence of large concentrations elsewhere. As a result of recent sampling Nemoto (1968) has shown the presence of large concentrations in the vicinity of the Kerguelen Gaussberg Ridge and at Longitude 150°W (see also map in Mackintosh 1973). This area of concentration is also suggested by Beklemishev (1960, 1961) on the basis of whale catches in the region.

Because krill concentrations tend to occur in certain clearly defined areas, it has been suggested that these may represent several self maintaining populations (implied by Mackintosh 1973) or even distinct races (Makarov 1974). Clearly whether or not such a system is present will have direct effect on the way in which this resource is managed. In this review, the distribution of all life stages has been considered in order to lead to an overall understanding of the population structure.

Distribution of eggs and early larvae

In an analysis of the vast collection of material collected by Discovery Investigations, Marr (1962) showed that E. superba spawns in the surface layers (although Fraser (1936) considered that spawning occurred on the bottom in the shelf zone). The eggs then sink and begin the processes of cleavage leading to hatching. The scarcity of cleaved eggs in the surface samples and the fact that Bargmann (1937) records spawning in aquaria but without subsequent cleavage implies that depth (probably pressure) may be necessary for development. Hatching is thought to occur in deep water and the resultant nauplii moult through the metanaupliar stage as they rise through the water column to reach the surface as first calyptopes. This description of the cycle of events is clear from Marr's (1962) analysis. What is not clear and which has been the subject of a great deal of study are the details of locality, time and conditions under which these events take place.

Although Marr (1962) recorded both gravid and spent females in the oceanic surface water, he considered that hatching in the oceanic deep water far away from the shelf was negligible. He did however consider that the early larvae were carried in the cold bottom water away from the continental shelf to undergo the developmental ascent in the oceanic deep water. This is shown diagrammatically in Fig. 6.3.

In his analysis Marr considers very carefully all the evidence both for and against this explanation because it clearly has a great deal of bearing on the dynamics of distribution. In this respect the important factors are the time taken over the early development and the rates of flow of the cold bottom water and warm deep water.

There is at present no direct information on early development rates for E. superba. Marr assumed that E. superba would take about half as long again as the 15 days Meganyctiphanes norvegica takes to reach the first calyptopis stage (p. 207). Mackintosh (1972) also considers three weeks to be a reasonable estimate although his analysis is based on much the same information as Marr's.

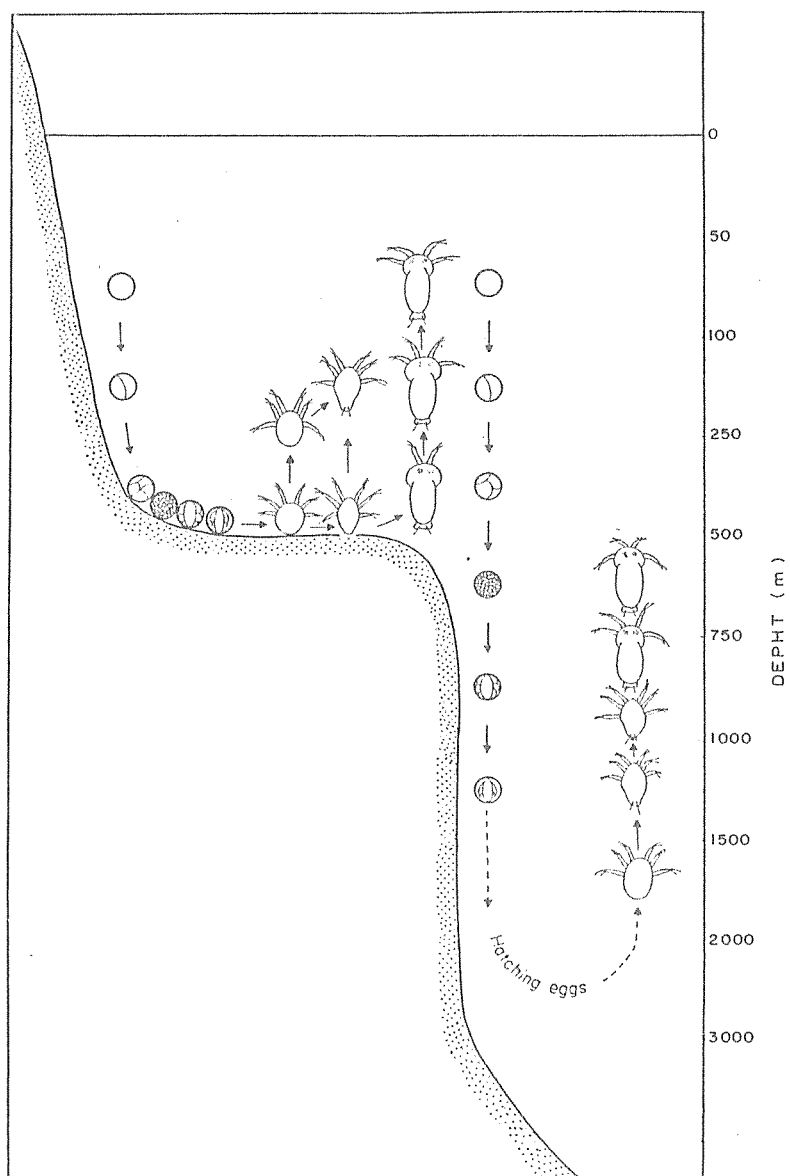


Fig.6.3 Vertical distribution and migration of the early development stages of krill on the shelf (left), and in deep water (right), (redrawn from Marr (1962)). Hatching in shallow water can give rise to the occurrence of nauplii and metamorphosis unusually close to the surface

Little evidence is available on the rate of flow of the various deep water masses although Marr (p. 212) does give evidence that in places the Antarctic Bottom Water could flow north with considerable force.

In a recent re-examination of the distribution of eggs and larvae, Voronina (1974) states that spawning occurs in oceanic waters (cites Dolzhenkov 1973 and Makarov 1973) and also at South Georgia, a marginal area of its distribution range (cites Mackintosh 1973 and Makarov 1972)^{1/} and suggests that spawning probably occurs over most of the range of the species. Voronina suggests that the Antarctic Bottom Water rather than carrying the eggs and larvae does in fact form the physical lower limit for the sinking eggs. Successful development is assumed to be a direct function of depth and a maximum depth of 1 800 m is suggested as being the greatest vertical distance through which the larvae can migrate using the limited food resources in their yolk sacs.

The 1 800 m boundary layer does encompass most of the localities in which early larvae have been found although Voronina does mention that some of the stations from which they were taken in the Scotia Sea fall outside this limit. Another criticism is that in many cases the larvae will not arrive in the surface water until late in the season after the peak of primary production. Adolescent and adult E. superba have been shown to be capable of feeding on detritus (Pavlov 1974) and there would seem no reason why the larvae should not do the same. In that case there is only an advantage in being at the surface during the primary production season. Thus although the 1 800 m boundary layer may for the most part describe the northern limit of successful spawning this is probably a coincidence.

In his analysis of the life cycle of E. superba, Mackintosh (1972) to a great extent avoids the direct issue of oceanic versus shelf area spawning and concentrates on the distribution of the subsequent developmental stages. However, the implication of his conclusions is that he, like Voronina, considers that spawning occurs over much of the ocean as well as the shelf area. He makes a strong case for the early larvae being distributed in areas where low sea temperatures extend to great depth (see also Marr, Fig. 81). The major areas he identifies as holding early larvae are the East Wind Drift, Bransfield Strait and the divergence zones he describes in the Scotia Sea and Weddell Drift.

Vertical distribution of later stages

In a long and detailed analysis of the "Discovery" samples, Marr (1962) suggests that the major concentrations of E. superba occur in the top 100 m and within this stratum most frequently in the top 10 m. In his analysis Marr is careful to minimise error due to avoidance, a major problem with the 1 m diameter and smaller nets from which his samples were obtained. Although massed in the surface waters for most of the day and night Marr does suggest that there is a pattern of diurnal migration but was unable to specify the conditions under which it occurred. The supporting evidence that Marr cites, based on the depths at which whales and birds feed, is not particularly helpful in this context as it only confirms that krill occur near the surface at some time during the day or night (a fact known from the net hauls). What is perhaps more important is that there is a clear indication (Marr 1962, Table 35) that adolescent and post larval krill are not present in significant numbers in the Warm Deep Water.

Recent Russian research using echosounders has shown a tendency for sexually mature krill to undergo diurnal vertical migration in the top 80 m of the water column (Shevtsov and Makarov 1969), and Pavlov (1969, 1974) has obtained results indicating that this vertical migration

^{1/} Makarov (1972) refers to spawning in the frontal zone between Weddell and Bellingshausen water which would be oceanic. Mackintosh (1972) does not describe spawning as occurring near South Georgia but considers it possible although Marr (1962) considers that no successful spawning occurs in the region.

is directly associated with feeding (although no indication is given of how widely applicable these observations are). When the krill are feeding actively they rise to the surface and are dispersed. They come together as swarms when they are replete, stop feeding and then descend. Pavlov suggests that the onset of swarm formation and the duration of the swarm is directly related to food availability. Nakamura (1974) described a similar type of vertical migration although he does not link this to feeding pattern directly. Assuming that availability of food is a major factor in controlling swarm formation it would be expected that swarms would occur more frequently during the summer when primary production is at its maximum than during the winter.

Feeding studies by Pavlov (1971, 1974) have shown that detritus plays an important part in the diet of E. superba which would allow them to feed all year round in deeper water. Although Pavlov (1969) describes the guts of krill caught at 300 m as being empty and therefore not feeding, the fact that their main lipid store is not in the form of waxes (Bottino 1974) suggests they do not go without food for long periods (see Sargeant and Lee 1975). Also Mauchline and Fischer (1969) suggest by comparison with other euphausiids that E. superba although feeding on phytoplankton by preference will also feed on detritus and animal material.

In addition to this information regarding migration in the surface water Shevtsov and Makarov (1969) also describe significant concentrations at over 200 m depth although it is not clear whether these were detected by echosounders or solely by fishing at predetermined depths. Confirmation of this observation may be inferred from Permitin's (1970) observation that krill forms an important component in the diet of several demersal fish species in the shelf area (see also section on Fish in this paper). More recently significant deep water concentrations of krill have been identified in shelf areas of the Scotia Arc where there was no marked temperature discontinuity (Fischer 1976).

The fact that these recent observations conflict with those of Marr can be attributed to either a changing behaviour pattern by the krill or else due to the different techniques involved in estimation. Marr, in considering reasons for the disparity in the daytime and night time catches finds some evidence that the difference is not due to a diurnal vertical migration beyond the normal range of the nets, but that it is more likely to be due to avoidance or the fact that subsurface swarms represent a poor target for obliquely hauled nets. The difference may also be due to the methods employed. There is clearly a need for standardised sampling in conjunction with acoustic detection devices in order to quantify the krill concentrations in both the surface water and also in the intermediate water.

Horizontal distribution of later stages

From the time that they arrive in the surface waters until they spawn two years or more later, a significant proportion of the krill must move, or be carried, to an area from which spawning will result in maintenance of the stock. Over most of the Southern Ocean the surface water has a mainly easterly and to a lesser extent northerly set. The result of this is that krill which occur in that area will be naturally carried away northwards.

Within the general area of the East Wind and Weddell Drifts, which contain the major concentration, the distribution is very patchy. In addition to this the habit of E. superba in forming swarms has made detailed distributional study liable to considerable error. Recent fishing expeditions have, however, identified concentrations regularly in clearly defined areas. These are in the area of mixing of the circumpolar and Weddell currents (Gershanovich and Lyubimova 1971) particularly to the north of the South Orkneys (Burukovskii and Yaragov 1967), on the lee side (in terms of dominant wind and current) of islands and submarine ridges and also in areas of descending currents bordered by ascending currents (Elizarov 1971) and off South Georgia (e.g., Elizarov 1971, Makarov, Naumov and Shevtsov 1970, Bogdanov and Solyanik 1970). In the East Wind Drift zone concentrations have been found around 100°E (Nasu 1974) and from 130°E to 170°W (Ozawa et al. 1968). All of these observations were made during the summer months and also in areas of swarms. The only major concentrations that occur outside the East Wind and Weddell Drift zones are reported from the north of the Ross

In his review of distributional control one of the mechanisms that Marr (1962) postulates is the possibility that a population of krill in the Bellingshausen Sea continually releases larvae and adolescents that seed the East Wind Drift. During the course of successive generations this process is continued around the continent (see section on zooplankton in this paper). Such a theory although possible with water circulation pattern may not seem very likely in view of the known higher density of krill at the end of the cycle (Weddell Sea). However, this could be explained by the Weddell Zone itself being a self maintaining system as described above. Marr also mentions the possibility that larvae could be carried from the Weddell to the Bellingshausen Sea via the Bransfield Strait. Although there is no evidence for a water movement the full distance, there is evidence that water does enter the Bransfield Strait from the Weddell Sea (Clowes 1934). It has also been suggested (Everson 1976) that the Bransfield Strait itself might contain a self maintaining system.

The only area containing large concentrations of krill that has not so far been considered in this review is South Georgia. This has been considered as an area in which there is no successful spawning (Marr 1962) and as a result it is suggested that the krill population there has its origins in other regions. Because Weddell Sea water has been considered to flow along the northeast coast of the island (Deacon 1937) and also because the Southern Scotia Sea has been shown to contain large concentrations of krill the Weddell Sea is often considered as being the origin of most of the South Georgia Krill (Marr 1962). Recent research has suggested that the frontal zone between Weddell Drift and West Wind Drift now passes well to the south of South Georgia (Bogdanov *et al.* 1969, see also section on Hydrography in this paper). Under normal conditions therefore it would seem unlikely that Weddell Drift krill could be carried to South Georgia. Bogdanov and Solyanik (1970) in an attempt to explain how Weddell Drift krill could get to South Georgia show a good correlation between whale catches and the mean annual air temperature at South Georgia and Laurie Islands (South Orkneys). They suggest that Weddell Drift surface water is carried to South Georgia as a result of wind action on the surface. Unfortunately the cold years (which should have produced largest krill concentrations and thus whales) were linked to low whale catches. Maslennikov (1972) considers that krill concentrations in the vicinity of South Georgia are present in the boundary region between a north westerly flowing coastal current and a south easterly flowing current further offshore. In years when this circulation pattern is ill defined, commercial krill catches have been poor (Maslennikov *et al.* 1971). The impression is given in their paper that the water in this area is from the Antarctic circumpolar current and that Weddell surface water is mixed in the manner described by Bogdanov and Solyanik (1970). It has also been suggested that the South Georgia Krill have their origins in the Bransfield Strait or Bellingshausen Sea area (discussed by Everson 1976) although there is only circumstantial evidence to support this idea.

It is an interesting point regarding all of the proposed theories of distributional control that they all rely on fairly precise limitation in timing of development and flow of water masses. This is in complete contrast to the mechanisms of distributional control proposed for other members of the macroplankton which in general rely on the southerly movement of the warm deep water and northerly movement of the surface water. (Mackintosh 1937, Foxton 1956, Voronina 1968). For a mechanism such as this to be applied to krill it is clearly necessary to prove the existence of a seasonal vertical migration. Recent evidence has shown the existence of significant concentrations of krill down to 400m although as yet there is no year round coverage of observations to suggest that a seasonal pattern of vertical migration exists.

Mention has already been made of the possibility that krill could feed in deeper water on detritus. The fact that the main lipid store is not waxes (Bottino 1974), indicating continuous feeding (Sargeant 1975), would require the krill to be in deeper water during the winter. (With almost zero primary production in the surface water in winter the only food at that time is likely to be detritus at greater depth).

Clearly there is a need for more research to identify which of these mechanisms are of major importance in maintaining the enormous standing stocks of krill.

6.3 Growth and Life Span

Several authors have published curves of size at age for E. superba (e.g., Ruud 1932, Bargmann 1945, Marr 1962) (Fig 6.5) which indicate a seasonal pattern of growth during a two year life span to a maximum size of about 6 cm. More recently Mackintosh (1972) has produced curves of "local apparent growth" based on the catches from specific regions. His analysis does not include a consideration of the origin of the krill at a given location but relies purely on the size of individuals at the time and place of capture.

The simple two year life span has been questioned by several authors (Marr 1962, Ivanov 1970, Makarov 1971, Mackintosh 1972) who were all working from information from size frequency distributions. Recently Makarov (1975) has demonstrated the ability of female E. superba to spawn more than once thus indicating a longer life span than two years.

Marr (1962) because of the presence of a few specimens of abnormal size in his samples suggested that under certain conditions full sexual maturity and spawning may be delayed until the third year. This phenomenon has been reported in the related E. triacantha (Baker 1959). The degree to which the odd size group was present in Marr's samples was very small indeed. However, Ivanov (1970) with a much smaller number of samples detected an intermediate size group in a large proportion of samples from the Scotia Sea. He discussed this in detail and concluded that the intermediate size group represented an additional year class.

At the moment there is insufficient evidence available to conclusively prove that this intermediate size group does not represent an additional year class. Relevant information for both points of view will therefore be considered.

At the same time that Ivanov was preparing his results Mackintosh (1972) was in the process of reanalysing in detail the Discovery material. As a result of his analyses he showed the presence of an intermediate size class in most of the areas of dense distribution. For those areas where there are sufficient samples Mackintosh has drawn an expected growth curve which shows the intermediate group as being midway between the previously accepted first and second year groups. Mackintosh argues that since the previously accepted one and two year classes follow on in a smooth curve with fast growth in spring and slow growth in winter, the cause of the intermediate size group must be something other than an additional year in the normal life history. On the assumption that the intermediate size group is real and not an artefact of sampling, Mackintosh considers the possibility of an early or late spawning producing the effect. On balance he favours the theory that the intermediate group results from a second spawning later in the year (perhaps in May) but it should be emphasized that this conclusion is based on extrapolation from the start of the intermediate growth curve back for over a year. Makarov (1975, 1976) has shown that a significant proportion of the population spawn more than once, first time spawners release their eggs during the later part of the summer and second time spawners in the early part of the summer. The release of eggs at more than one time during the season of maximum primary production (and therefore growth) is likely to produce considerable blurring of the peaks in any size frequency distribution. Compared to E. triacantha the size frequency distributions for E. superba show relatively indistinct peaks (see Baker 1959, Marr 1962, Bargmann 1945, Ivanov 1970, etc.).

Mackintosh (1972) detected a correlation between the presence of the intermediate group and an above average temperature in the preceding half year (but not earlier). Although it is unlikely that a warmer year would cause a second spawning, it is possible that a warm year could result in a greater disparity in the growth of larvae resulting from spawnings at different times in the production season.

Makarov (1971) in a paper that also considers the conclusions of Ivanov (1970) is of the opinion that the extra size group does not represent an extra year class, but is a result of the mixing of krill from different sources. This suggestion is supported by the fact that the Bransfield Strait and South Georgia, areas of possible mixing, show the phenomenon quite frequently. Against the idea is the fact that the East Wind Drift zone also contains an

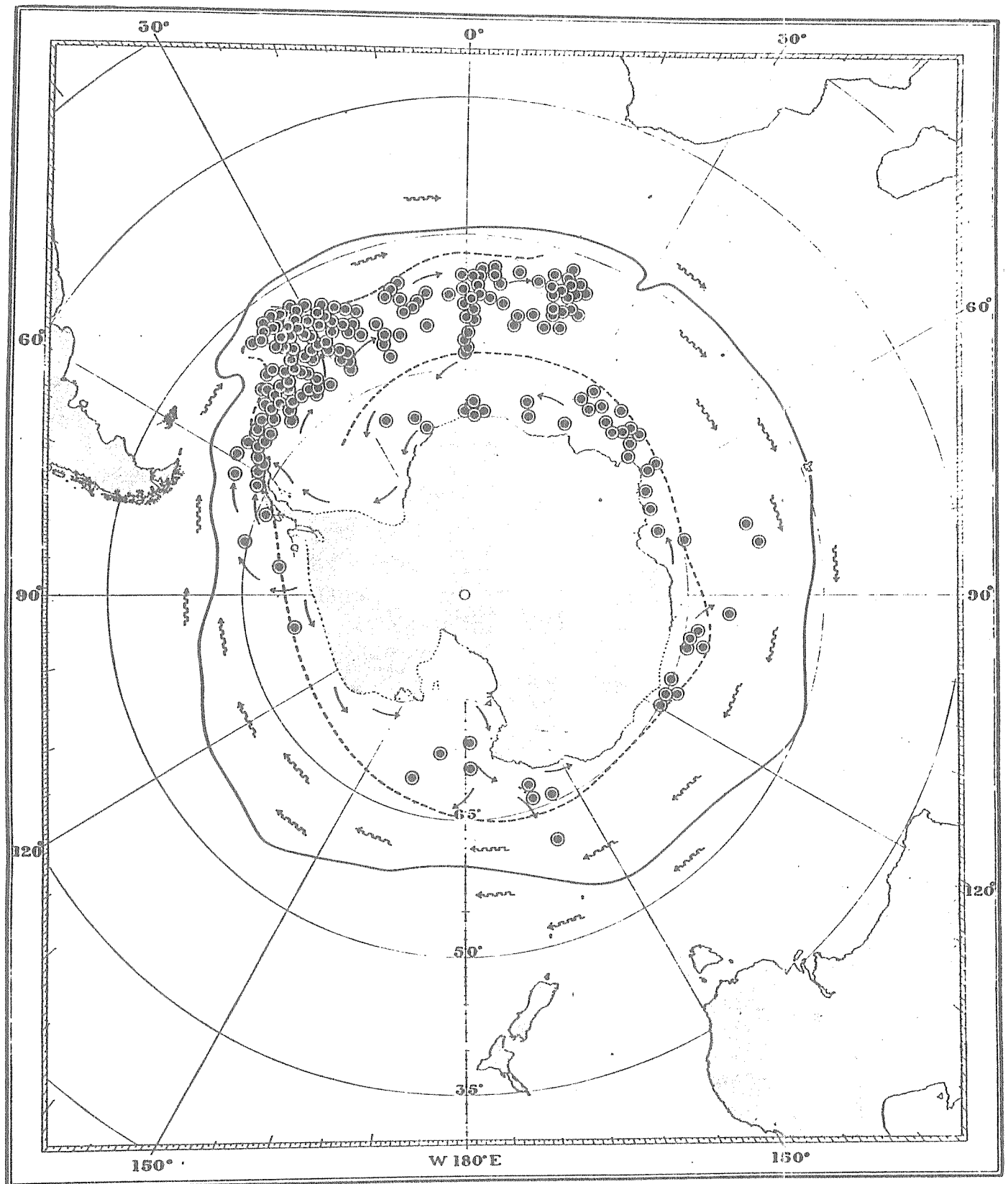


Fig. 6.4 Principal concentrations of the Antarctic krill (Marr 1962).

Sea (Hodgson 1902, Marr 1962) and the Kerguelen Gaussberg Ridge area (Nemoto 1968) a region poorly sampled by Discovery Investigations (16 stations total from November to April).

The catches by commercial type operations indicate a distribution very similar to that described by Marr (1962) on the basis of plankton net samples (his Fig. 5 and 6). (see Figure 6.4). The limited number of large catches in the West Wind Drift zone can be attributed to one of two factors. Either krill in this zone do not tend to swarm and although present in large quantities do not occur in dense concentrations or their total quantity in the region is lower. Mackintosh (1973) suggests that krill concentrations in Indian Ocean sector of the West Wind Drift are progressively grazed down by the whales as they migrate south. It is not however clear whether the whale migration south is maintained because of food requirements.

Theories of distribution control

There are in the literature a wide variety of theories which attempt to explain the reasons for the occurrence of the various life stages around the Antarctic continent. None of these theories is totally proven. The more plausible will therefore be considered along with the major evidence that is available in support and against.

Perhaps the simplest explanation is that throughout their life history krill remain more or less in the same location (Marr 1962). Mackintosh (1972) quotes an average surface flow rate in the West Wind and Weddell Drifts of 18 cm/sec. which is within the range of swimming speeds determined by Semenov (1969) for adolescent and adult krill. Although it is not known for how long krill could maintain this speed Marr (1962, p. 155) quotes from some notes made by E. R. Gunther who observed a swarm of krill swimming against an estimated $\frac{1}{3}$ knot current for several hours. It is also possible for krill to be maintained in more or less the same locality by migrating between the warm deep water and surface water (they are known to occur in significant numbers down to 400 m (Shevtsov and Makarov 1969)) although Fischer (1976) has suggested that such a temperature discontinuity may represent a physical barrier. The eddying effect around islands and submarine rises could also, as suggested by Makarov (1972) and Khvatskiy (1972) hold krill in an area for a prolonged period.

The remaining theories require that the krill are carried in a wide circulation pattern and the most frequently considered area from this point of view has been the Weddell Sea. Ruud (1932) basing his ideas on the circulation pattern of Meyer (1923) suggests that some larvae and adults get carried back to the high latitudes in the surface stream. Marr (1962) whilst agreeing that there is an undoubted circulation pattern of this type believes that the circulation involves an area far further east and that in addition in order to complete the cycle the larvae would need to be carried south in the intermediate water during the developmental ascent. The easterly spreading of early larvae in the surface waters is clearly shown in Marr's distribution maps (Fig. 64 onwards) which gives considerable weight to the greater part of this circulation theory.

Makarov (1972) using recent information from the Scotia Sea has taken the theory still further and suggests that the main circulation pattern described above applies and the main stock is maintained by spawning in the vicinity of the South Orkney Islands. He suggests that the larvae are carried around the Weddell Sea in a clockwise direction to arrive back at the South Orkneys a year later. Some of these krill are carried around for a second year to spawn whilst the remainder drift out of this circulation pattern. This theory requires confirmation of the existence of the recurvature current (see Kumagori and Yanagawa 1958 and also Fraser 1936, p 165) and also a better understanding of total circulation in the Weddell Drift (see Deacon 1976).

In an extension of this cyclonic circulation theory Makarov (1972) has suggested that a similar system to that in the Weddell Zone could operate in the Ross Sea and Kerguelen Gaussberg ridge areas. Treshnikov (1971) describes six cyclonic gyres produced by prevailing cyclonic winds in coastal regions around the continent. These may represent areas of krill concentration as suggested by Beklemishev (1960).

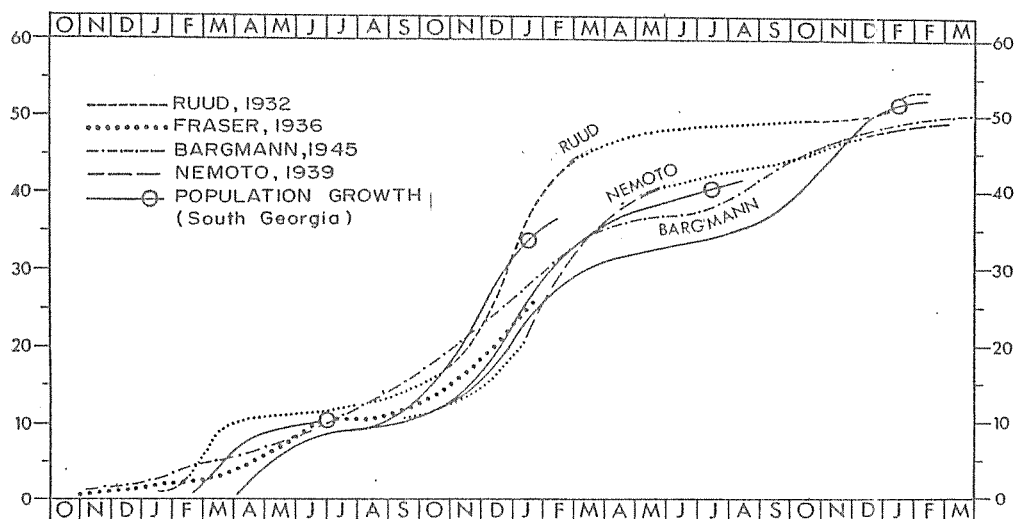


Fig.6.5 Published growth curves of krill (redrawn from Mackintosh (1972))

intermediate group, but on infrequent occasions and since the East Wind Drift has the slowest growing krill of all areas, the mixing would have to be with krill growing more slowly even than these which is clearly impossible.

Evidence on growth rate by other methods is at present inconclusive. Mackintosh (1967) McWhinnie (1976) and Clarke (1976) maintained several individual adolescent and adult krill in experimental aquaria and studied growth over several moults. In all cases growth increment was very small although both authors consider that their experiments were not a true reflection of growth in the natural state. The slow growth rate indicated by these experiments may indicate a slow growth rate in the wild. However, more sophistication in experimentation will be needed before this approach can be considered as giving a definitive answer to the problem.

In an analysis of growth curves for a variety of euphausiids Mauchline and Fisher (1969) have calculated average daily growth rates. These are summarised in Table 6.1.

Table 6.1 Calculated daily growth increment for a variety of euphausiid crustacea (Mauchline and Fisher 1969)

| Species | Life Time (Days) | Growth Increment (mg/day) |
|--|---------------------|------------------------------|
| <i>Thysanopoda acutifrons</i> | 730 | 0.356 |
| <i>Euphausia triacantha</i> | 730 | 0.246 |
| <i>Meganyctiphanes norvegica</i> (Iceland) | 730 | 0.274 |
| (Clyde) | 730 | 0.427 |
| (Cadiz) | 365 | 0.383 |
| <i>Thysanoëssa raschii</i> | 730 | 0.155 |
| <i>T. inermis</i> (N.Iceland) | 1 095 | 0.132 |
| (S.Iceland) | 730 | 0.101 |
| <i>T. longicaudata</i> (Gulf Stream) | 365 | 0.032 |
| (Greenland) | 365 | 0.028 |
| <i>T. longipes</i> ♂ | 730 | 0.100 |
| ♀ | 730 | 0.141 |
| <i>E. superba</i> (Bargmann) ♂ | 730 | 0.849 |
| ♀ | 730 | 0.570 |
| (Ruud) | 730 | 0.808 |
| (Nemoto) | 730 | 1.340 |
| (Mauchline) | 730 | 0.822 |

The fact that the figures for *E. superba* are much higher than those for any of the other species may indicate that the lifespan used as the base (two years) is too short. A greater lifespan would reduce the daily growth increment to nearer the values for the other species.

A more detailed examination of the growth characteristics indicates that this high figure for daily growth increment may not be totally unexpected. In his analysis of growth in E. triacantha, Baker (1959) suggests that the larger size of E. superba is reached by a longer period of growth rather than by a faster average rate. Although at first sight this conclusion appears to be at variance with the calculated rates of Mauchline and Fisher, when considered in relation to season the similarities become apparent. The percentage increase in length during each month for the two species E. superba and E. triacantha has been plotted in Fig. 6.6 and the seasonal changes divided up into a series of growth stanzas leading to a first spawning. The changes occurring are tabulated in Table 6.2.

The difference in the spawning season of the two species means that by September or October, E. triacantha larvae are twice the length of E. superba larvae and it is only in the second growing season that E. superba become larger than E. triacantha. Bearing in mind that the E. superba were only present for the last part of the productive season stanza C is effectively the first production season that the young E. superba will experience. This is in effect the equivalent to stanza A for E. triacantha. Plotting growth during stanzas A and B for E. triacantha with those of E. superba for stanzas C and D (Fig. 6.7) show how similar growth is for the two species during this period.

Table 6.2. Subjective analysis of growth stanzas in Fig. 6.7 leading to a first spawning in E. superba and E. triacantha

| Growth Stanza | Season | Growth in | |
|---------------|--|---|---|
| | | <u>E. triacantha</u> | <u>E. superba</u> |
| A | Summer High primary production | Larvae present at start of season rapid growth throughout season | Larvae present at end of season |
| B | Winter Very little primary production | Slow growth rate | Slow growth rate |
| C | Summer High primary production | Moderate growth rate possibly due to development of gonads later | Fast growth rate throughout most of season |
| D | Winter Very little primary production | Slow growth rate leading to spawning at end of period | Slow growth rate |
| E | Summer High primary production | - | Slow growth. Build up to spawning condition |

Although providing some evidence in support of the originally published growth curves this evidence should not be considered conclusive for several reasons. Firstly although it might be expected that similar species should grow in a similar way this does not necessarily follow. Secondly, no account has been taken of growth by larvae resulting from the early (normal for E. triacantha) spawning in E. superba.

The information related to growth in E. superba is summarised in Table 6.3.

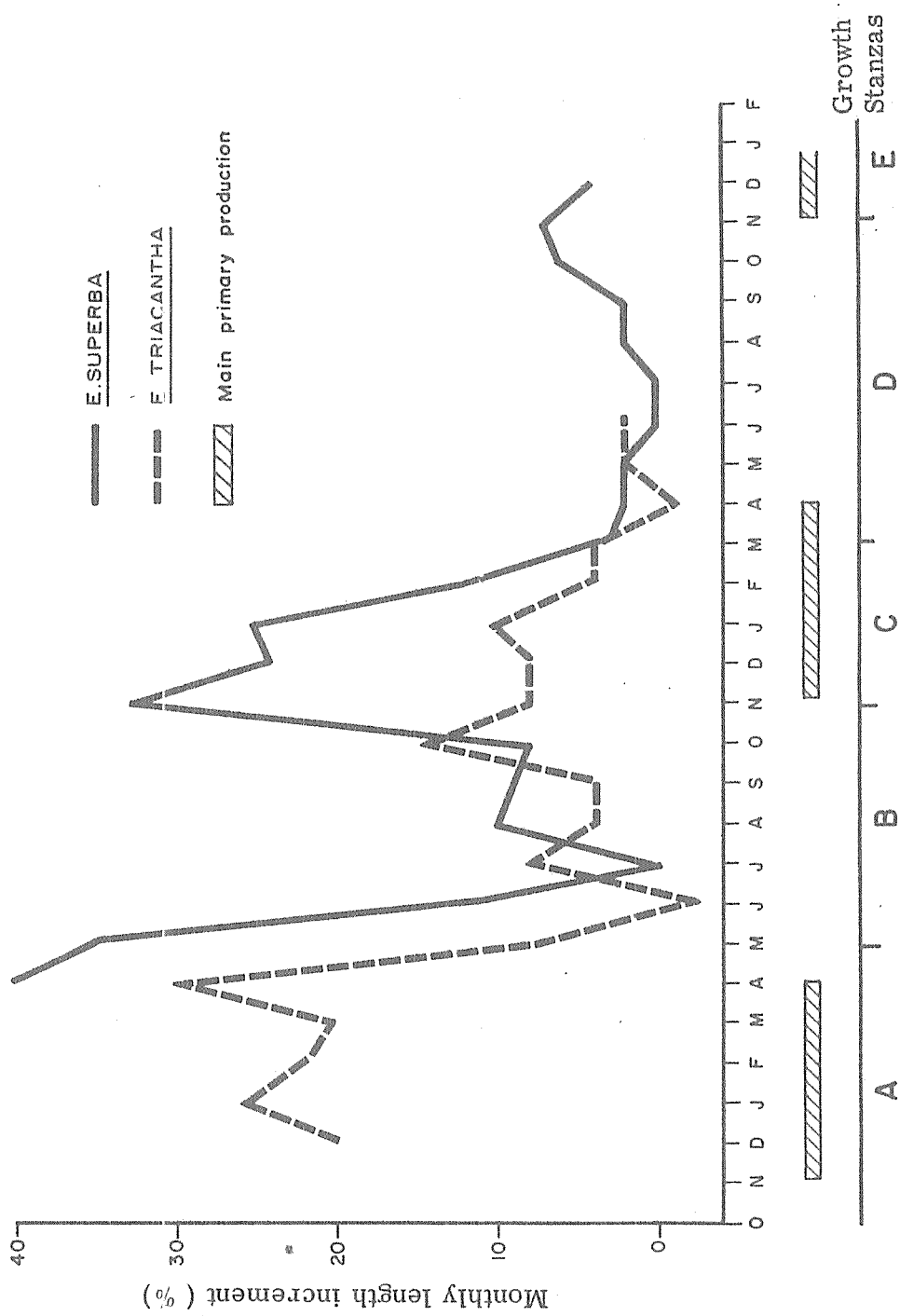


Fig.6.6 Seasonal growth of two species of euphausiid, related to the time of the main primary production. Growth is shown as the increment during the month, expressed as a percentage of the length in the previous month. Data for E.superba in the northern Weddell drift (from Mackintosh(1972)) and for E.triacantha(from Baker 1959))

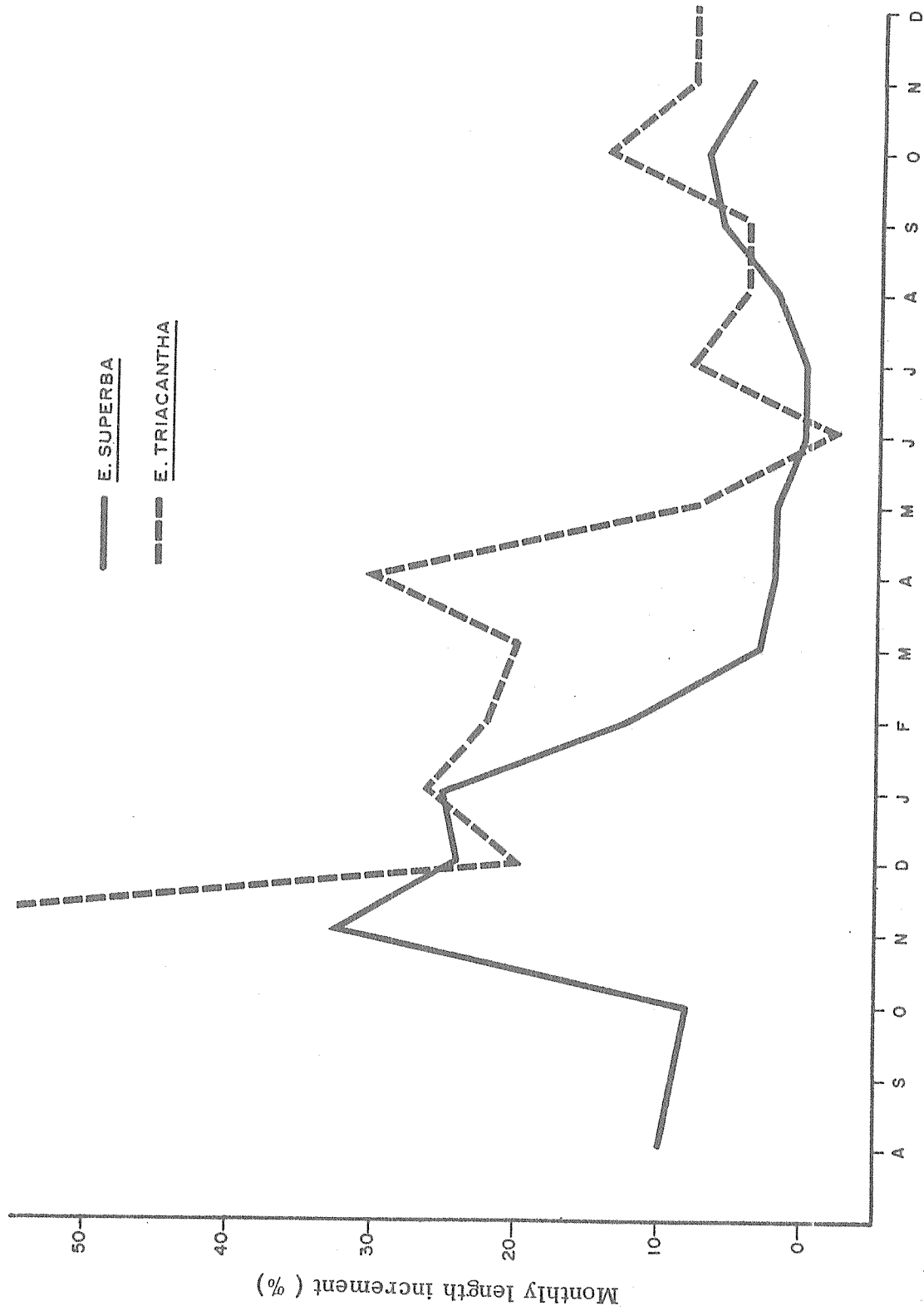


Fig.6.7 Comparison of growth in *E. superba* in the second season of growth with that of *E. triacantha* in the season of spawning

Table 6.3. Summary of information related to life span in Euphausia superba

| Observations | Evidence for 2 years to first spawning | Evidence for more than 2 years to first spawning |
|--|---|---|
| Size frequency analysis of Bargmann, etc. | "Smooth" curve | "Intermediate" size group |
| "Intermediate" size group | Does not fit anticipated smooth curve | Additional peak or peaks in many size frequency distributions in summer |
| Growth rate based on two years to first spawning | Summer growth pattern similar to <u>E. triacantha</u> | Overall growth rate appears high |
| Laboratory growth experiments | Probably not valid for "natural" conditions | Measured growth rate very slow |

Recent work (reviewed in the section on Reproduction) has shown that a significant proportion of the population spawn for a second time although the growth increment in this additional year is only small.

The information that is available although far from conclusive indicates that the growth pattern originally described by Ruud (1932) and Bargmann (1945) is probably correct. There is however considerable doubt about this and the possibility that the intermediate size group does represent an additional year class has neither been conclusively proved nor disproved.

6.4 Reproduction

A good general description of the reproductive biology of euphausiids is given by Mauchline and Fisher (1969), whilst detailed specific information covering the main aspects of reproductive biology is available in Bargmann (1937) and Fraser (1936). The topics of particular interest in this review are spawning season, fecundity and the phenomenon of repeated spawning.

Spawning season

It is now generally accepted that spawning by E. superba occurs at the surface (see Marr 1972, Fig. 30, Voronina 1974, Makarov 1974) during the summer months. In a brief review of published information on the precise spawning period Mackintosh (1972) suggests that it is at its peak in February and March although gravid and freshly spent females were found from November to April. In general he describes the spawning season as being earlier in the northern end of the range than nearer the continent and gives the following "best estimates" of mean hatching and spawning dates (Table 6.4).

The dates (Table 6.4) were calculated to provide the origins of growth curves from the different regions and are estimates based on the known spawning dates in the Weddell and East Wind Drift zones. Thus, although they are presented within fairly broad limits and are subject to local annual variation, they are useful at this stage as a first approximation.

Table 6.4. (From Mackintosh 1972) Mean dates for major spawning and hatching of E. superba

| Locality | Spawning date | Hatching date |
|------------------------------------|---------------|---------------|
| South Georgia ^{1/} | 25 January | 3 February |
| Northern Weddell Drift | 31 January | 9 February |
| Scotia Sea | 20 February | 1 March |
| Central and Southern Weddell Drift | 5 March | 14 March |
| Bransfield Strait | 11 March | 20 March |
| East Wind Drift | 20 March | 29 March |

Working on samples collected in the vicinity of the South Orkney Islands (equivalent to Mackintosh's Scotia Sea area) Makarov (1973) describes spawning as occurring at the end of February and that the timing of the peak is very much dependent on temperature. In warm years he suggests the sea ice clears earlier thus allowing an earlier start to the growing season with a resultant earlier spawning.

The main purpose of Mackintosh's analysis of spawning date was aimed at providing an origin for the growth curves for results from different areas. He was therefore only concerned with the mean date of spawning and took little account of the several month variation in the observed dates on which eggs were found. Marr (1962) in considering the overall spawning season in the northern or Weddell zone did not consider spawning as a short-term outburst, as had been suggested by Ruud (1932), but suggested it occurred over the period November to March. The recent work of Makarov (1975, 1976) has indicated that individuals spawning for the first time do so late in the season (February, March) whilst those which live for a further year spawn for a second time during the November, December, January period. The release of eggs during most months of the production season will almost certainly result in a broad size frequency distribution for each year class (if year classes can be identified). This in turn could also result in the production of an intermediate size group (see section on growth) as has already been discussed. Clearly it is only when definitive spawning periods in given locations are identified and the development of the subsequent size groups are followed that it will be possible to subdivide the broad size frequency distributions and thus help in unravelling the growth story.

The information reviewed by Mauchline and Fisher (1969) indicates that euphausiids generally spawn in the spring or early summer and that by spawning at the end of the summer E. superba is an exception. It is however possible that originally the spring breeding season now identified by Makarov may have been the norm and that the late summer spawning has only recently evolved. No matter what the sequence of evolution it is probable that the two spawning periods represent a fail safe device in maintaining a high biomass.

Fecundity

Estimates of fecundity are few and include a wide range of values as a result of different techniques in estimation. These are reviewed by Mauchline and Fisher (1969) who consider

^{1/} (N.B. There is very little evidence of successful spawning in the vicinity of South Georgia).

that for euphausiids in general the best estimation technique is that based on the calculated number of eggs whose volume is equal to half the mature ovary and that the ripe ovary occupies about 10% of the body volume. Makarov (1975) states that the eggs released amount to 34-39% of the body weight in *E. superba* which, assuming that weight is proportional to volume and that eggs have a volume of 1×10^{-4} ml, indicates a very much higher fecundity. This estimate is in closer agreement with the results of Naumov (1962) who counted ripening eggs present in the ovary. The estimates are compared in Table 6.5. The figure of over 11 000 determined by Bargmann (1937) is probably an estimate of all the eggs at all stages present in the ovary rather than an estimate of the number that would actually be released. This figure has therefore not been included in the tabulated results.

Table 6.5. Fecundity of *Euphausia superba*. Data from Mauchline and Fisher (1969), Makarov (1975), Naumov (1962) and Nemoto *et al* (in press).

| Body Length mm | Body Volume | | No. of eggs (1×10^{-4} m (each)) | | | |
|-------------------|-------------|-----|--|---|--------------------------------------|-----------------------|
| | ml | mg | Equal to 50% ovary Mauchline and Fisher | Equal to 34-39% Body Volume Makarov | | Counted Naumov |
| 36 | 0.62 | 851 | 310 | 2110-2420 | 3502(2222-7792) | 2362 |
| 38 | | | | | | 2655 |
| 40 | | | | | | 3007 |
| 41 | | | | | | 3590 |
| 43 | | | | | | 3520 |
| 43.5 | | | | | | 3320 |
| 44 | 1.0 | 851 | 800 | 3400-3900 5440-6240 | 7146(2482-14086) 8370(3889-13091) | 2960 |
| 45 | | | | | | 3480 |
| 46.7 | 1.6 | 927 | 800 | 3400-3900 5440-6240 | 7146(2482-14086) 8370(3889-13091) | |
| 50.3 | | | | | | |

It is not clear what is the reason for the enormous variation in the estimated values of fecundity. The egg size noted by Naumov (1962) in the ovaries of the individuals he examined would indicate that the eggs released represent nearly 60% of the body volume. The release of such a large proportion of the body volume as eggs just prior to the winter season seems unlikely if the same individual is going to spawn a second time in the following spring. On the other hand the general figures derived by Mauchline and Fisher (1969), as they point out, are not always correct and in this context it may be that *E. superba* is an exception. There is therefore a clear need to identify what proportion of the eggs present in the ovary are released and also to generally improve the refinement of these estimations.

6.5. Swarming

The habit of *E. superba* of forming dense aggregations has been well known for a long time and because of the concentration of individuals within the swarms they are often thought of as ideal for exploitation. What is not clear however is the proportion of the total krill population that is present in the swarms nor the absolute density. The former point is vital to resource management and the latter to rational fishing.

In this context a swarm can be defined as a dense aggregation of individuals moving harmoniously and is probably the type of aggregation that will give a strong indication on an echosounder. A swarm may therefore be considered as the extreme case in terms of co-ordinated movement of individuals in a group. The other extreme would be independently random movements by individuals. Between these two extremes there almost certainly exist concentrations that are intermediate in terms of aggregation and organization.

Swarming has already been discussed briefly in the section on zooplankton where it was suggested that swarming was a result of some social behaviour pattern (as yet unidentified) working in areas of high average concentration (such as discussed in the section on krill distribution). The section which follows is a review of information on swarm formation and disintegration.

Marr (1962) concluded on the basis of analysis of plankton net samples that from hatching onwards the number of krill outside of swarms was negligible. Although Marr was well aware of the maximum density krill attained when swarming his definition of a swarm was not nearly as restricted as that given above.

Other authors have been more evasive on the point only mentioning swarms without making any firm comment on the proportion of the total population present in swarms. The observations of Pavlov (1969) and Shust (1969) indicate that swarming is a transient phenomenon related to food availability. These observations were based on the state of the gut in freshly caught animals, a method also used by Nemoto (1968). According to Pavlov when phytoplankton is abundant the krill spend part of the day actively feeding in the surface water until they are replete at which time they aggregate into swarms and sink. In one region in which Pavlov made his observations this cycle occurred twice in 24 hours. The cycle of swarming and dispersion was repeated in other areas although without vertical migration; Pavlov attributes this difference to one of size; adolescent krill, he suggests, migrate vertically whereas adult krill do not. Shevtsov and Makarov (1969), however, note that in the course of vertical migration the adult krill tended to be deeper and in fact on occasions formed a separate layer (detected by echosounder) beneath the adolescent krill; they make no comment on the causes of swarming.

Nakamura (1973) identified several types of krill aggregation and related their presence and formation to light intensity. He found the densest swarms at the surface on the darkest nights and when the light intensity increased the density decreased as the animals migrated down. The commonest pattern of aggregation that he identified was a layer generally within the range 30 to 100 m depth or about 20 m above the thermocline. The results of Ozawa *et al.* (1968) conflict with these observations and indicate surface aggregations in daytime; they were however a result solely of visual observations. Shust (1969) considered that the level of illumination (cloudiness) of the environmental factors he measured (wind, sea state, atmospheric pressure) was the most important although he considered feeding also to be of major importance.

The suggestions of Ruud (1932), Beklemishev (1960) and Bogdanov (1974) that turbulence and eddy currents are responsible for the formation of swarms is probably not valid on the above definition of a swarm but more likely applies to the formation of high average abundance. Marr (1962) and Naumov (1962a) suggested that some swarms were in part spawning concentrations. Although there does not appear to be any conclusive evidence (no catches have knowingly been made of krill in the act of spawning) Makarov (1973) has shown the presence of concentrations of ripe individuals during the spawning period; he does not, however, describe the concentrations as swarms as defined above. It has also been suggested that swarming is a result of increased buoyancy due to the increase in lipid content during the summer (Burukovskii 1967). Presumably this would be expected to have the effect of concentrating the krill into Langmuir cells as described by Stavn (1971) for *Daphnia* although there is no evidence to suggest that for krill this does in fact occur.

The major factors that have been positively identified as being associated with swarming are therefore light and feeding activity. Reactions of planktonic animals to light have been well documented by Cushing (1951), Stassenko (1967) and Burukovskii (1967) describe krill being attracted to a red light source but moving away from a strong white light source while Ivanov (1969) has drawn attention to the luminescence of krill in swarms. Further information is clearly needed to identify a possible wide variety of reactions by krill to light.

The suggestion by Pavlov (1969) that krill swarm as part of a feeding cycle implies dependence to a great extent on food availability - the more food that is available the more rapidly the animals become replete and swarm. As mentioned earlier a direct result would be that swarms would tend to appear during the early summer and be most frequent in abundance during the summer peak of primary production. Hardy and Gunther (1935) showed that in the South Georgia area the densest concentrations of phytoplankton were not coincident with the largest concentrations of krill (or other zooplankton) (see Table 4.1).

This general pattern is confirmed by Avilov *et al.* (1969) who found the largest concentrations of krill in areas of the Scotia Sea where the mean biomass of phytoplankton was $1-5 \text{ ml/m}^3$. In areas where the mean biomass of phytoplankton was less than 0.5 ml/m^3 or more than 5 ml/m^3 they found few krill concentrations. This observation is not confirmed by Shust (1969) who reports numerous krill swarms in areas where the phytoplankton density varied from 0.1 to 8 ml/m^3 . He does however relate duration and size of swarm to phytoplankton standing crop - swarms persisting longer in areas of high phytoplankton standing crop. It is possible that the inverse relationship reported by Hardy and Gunther (1935) and Avilov *et al.* (1969) is due to grazing effect whereby there is a time lag before the herbivores eat down the phytoplankton (Cushing *et al.* 1963 and Cushing 1975). The direct relationship in that case would be expected during the initial phytoplankton bloom in areas where overwintering herbivorous zooplankton concentrations occur. Although this explanation is not proven in this instance, it does fit the facts and therefore indicates that studies investigating this interaction, and thus by implication other factors that might control krill microdistribution, should take account of short-term changes.

Swarm Size

Estimates of swarm size have been made by both visual observation and analysis of echosounder records. Marr (1962) published a series of drawings of the horizontal outline of several swarms that were observed near to the surface. These swarms were all quite amorphous in shape and varied in size from a few to several hundred metres across and were continually changing shape in an amoeboid fashion. Nemoto *et al.* (in press) describe surface swarms as being generally round or oval in shape and that some changed shape as a result of wind stress becoming more oval with the greatest axis at right angles to the wind direction.

A comparison of swarm size between areas is made by Nemoto *et al.* (in press) who considered that swarms in the Scotia Sea area were on average smaller than those in the Queen Maud Land area.

In the vertical plane swarm size has been mapped using echosounders. Certain of the small swarms are so dense that it is impossible to define the vertical size. However, where density within the swarm is lower, authors have mapped the vertical distribution and size of swarms. In an analysis of this type, Shevtsov and Makarov (1969) describe various patterns in the changing shape of swarms observed in the Scotia Sea. From their observations it appears that there are a few common patterns throughout the area. The following types of vertical movement and configuration are described in Table 6.6.

Formation of two layers (Table 6.6) during the day and amalgamation at night with a tendency for adult krill to be at the deeper levels seem fairly standard. A much greater vertical movement was observed by Mohr (1976) who, using an echosounder, followed a concentration of krill in the vicinity of the South Sandwich Islands for 6 days in April 1976. At midnight the krill were massed in the top 20 m but by 0600 hours they had migrated to a depth of 70 - 110 m, to slowly migrate back to the surface during the following 10 to 12 hours. Since all these observations were made in a fairly brief period of time during one season, more information will be required to amplify these observations and conclusions.

Table 6.6 Information on the vertical range of krill swarms
(From information in Shevtsov and Makarov)

| Locality | Depth Range (m) of: | | | | Composition and other comment |
|--------------------------------|---------------------|---------|-------------|-------|---|
| | Upper layer | | Lower layer | | |
| | Day | Night | Day | Night | |
| | | | | | |
| Northern Weddell Sea | | | | | 2 Layers day time; one layer night, nearer surface. More adults with increasing depth |
| Northeast of S. Orkneys (a) | 10-30 | | 30-60 | | One layer at night. Catch mainly adults. |
| (b) | 15-30 | (10-40) | 40-70 | | One layer at night. Mainly juveniles near surface. Mainly adults at depth (200-400 m). |
| S. Orkney S. Sandwich | 10-15 | 10-15 | | | Mostly juveniles |
| West of Sandwich | 10-20 | 20-45 | 40-80 | | Surface swarms also. Few mature krill. |
| N.E. of South Georgia | 15-40 | | 50-100 | | Few adults |
| S.W. of South Georgia | 40-60 | | 40-60 | | Few adults, no vertical migration. |

Swarm density

Several authors have published estimates of the density in terms of number and weight of krill within swarms. These are summarised in Table 6.7.

Most of the estimates (Table 6.7) of swarm density were made by means of acoustic fish-finders in conjunction with actual catches. There are clearly several sources of possible error in this type of estimation. Although the echosounder may give some indication of the vertical extent of the swarm it will give no indication of its lateral size; also, it is often difficult to confirm that a particular acoustic indication resulted in a particular catch.

The two estimates given by Marr (1962) are based on separate observations. The figure of one per cubic inch is based on the density estimated by an observer looking vertically down into a swarm from above. The figure of one per eight cubic inches was calculated from a single lateral haul in a large swarm (the net was towed for 36 sec at 1½ kt through the swarm). Assuming a mean weight of one gramme per individual, this represents a density of about 6kg/m³.

Table 6.7 Estimates of krill density in swarms

| Density | | Reference |
|--|--|--|
| Numerical | By Weight | |
| 1 per in. ³ 1 per 8 in. ³ | | Marr 1962 |
| | 10 - 16 kg/m ³ up to 15 kg/m ³ or more | Moiseev 1970 Makarov <u>et al.</u> 1970 |
| | generally up to 5 kg/m ³ max. 6-33 kg/m ³ | Nemoto and Nasu 1975 |
| 2000 - 8000/m ³ * Max. 40 000/m ³ | mean 1.5 kg/m ³ | Nemoto <u>et al.</u> (in press) |

* Absolute range 521-49,153

As a first approximation therefore the acoustic estimates largely confirm those from plankton hauls. From the point of undertaking fishing operations it is clearly possible to detect krill concentrations using echosounders. The magnitude of any diurnal vertical movement is likely to be of little consequence in catching technique. However, greater sophistication is required to quantify echo sounder indications in order to use them for estimation of standing stock or as "ground truth" for estimation by satellite imagery.

6.6 Food and Feeding

An extensive study of the food organisms found in the stomachs of a large sample of Euphausia superba was made by Barkley (1940). The species list that he gives is largely confirmed by the observations of Hart (both lists are discussed at length by Marr 1962, pp. 172-176). While there are local differences in the occurrence of the various species (see also Hustedt 1958, Nemoto 1968, Kawamura, in press) the diatoms clearly predominate from these analyses. The preponderance of diatom remains is generally thought to result from the relative indigestibility of the siliceous frustules and therefore probably does not represent the true situation (see discussions by Marr 1962 and Mauchline and Fisher 1969) and although the feeding appendages are adapted to a herbivorous diet it seems clear that, when necessary, representatives of other groups can be taken. Mauchline and Fisher (1969) list the following groups as being represented in the diet:-

Algae, Diatoms, Dinoflagellates, Tintinnids, Radiolarians, Foraminifera and Crustacea.

In addition, Pavlov (1971) increases the list to include detritus and in extreme cases cannibalism. As already mentioned with regard to distribution detritus may well represent a major part of the diet in winter although there are no results to confirm this.

The only information available on diurnal feeding cycles is that of Pavlov (1969) who related the occurrence of swarms, feeding and food availability, (see section 6.5). It is not however clear to what extent these results are typical of the Southern Ocean as a whole or how they vary seasonally. Since the presence of certain diatoms in the guts of krill can have adverse effect on the quality of products made from them there is clearly a need for more study in this field.

6.7 Production and Biomass

The extreme variability in the density of krill caused mainly by its swarming habit has presented enormous problems in estimating biomass and production. There are quite a large number of papers giving estimates calculated both by direct and indirect means and these will be considered along with the major sources of error.

Based on visual observations from the deck of RRS William Scoresby and assuming a density of one individual per cubic inch in the top yard of the water column, Marr (1962) estimated a mean biomass of 2.5 g/m^2 for krill. In the same paper he recalculates the biomass using the results of Heyerdahl (1932) for mean weight and gets a figure of $29\text{--}28 \text{ g/m}^2$. The possible error in these estimates is enormous since the area under consideration is 500 yards on either side of the ship's track and swarms are assumed to be one yard deep. These rough calculations presented with great reserve, as Marr puts it, may be, he thinks, representative of the East Wind and Weddell Drift zones. Assuming that this area is about half that described by Mackintosh and Brown (1956) as south of the Antarctic convergence the total biomass is 521 million tons (based on $29\text{--}28 \text{ g/m}^2$) or 44.5 million tons (based on 2.5 g/m^2). Marr, basing his reasoning on the probable consumption of krill by whales is of the opinion that the higher figure is the more reasonable. This is the only direct estimate I have so far come across that is supported by calculation and yet even in this case the figures are presented within very broad limits since they are calculated by extrapolation from a relatively very small area that was at the time seen to be unusual.

In an analysis based on echosounder survey and fishing catches, Nemoto *et al.* (in press) have estimated standing stock as being from 0.5 kg/m^3 to 30 kg/m^3 although they do not indicate how these figures apply to the total Southern Ocean.

Makarov and Shevtsov (1972) quote a range of 953 to 1 350 million tons for the biomass of krill (abstract only seen) while Gulland (1970) estimated the total zooplankton biomass to be about 10 g dry weight per square metre or 150 million tons for the whole Antarctic and assumes that 50% of this is krill. Based on Gulland's estimates the krill biomass is therefore 75 million tons dry weight, or perhaps 750 million tons wet weight. The figure of 50% for the proportion of krill in the zooplankton is open to question as Voronina and Naumov (1968) found that Euphausiids made up only 7.6% of their zooplankton catches. However, since their nets may well have missed a significant proportion of the Euphausiid population this figure cannot be taken as firm even though it is based on a large number of observations.

To estimate production from these biomass figures, a conversion rate of 1:1 has been suggested (Gulland 1970, Hempel 1970) based on a mean life span of one year. Allen (1971) has questioned this ratio and by comparison with mortality rates in other Euphausiids (there being no information available for *E. superba*) he suggests that the production is between 1.8 and 2.1 times the biomass with the lower figure the more likely. On this basis the krill production is 940 million ton/year from Marr's figures and 1 350 million ton/year based on Gulland's figure.

Indirect estimates of biomass and production have been made based on both higher and lower trophic levels. First of all considering estimates based on primary production, Hempel (1970) quotes results from localities all round the Antarctic continent for annual carbon fixation of 43 g C/m^2 (Currie 1964), 84 g C/m^2 (El-Sayed 1967) and 100 g C/m^2 (Ryther 1963) and suggests that since the measurements tended to be in the richer areas a figure of 50 g C/m^2 is a reasonable approximation. Taking a conversion ratio of carbon to fresh weight

of 1:10 primary production is estimated as 10 000 million ton/year (Gulland 1970). There does not appear in the literature any firm figure for the conversion rate of phytoplankton by Euphausiids although a 10% figure has been used (Gulland 1970). Chekunova and Rynkova (1974) estimate that in growing to 1.5 g an individual consumes 60 g of phytoplankton. This gives a conversion ratio of 1:40, but since this is an average figure for an individual to achieve a maximum size the mean population figure may well be nearer the 1:10 ratio generally used ^{1/}. On the basis that krill represents between 10 and 50% of the total herbivorous zooplankton, the production figures calculated are given below:

| | | Conversion Ratio Phytoplankton: Krill | |
|--|-----|---------------------------------------|------|
| | | 1:10 | 1:40 |
| Krill as Proportion of Herbivorous zooplankton | 50% | 500 | 125 |
| | 10% | 100 | 25 |

Estimates of krill production (millions of tons per annum) calculated on the basis of total primary production of 10 000 million ton per annum.

Calculations of the amount of krill eaten by whales have been made by several authors and more recently the same calculation has been made based on the estimated initial whale stocks to give an estimate of "surplus" krill.

Independent estimates of krill consumed by whales are given in Table 6.8.

Laws (in press) has also estimated the amount of krill consumed by Crabeater, Leopard, Ross and Fur Seals at 53 920 thousand tons each year of which about 99% is taken by the Crabeater Seal.

Estimates of krill consumption by birds have been made by Prévost (in press) and Croxall (pers. comm.). Both agree that the major consumer is the Adelie Penguin (*Pygoscelis adeliae*) which it is estimated takes about two-thirds of the 14.7 to 20.3 million tons total eaten by birds.

There are no estimates in the literature for krill consumption by other groups such as fish and squid although it is quite likely that either or both could be major consumers. Laws (in press) estimates that sperm whales consume annually 4.6 million tons of squid which, assuming they feed predominantly on krill and assuming a ten to one conversion ratio, would account for 46 million tons of krill. The same calculation applied to the estimates based on squid eaten by the total initial whale stocks would account for 102 million tons of krill per annum.

^{1/} In their paper Chekunova and Rynkova give a detailed breakdown of food consumed at monthly intervals during the lifespan. In the absence of realistic size frequency information it is not possible to produce a better conversion ratio.

Table 6.8 Estimates of Annual Consumption of Krill by Whales

| Author | Krill eaten by initial whale stock Ton x 10 ⁶ | Krill eaten by present whale stock Ton x 10 ⁶ | Potential "Surplus" Ton x 10 ⁶ |
|-------------------------|---|---|--|
| Marr (1962) | <u>38</u> | - | - |
| Studentskiy (1967) | - | 270 | - |
| Kasahara (1967) | | 24 - 36 (Fin Whale) | |
| Zenkovich (1970) | <u>150</u> | - | - |
| Mackintosh (1970) | <u>120 - 170</u> | (10)**** | <u>100 - 150</u> |
| Hempel (1970) | <u>45 - 60</u> | - | - |
| Gulland (1970) | >50 | - | - |
| Nemoto (1970)* | 77 | - | - |
| Doi (1973)** | 200 | - | - |
| Lyubimova et al. (1973) | (800 - 5000)*** | - | - |
| Ohmura | 250 | (40)**** | 100 - 200 |
| Laws (1977) | - | - | <u>153</u> |
| Laws (in press) | <u>190</u> | <u>43</u> | <u>147</u> |

Results where all the factors in the calculation have been given are underlined

* Cited by Nemoto and Nasu 1975 but reference not given

** Cited by Nemoto and Nasu 1975

*** May refer to total krill biomass

**** Calculated from his results

N.B. (There is a much longer list of references quoting krill consumption by whales but those seen are derived from those tabulated).

The total estimated production based on consumption by predators is summarized in Table 6.9.

Clearly, in spite of the enormous uncertainty attached to these estimates (Table 6.9) the total amount of krill consumed by predators is large, thus confirming the estimates by other methods.

Table 6.9. Estimated consumption of krill by major predators ^{1/}
(for detailed breakdown see relevant consumer section)

| | Estimated consumption of krill prior to whaling million ton/year | Estimated consumption now million ton/year |
|--------|--|--|
| Whales | 190 | 43 |
| Seals | (?) | 64 |
| Birds | (?) | 15 - 20 |
| Squid | (?) | (100 ?) |
| Fish | (?) | (?) |
| TOTAL | > 190 | > 200 |

6.8 Exploitation

Annual catch

Exploratory fishing for krill has been in progress now for several years. Solyanik (1960) obtained a small catch of krill using a small pelagic net from a whaling ship. Catches from the subsequent krill fishing expeditions are shown in tables 6.10, 6.11 and 6.12.

In addition to these exploratory fishing expeditions there are catches reported in FAO Yearbook of Fishery Statistics Vol. 40 (FAO 1976) that probably refer to krill ("Marine Crustacea, unspecified" taken from areas adjacent to the Fisheries Statistics Antarctic regions). These figures, together with actual krill catches recorded in the Yearbook, are set out in Table 6.13.

^{1/} A single estimate of standing stock of between 1.5 and 5 milliard tons is given by Bogdanov (1974). Since this figure was calculated on the basis of consumption by whales and other consumers it probably refers to production rather than biomass. Even allowing for the production/biomass factor proposed by Allen (1971) this figure is still enormous compared to all other estimates of the resource. In the same paper Bogdanov estimates the standing stock in the Southern Scotia Sea in 1967 as 5 million tons, half of which is in the zone of mixing between Weddell Sea and circumpolar water. Also, he estimates that at South Georgia the stock is 0.7 million tons. These estimates were made directly and although the precise method employed was not stated it was probably using echosounders and commercial catch data.

Table 6.10 Exploratory fishing by vessels of the USSR

| Vessels | Season | Catch (tons) | Reference |
|---------------------|--------|--------------------|--------------------------------|
| Muksun | 61/62 | 4 | Burukovskii and Yaragov (1967) |
| Muksun | 63/64 | (70) ^{1/} | Stasenko (1967) |
| Academik Knipovich) | | 185 | Nemoto and Nasu (1975) |
| Orehova, Obdorsk) | 64/65 | 121 | |
| Academik Knipovich | 66/67 | ? | |
| Academik Knipovich | 67/68 | >140 | Ivanov (1970) |

Table 6.11. Exploratory fishing by Japanese vessels

| Vessels | Season | Catch (tons) | Reference |
|---------------------|--------|--------------|------------------------|
| Chiyoda-Marui | 72/73 | 59 | Nemoto and Nasu (1975) |
| Taishin-Marui No.11 | 73/74 | 646 | Nemoto and Nasu (1975) |
| Taishin-Marui and | 74/75 | 1 140 | |
| Aso-Marui | | 1 460 | Anon (1976) |
| Exploratory Vessel) | 75/76 | | |
| Commercial Vessel) | | 5 000 | Anon (1976) |
| Planned Catch | 76/77 | (10 000) | Anon (1976) |

Table 6.12. Exploratory fishing by other nationalities

| Nationality of Expedition | Season | Catch (tons) | Reference |
|---------------------------|---------|--------------|-------------|
| Chile | 74/75 | 60 | Anon 1975 |
| | 75/76 | | |
| West Germany | 75/76 | 400 | Anon 1976 a |
| (2 vessels) | (77/78) | | |
| Poland | 75/76 | ? | Anon 1976 b |
| (2 vessels) | | | |
| Other Asian Countries | 76/77 | ? | Anon 1977 |
| Norway | 76/77 | Small | Anon 1977 a |

^{1/} The total catch in his tables is only 23 tons

Table 6.13. Catches of krill in area 58, and of unspecified Marine Crustacea by certain countries in areas 41, 47, 51, 57 and 87

metric tons

| Country \ Year | 1969/70 | 1970/71 | 1971/72 | 1972/73 | 1973/74 | 1974/75 |
|------------------------|---------|---------|---------|---------|---------|---------|
| <u>Krill</u> | | | | | | |
| Japan | - | - | - | - | 643 | 1081 |
| <u>U. Marine Crust</u> | | | | | | |
| USSR | 100 | 1300 | 2100 | 7400 | 4412 | 6965 |
| Chile | 1900 | 1200 | 4400 | 2600 | 821 | 821 |

In addition to these figures McWhinnie (1974) and El-Sayed (1975), estimate that a total of 200 000 tons of krill have been taken per season in recent years. This figure is not supported by further evidence and it probably refers to total landings of krill and fish (see section on fish exploitation).

From the foregoing it is evident that the present fishery, taking as it does about 20 000 tons per year, is still only having minimal effect on the resource. However, all of the nations presently involved in exploratory fishing are capable of mounting quite a considerable effort and thus increase the size of the fishery very quickly.

Catch Rates

Development of a fishery based on a novel resource means that exploratory fishing operations may well meet with only limited success initially. In the early stages there have been problems with detection as well as gear operation and although a critical review is outside the terms of reference for this paper information on the development of the fishery is set out in Table 6.14.

Although the figures of 10-12 ton/hr by "special midwater trawl" for the early stages of commercial fishing by USSR in the Scotia Sea (Lyubimova *et al.* 1973)^{1/} appear exaggerated, the evidence of the West German expedition suggests that catch rates of this order are now reasonable.

6.9 Stock Assessment

Some Theoretical Considerations

The build up in sophistication of fishing technique over the past few years clearly indicates the possibility that a large scale fishery could be established in a relatively short period of time. Detection and catching methods have now reached the point when an excess of material can be provided for currently available processing operations. The main obstacles to the expansion of the fishery now lie in product development and marketing and these are receiving increasing attention. Any of the nations currently involved in fishing for krill (USSR, Japan, Federal Republic of Germany, Poland, Chile) could either on their own or with outside help solve the processing and marketing problems and vastly increase their present catch so that a total catch of a million tons or more is a distinct possibility in the immediate future. Even allowing for the fact that this is a small figure in comparison to the estimated krill production, once fisheries of this size are established they tend rapidly to expand to their fullest capacity. Therefore even though it is not certain that the krill fishery will expand it is necessary to formulate a management plan now to enable the needs of conservation and capital investment to be fulfilled. There is clearly a need therefore for:

^{1/} See also Kryuchkova *et al.* 1971.

Table 6.14. Information on fishing activities for krill

| Vessel Nationality | Year | Gear | Catch Rate Ton / Haul | Detection Method | Notes | Reference |
|-------------------------------|-------|---------------------------------------|---|--------------------|--|--|
| Muksun (USSR) | 61/62 | MWT Side Trawl Conical Net " | 0.13 0.07 | Visual/ Random? | 3 Ton Total 150 kg/12 Hauls | Burukovskii & Yaragov 1967 Stasenko 1967 |
| | 63/64 | 31m MWT Side Trawl | 0.13 0.025-0.5 0.65 | Visual/ Random? | 107 Hauls Night (Max. hauls 0.75 t) Day (Max. catch 2.5 t average of all hauls 0.6 t) | Stasenko 1967 |
| Orechova Obdorsk (USSR) | 64/65 | 17.5 m | 0.7 | | Slightly higher catch rate when pair trawling | Nemoto & Nasu 1975 |
| Akad. Knipovich (USSR) | 64/65 | 31m MWT | 1.7 0.5 | E/Sounder | At surface Midwater | Groisman, <u>et al.</u> |
| | 67/68 | MWT | 2 | E/Sounder | Max. 7 t/haul | Ivanov 1970 |
| Chiyoda Maru | 72/73 | Side Trawl | 0.1 | Visual | 251 Hauls | Nemoto & Nasu |
| No.11 Taishin Maru (Japan) | 73/74 | 17.3 m MWT | 1 | | 691 Hauls | |
| | 74/75 | | 2.3 | E/Sounder | | Nasu (in press) |
| | 75/76 | | 4.6 | E/Sounder | | " " " |
| Weser. (German Fed. Rep) | 75/76 | MWT | 24.1 t/h 15.6 t/h 28.8 t/h 8.5 t/h | E/Sounder | 7 hauls N.E. of S.Georgia. East of S.Georgia (largest haul 35 t in 8 min). Between S.Orkney and S.Georgia N.W. of South Sandwich | Kock & Neudecker 1977 |
| | | | 2.5, 25 | E/Sounder | Two experimental deep hauls | Fischer 1976 |

Note: A purse seine has been tried by Japanese workers with very limited success (Nasu 1974)

- a. Sound scientific information on the state of krill stocks.
- b. Advice on the effect of exploitation on the stocks of krill and its consumers and prediction of anticipated changes as a result of different fishing strategies.
- c. International agreement on management plans resulting from a and b.
- d. Implementation of management plans.

The known reliance by most of the whales, seals and birds indicated in section 6.7 plus the probable reliance of a significant proportion of the fish and squid stocks on krill indicates that, as far as management decisions are concerned, krill cannot be considered in isolation. These interactions are discussed later in Chapter 10 in which the conclusions based on an assessment of each single resource are brought together. The remainder of this section will be concerned with stock assessment as related solely to krill.

A convenient, and often used, estimate for the maximum size to which a fishery should be permitted to develop is the maximum sustainable yield (MSY). This may be defined as the greatest constant amount of the resource that can be extracted annually (and therefore by implication be replaced at the same annual rate) in the long term. This does not mean that an aim of management is to achieve this level of exploitation, but rather to define an upper limit beyond which a long term fishery should not develop. In the case of krill because of the wide range of consumers in addition to man that are utilizing krill the fishery could not develop to the theoretical MSY without causing considerable imbalance in the ecosystem.

As a first approximation a "SCHAEFER" type model can probably be used. This requires information in two of three forms: catch, effort and biomass. Of these three the catch is the simplest to determine. Estimation of fishing effort presents several problems in deciding on a realistic index. The present trend in the fishery suggests that any major expansion will be as a pelagic trawl fishery. The fishing effort may be divided into a series of components each of different relative importance (Table 6.15).

Table 6.15. Major components of fishing effort in a trawl fishery for krill with their relative importance.

| Fishing Effort Component | Relative Importance |
|---|--|
| 1. <u>Gear</u> | |
| a) Size of net | Moderate importance, depends on engine power. |
| b) Gear saturation (includes saturation of handling capacity) | Likely problem since present evidence suggests catching capability may exceed processing capacity. |
| 2. <u>Vessel</u> | |
| a) Size | Low importance. Only relatively large vessels may be able to operate in Southern Ocean. |
| b) Power | Moderate importance since technique is essentially aimed trawling. |

Table 6.15 (continued)

| Fishing Effort Component | Relative Importance |
|-------------------------------|--|
| 3. <u>Fishing Time</u> | |
| a) Catching time | Low importance since catch more dependent on fish finding equipment. |
| b) Search time | Great importance due to extreme patchy nature of resource. |
| 4. <u>Fishermen</u> | |
| a) Skill | Moderate importance. |
| b) Within fleet communication | Moderate importance. |

Of these components probably the most useful as far as providing a reliable index of fishing effort are the power of the vessel combined with an indication of fishing time that takes account of "idle time" caused by gear/vessel saturation.

At the moment there is no well-established method of monitoring the changes in abundance of krill, in either relative or absolute terms, although suitable techniques are being developed. Since it is a member of the zooplankton, krill can be caught by specially designed quantitative nets such as the Rectangular Midwater Trawl with 8 square metre mouth (RMT 8) developed by the Institute of Oceanographic Sciences (U.K.) and used with success by the Federal Republic of Germany's Antarctic Expedition. This type of direct method is very time consuming and expensive in ship's time and is therefore not an efficient method of estimating standing stock over the whole region. Quantitative net hauls can be made to identify echosounder indications and thus form the basis of a remote sensing survey. The dense concentrations of krill when they occur near the surface may also be detected by satellite photographs. Both the remote sensing methods mentioned above rely on the occurrence of swarms and since these are almost certainly varying in occurrence, depth and density with season there is clearly a great deal of scope for biological investigations in this field.

The next stage in resource assessment will almost certainly be the design and application of an analytical model with the intention of adding increased precision to the estimates and predictions. The classical Beverton and Holt type model assumes constant recruitment and also that the level of natural mortality remains constant and independent of fishing intensity. For a short lived species such as krill it is very likely that there will be large year to year fluctuations in recruitment caused by both physical and biological variation. (There is no evidence to either prove or disprove this suggestion -- a situation that is likely to remain until some reliable estimates for standing stock are available.)

Natural mortality is, for convenience, generally assumed to be more or less constant and independent of fishing. However, for a short-lived animal (with possibly only one year class in the exploited population) in the centre of a food chain this assumption is almost certainly not valid.

Natural mortality can for convenience be attributed to two causes: consumption by predators and natural death direct to decomposers. The mortality due to predation can be further subdivided depending on whether a given stock of predators take a fixed quantity (so that the rate decreases as the prey stock increases) or exert a fixed rate of predation

(so that the quantity increases as the prey stock increases). These correspond, somewhat roughly, to predation by warm-blooded and cold-blooded predators respectively.

On the assumption that krill production is independent of fishing, the yield from a fishery will be largely at the expense of natural mortality as is indicated in equation (A) below:

$$\begin{aligned}\frac{dN}{dt} &= -ZN \\ &= -FN - C - M_c N - M_d N\end{aligned}\quad (A)$$

N = Population Size

Z = Coefficient of total mortality

F = Coefficient of mortality due to fishing

C = Consumption by warm blooded predators (N.B. dependent on consumer stock size.
Consumption/individual varying with consumer density)

M_c = Coefficient of mortality due to other predators

M_d = Coefficient of mortality leading directly to decomposers

Intuitively it is to be expected that fishing will first of all be at the expense of M_d and then reduce the proportion of M_c. Since C is for the most part dependent on the predator population size and the duration of the feeding season, this could be the least affected by fishing. Although this conclusion is tentative it does indicate the need for consideration of the effects of predators in a predictive model of a krill fishery.

Just as predation is an important factor in considering a krill fishery, it is equally important in studies of the predators themselves. This applies whether the predators themselves are likely to form the basis for a fishery (in which case the need for such an analysis is obvious) or not (in which case the information will be useful in understanding ecosystem dynamics). In order to gain some insight and begin to understand the interspecific interactions it is useful to consider the situation of an intensive krill fishery in one limited area. The effect that this fishery has on the krill consumers will depend on the size of the Unit Stock being fished. The hypothetical nature of much of the information on the control of krill distribution shows that at this stage it is impossible to define more than one management stock (Mackintosh 1973 indicates the possibility of there being several although the information is not conclusive) and, bearing in mind that there may exist several stocks it is worth considering the possible magnitude of any changes in relation to the stock size. On the assumption that fishing would be restricted to one defined area a few of the effects that it may be possible to quantify are listed in Table 6.16. The effects themselves are described in subjective terms because the effects may differ from area to area. For the purposes of the krill fishery these effects could indicate changes in the krill stocks which would thus add weight to conclusions based on direct observations. The changes in consumer stocks also form part of a much larger family of observations concerned with ecosystem modelling, a subject discussed in a later section.

Stock Assessment

Some Practical Considerations

The fragile nature of euphausiids means that any individuals which pass through the meshes of a trawl net are unlikely to survive so that irrespective of whether the krill

Table 6.16. Effects of an intensive krill fishery in one limited area.

| | One large 'Antarctic' Unit Stock | Several Unit Stocks defined by area. Fishing in one only |
|--|--|--|
| <p>Effect on Stock Assessment Parameters</p> <p>a) Growth</p> <p>b) Mortality</p> <p>c) Biomass</p> | <p>Small</p> <p>M - no change</p> <p>F - small</p> <p>Small</p> | <p>Probably small</p> <p>M - may change</p> <p>F - large</p> <p>Significant reduction subsequent to start of fishing</p> |
| <p>Effect on Natural Consumer</p> <p>1. Species linked closely to fishing area (e.g., Breeding Birds)</p> <p>a) Intensive fishing prior to critical predation period each season</p> <p>b) Intensive fishing during and after critical predation period</p> <p>2. Species not tied to fishing area (e.g., whales)</p> <p>a) Heavy fishing before normally present in area</p> <p>b) Heavy fishing during and after normal presence in area</p> | <p>Significant in fishing area, elsewhere minimal</p> <p>Small effect</p> <p>Small overall effect</p> <p>Zero or slight reduction in density</p> | <p>Significant. Increasing effect with time to eventually level off</p> <p>Significant in subsequent years</p> <p>Reduced density (i.e. feeding elsewhere)</p> <p>Slight reduction in short term</p> <p>Major reduction in long term</p> |

are retained by the net (or are of a size suitable for processing) none that enter the mouth of the net will survive. The effect of this is that unless trawls can be aimed at swarms containing individuals of the desired size the fishery will be totally unselective as regards size of krill caught. One of the objectives of management must clearly be to ensure that sufficient individuals spawn to maintain the population. This implies that the fishery should be based on the largest sized individuals in the population.

The presently developing fishery is largely based on fishing at swarms identified on echosounders. However at the moment it seems unlikely that the presently developed acoustic techniques can discriminate between large and small animals and unless there is shown to be a requirement for processing to only use large individuals it seems unlikely that sufficient funds will be channelled in this direction for developing the necessary technology. There may be behavioural characteristics of krill which segregate adult and adolescent concentrations; these would need to be identified by biological sampling in conjunction with the "learning processes" that fishing captains would inevitably go through. It may also be possible to regulate fishing to within areas that do not contribute to maintaining the population (it has been suggested that South Georgia is such an area).

Mention has already been made of the proposed use of remote sensing techniques for estimating the standing stock of krill. The method depends on the identification of swarms of krill either by satellite photography or acoustically and confirming the presence of krill by field sampling. The identification of indications as being krill swarms is a technological problem which can probably be solved. However, some caution should be exercised in the interpretation of the results.

Presently available information indicates that krill swarms are transient phenomena depending for their formation on a variety of external causes one of which is probably food availability. In addition it is not known what proportion of the krill population at any one time is present in swarms.

On the assumption that food availability is a factor leading to swarm formation (the more food, the more swarms) it is arguable that consumption of krill (whether by predation or fishing) would increase the amount of krill in swarms, because the decreased grazing by krill would tend to increase the relative food availability. The effect would be that observations on the abundance or density of krill in swarms would tend to underestimate the change in total krill abundance as the season progressed. In order to overcome this problem it is almost certainly necessary to gain information on the amount of krill not present in swarms in relation to season, the presence of swarms and food and also environmental characteristics.

6.10. Harvesting at higher trophic levels

Due to the supposed sensitivity of the Antarctic ecosystem it has been suggested that a safer method of harvesting krill might be by harvesting krill consumers (either natural or introduced) rather than krill. In this context natural consumers are generally considered synonymous with whales although it could equally well apply to seals, fish or squid. From the conservation viewpoint the utilization of krill via the whales has several points in its favour (e.g. exploitation of whales is now under international control, the catch limits are based on scientific information that, if not as reliable as might be wished, is at least much more reliable than that on krill, and the present resolve by conservation pressure groups in particular and scientists in general that overexploitation should not recur) which will buffer it against overexploitation. In the present situation it is more sensible to consider the feasibility from all points of view of exploiting both krill and its consumers and in this context the relative levels of exploitation would be considered in the context of a multispecies fishery (Horwood, 1976).

In a paper discussing the interactions between the North Sea fisheries for dogfish and herring (the herring being an important food organism of the dogfish) Gulland (1970a)

derived the general equation below comparing the relative merits in terms of value of harvesting the predator or prey species:

$$\sum_{i=1}^n V' E' K_i w_i > \sum_{i=1}^n V_i E_i \bar{w}_i$$

V, V' = Value per unit weight of prey and predators respectively

E, E' = Exploitation rate of prey and predators respectively

K = Conversion ratio prey to predator

w, \bar{w} = Mean weight of individual items eaten and in the catches respectively

The summation is over all prey species.

In the form that the equation is written here the greatest value would result from harvesting the predator.

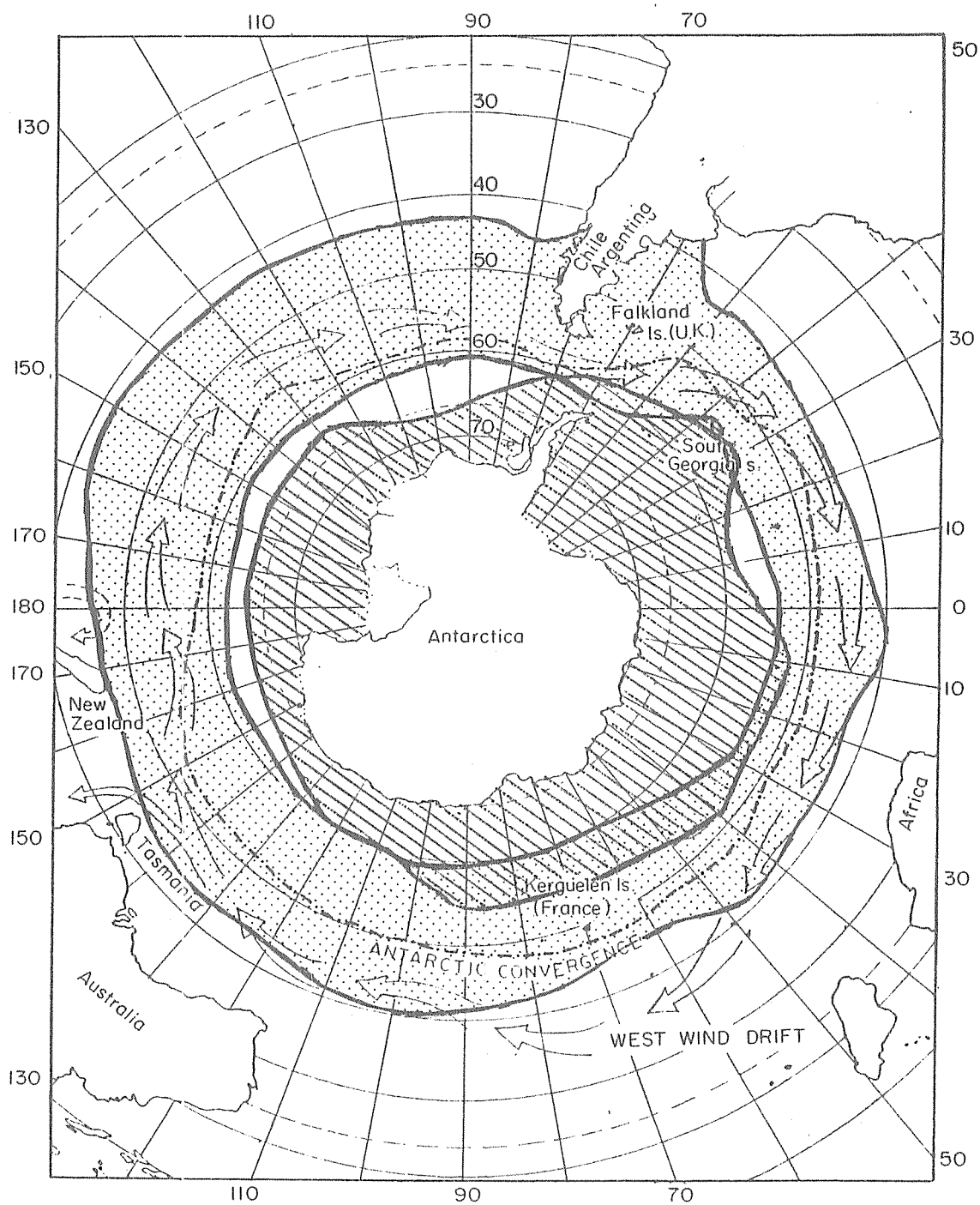
With only slight rearrangement this general equation may be applied to the krill/whales type situation. In this case there is only one prey species but several predators. Using the same notation except that the summation is over the different predator species (whales, seals, etc.) the equation then becomes:

$$\sum_{i=1}^n V' E' K_i W_i > V E \bar{w}$$

Implicit in this equation is the fact that, as Gulland pointed out, the efficiency of utilization (K) should be greater than the product of the relative value, the relative exploitation and the probable growth of the prey.

In this equation a lot clearly depends on the relation between V' and V and K . Gulland (1974) suggests that the overall conversion efficiency of krill to whales is very low and of the order of 2% and suggests that if the problem facing the world were of more food at all costs, and the choice were between 1.7 million tons of whales, and 100 million tons of krill, there would be no doubt that preference would have to be given to harvesting krill. Clearly this represents an extreme case which in reality seems unlikely to occur. Between these two extremes there are an infinite number of potential answers particularly if the other exploitable resources are included into the analysis. The problem then reduces to one of making management decisions to utilize and at the same time safeguard the resources.

An alternative indirect method of harvesting krill has been proposed by Joyner et al. (1974) who suggest that the West Wind Drift is a suitable environment for salmon (see also Hardy 1975, Joyner 1976). On the basis of published information on seasonal sea temperature and the distribution of krill they consider that salmon fry released from Southern South America could search out and feed on krill in the Antarctic. Because of the known fast growth rate of salmon they estimate that a salmon fishery of several million tons could be established in the Tierra del Fuego area. They point out the obvious advantage of such a system that since the salmon will probably return to their area of release the expense involved in fishing will be minimal. However, from the information they give it seems unlikely that the salmon will feed on krill since the main concentrations are south of the area regarded as seasonally acceptable to salmon (Fig. 6.8 which is derived from information in Joyner et al. 1974).



Areas of seasonally acceptable temperature to salmon

Summer distribution of krill

Fig.6.8 The northern limit of krill distribution (see Fig.6.1) compared with that of the range of surface temperatures acceptable to salmon (shaded area) (from Joyner *et al.*, 1974)

7. CEPHALOPODS

7.1 Introduction

The very common occurrence of squid remains (tentacles, beaks, etc.) in the stomach contents of whales, seals and birds in the Antarctic implies that this group is of major importance in the Antarctic ecosystem. However, in spite of the agreed importance of the group (see Holdgate 1967, Knox 1970, Laws 1977) very little information is available. The paucity of information is mainly due to the inadequacies of sampling techniques as is indicated in Table 7.1.

Table 7.1. The most numerically important Cephalopod families in samples obtained by three different methods (unpublished manuscript of M.R. Clarke)

| Family | Stomach contents of | | Nets |
|------------------|---------------------|--------------|------|
| | Sperm Whale | Weddell Seal | |
| Onychoteuthidae | 54% | 32% | 25% |
| Cranchidae | 23% | | |
| Histioteuthidae | 11% | | |
| Octopoda | | 35% | 42% |
| Bathyteuthidae | | | |
| Brachioteuthidae | | | |
| | | | 13% |

The clear indication of these results is that the small nets used for scientific sampling are missing many species known to be present. Also, since Sperm Whales and Weddell Seals are generally taking squid of a larger size than those represented in scientific nets, it is clear that the nets will give a very poor indication of the standing stock. At the moment there is no cephalopod fishery in waters south of the Antarctic Convergence which, in view of the shortcomings in scientific sampling mentioned above, makes it very difficult to specify whether or not there are resources of commercial potential although Burukovskii, Ivanov and Nesin (1974) indicated that Mesonychoteuthis hamiltoni the "giant squid" may be a promising commercial possibility. North of the Antarctic Convergence the only reported fisheries from areas adjacent to the Antarctic Zone are in the South American (Voss 1973) and New Zealand shelf areas (Voss 1973, Saito 1976, and Okutani, in prep.).

Species

Because of their ability to make large diurnal vertical migrations the Antarctic Convergence, an essentially surface water phenomenon, is unlikely to have a great influence in controlling distribution. A clear demarcation for the northern limit of what might be considered as Antarctic species is therefore impractical. For this group therefore consideration has been given to species occurring as far north as about 40°S.

Cephalopods may conveniently be considered as three general groups: squids, cuttlefish, and octopus. In general squid are wide ranging nektonic animals that occur in all the world's oceans. Cuttlefish are in many respects similar to squid. They are however generally considered separately since most are neritic and most have an internal shell. Squid and cuttlefish

both have ten arms in contrast to octopuses which have eight. The best known species are benthic although there are nektonic and planktonic forms.

A list of species and groups has been compiled from several sources and those of potential commercial importance along with some additional information are included in Table 7.2. The criteria for inclusion have been that the species should attain a reasonable size (i.e., species known to attain a size of 10 cm mantle length or 100 g total weight have been included) and there should be some indication of their occurrence in reasonable concentrations. Interesting additional information is included in Clarke 1977.

In addition to the species included in Table 7.2, the following may also be of importance: Alluroteuthis antarcticus, Psychroteuthis glacialis, Oregoniateuthis lorigera, Calliteuthis miranda, Crystalloteuthis glacialis, Teuthowenia antarctica, Taonius pavo, Galiteuthis armata, Mesonychoteuthis hamiltoni, Rossia tenera. This species list must only be considered as being provisional since the information on which it is based is in many cases very sparse.

7.2 Biology

In general, cephalopods seem to be relatively shortlived animals since many species appear to attain sexual maturity in one year or less and only spawn once (Voss 1973). This conclusion is based mainly on size frequency distributions, a method relying on a clearly defined and relatively short spawning season (a feature not always present). Attempts to age individuals by analysis of the laminations in the beak have so far met with limited success (Clarke 1966) although the indications are that it will eventually prove successful at least for temperate and polar species. Kato and Hardwick (1976) have also had some success in correlating growth with lamellae in the statoliths.

Squires (1957) suggested that Illex illecebrosus off Newfoundland become sexually mature after about 18 months and spawn at two years of age. The growth increment during this period was similar to the 2-2.5 cm/month for the first year and 1-1.2 cm/month for the second reported by Nesis (1970) for Dosidicus gigas off Chile. A similar growth rate was found by Kato (1959) for Todarodes pacificus although for this species relatively few individuals are thought to survive to a second breeding season at age two years. A massed mortality following spawning has been described for Loligo opalescens off California (Kato and Hardwick 1976) and it is to be expected that such a pattern will almost certainly lead to large annual variations in abundance such as have been noted by Voss (1973) for Illex illecebrosus. Seasonal variations in abundance may also be caused by external factors (e.g., water temperature, wind, salinity, etc.) possibly affecting migration patterns.

Very little is known of the breeding biology of the oceanic squids in general and virtually nothing of Antarctic species. Egg masses which may contain several thousand eggs have been identified for some species (Clarke 1966) whilst other species lay single eggs (Okutani in prep.). In Todarodes pacificus the distribution pattern of the larvae corresponds to the meandering of the major current around Japan suggesting that the larvae are spread out by the water movement (Okutani in prep.). Benthic octopods make up a nest and stake out a territory prior to spawning while nektonic squid amass in vast concentrations for spawning (Okutani in prep.).

In the Antarctic it is clear that squid are major predators on krill (Marr 1962) although fish and other squid form an important part of the diet of larger individuals (Clarke 1966). Also Clarke (in press) considers that the squid eaten by Sperm Whales in the Antarctic are generally not feeding on krill. This conclusion is consistent with the report of Filippova (cited by Burukovskiy, Ivanov and Nesis 1974 but no reference given) who investigated the mode of life of antarctic and sub-antarctic squid and distinguished two trophic groups: squid that feed in the euphotic zone chiefly on krill, and meso bathypelagic species that feed basically on fish and other squid.

Table 7.2. Cephalopod species which may be present in the Southern Ocean in fishable concentrations

| | Distribution (S. Hemisphere) | Vert. Range (m) | Size Mantle length/ weight (cm/kg) | Diet of Sperm Whales | Current Fishery | Notes | Reference |
|--|--|-----------------------|--|----------------------------|--------------------|--|-----------|
| <u>ONYCHOTEUTHIDAE</u> | | | | | | | |
| <i>Onychoteuthis banksii</i> | Sub-Antarctic | 0-150 (800) | 30/1 | X | X | | 1, 7 |
| <i>Moroteuthis ingens</i> | Antarctic | 0-400 | 100/25 | X | | | 1, 7 |
| <i>Moroteuthis robsoni</i> | S. Atlantic | 0-500 | 47/ | X | | | 1 |
| <u>THYSANOTEUTHIDAE</u> | | | | | | | |
| <i>Thysanoteuthis rhombus</i> | S. Atlantic | | 60/ | | | | 1 |
| <u>OMMASTREPHIDAE</u> | | | | | | | |
| <i>Nototodarus sloani sloani</i> | New Zealand | 0-500 | 40/1.5 | | X | See Section | 1, 8 |
| <i>Nototodarus gouldi</i> | Southern Australia | 0-500 | 40/1.5 | | X | Small Fishery. Preyed on by bluefin tuna | 1, 3, 4 |
| <i>Todarodes sagittatus</i> | S. Atlantic, S. Ind. S. Africa | 0-600 | 50/3 | X | X | Fished for bait | 1, 5 |
| <i>Todarodes filippovae</i> | Sub-Antarctic | | 40/1.5 | | | | |
| <i>Illex argentinus</i> | Patagonian Shelf | 0-500 | 40/1.5 | | X | | 2 |
| <i>Martialia hyadesi</i> | S. Pac. Convergence | | 40/1.5 | | | | 2 |
| <i>Symplectoteuthis Oualaniensis</i> | S. Ind. S. Pac. S. Afr. | 0-1000 | 30/1 | | X | | 1 |
| <i>Dosidicus gigas</i> | S. Pac. Chile | 0-1000 | 150/25 | X | X | | 1, 2, 6 |
| <i>Ommastrephes pteropus</i> | S. Atl. S. Afr. | 0-1000 | 40/2 | | | | 1 |
| <i>Ommastrephes bartrami</i> | S. Pac. Chile | 0-1000 | 30/1.5 | | | | 1 |
| <u>HISTIOTEUTHIDAE</u> | | | | | | | |
| <i>Histioteuthis bonelli</i> | Sub-Antarctic | 100-800 | | X | | | 1 |
| <u>ARCHITEUTHIDAE</u> | | | | | | | |
| <i>Architeuthis</i> sp. | Atl. Pac. Ind. | | 500/1000 | X | | | 1, 7 |
| <u>GONATIDAE</u> | | | | | | | |
| <i>Gonatus fabricii</i> (antarcticus) | Antarctic Sub-Antarctic | | 20/1 20/1 | X X | | | 1 1 |
| <u>LOLIGINIDAE</u> | | | | | | | |
| <i>Loligo</i> sp. | Sub-Antarctic Patagonian Shelf S. Atl. | 0-200 | | | X | | 2 |
| <u>OCTOPODINAE</u> | | | | | | | |
| <i>Parledone</i> sp. | Antarctic Sub-Antarctic | | | | | Demersal Shelf Area | |

References:

1. Clarke 1966
2. Voss 1973
3. Anon 1964
4. Allen 1945
5. Nesis 1964
6. Nesis 1970
7. Listed by Castellanos (1964) as being of economic importance although no data available to suggest that commercial concentrations exist (Voss 1973)
8. Saito 1976

7.3 Production and Biomass

There are no published direct estimates of production and biomass although there are several estimates of production based on the consumption of squid by predators.

Estimates of the present day consumption of Cephalopods have been made by Laws (1977) for whales and seals and Croxall (unpublished MS) for birds, and these are summarized in Table 7.3.

Table 7.3. Estimated present day consumption of Cephalopods in the Antarctic Zone.

| Consumer | Estimated Annual Consumption ($t \times 10^3$) | | Reference |
|----------|--|--------|----------------------|
| Birds | 5 900 -- 7 900 | 7 000 | Croxall (Unpubl. MS) |
| Seals | | 5 550 | Laws 1977 |
| Whales | | | Laws 1977 |
| Baleen | 441 | | |
| Sperm | 4 632 | 5 073 | |
| Total | | 17 623 | |

It is not known how the population density of squid is distributed throughout the Southern Ocean since only small numbers have been taken by commercial vessels fishing for krill and fish. In contrast squids are frequently found in catches of pelagic hauls north of the Antarctic Convergence. This may well indicate that the main bulk of the Southern Ocean is not a particularly productive sea for squids and that the greater concentrations are likely to occur in lower latitudes probably north of the Convergence. Further studies with suitable collecting gear are clearly required before such a suggestion can be validated. Additional corroborative information may be forthcoming from the examination of bottom sediments for squid beaks.

The Octopoda of potential commercial importance (*Pareledone* sp.) are restricted to the shelf. Although frequently taken as part of the by catch in demersal hauls because they are generally indicators of rough ground, this type of gear only gives a poor indication of standing stock. Thus although it is possible that reasonable concentrations exist a more thorough sampling programme using specifically designed gear will be needed.

7.4 Exploitation

Currently there is no fishery for Cephalopods in the Southern Ocean. There are however fisheries in areas adjacent to the Southern Ocean which could expand their range south and there is also the likelihood that squid fishing may develop as an offshoot of a krill or fish orientated fishery. As an indication of the size of the current fisheries in areas adjacent to the Southern Ocean (Areas 48, 58, 88) the reported catches are given in Table 7.4.

Table 7.4. Reported catches and landings of Squid, Cuttlefish and Octopus from areas adjacent to the Southern Ocean (FAO 1976). Figures in parenthesis refer to catches probably made well north of the Antarctic.

(metric tons)

| | Statistical Area | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|---------------------|------------------|---------|---------|----------|-----------|---------|---------|
| Cuttlefish | 47 | 100 | 0 | (100) | 0 | (7) | 16 |
| | 51 | (7 100) | (9 100) | (13 800) | (11 800F) | 5 359 | 3 665 |
| | 57 | (100) | (100) | (100) | (300) | (580) | (476) |
| Squids (Loligo Sp.) | 41 | (700) | (500) | (500) | (600F) | (600F) | (540F) |
| | 47 | 300 | 200 | 300 | 600 | 1 318 | 839 |
| | 57 | (900) | (900) | (800) | (900) | (1 500) | (1 301) |
| | 87 | (300) | (400) | (700) | (300) | (92) | (466) |
| Illex | 41 | 1 300 | 1 800 | 1 800 | 4 100 | 5 000 | 4 600 |
| Nototodarus | 57 | | | | | | 232 |
| | 81 | | | | 13 400 | 19 620 | 6 682 |
| Other Squids | 47 | 1 300 | 1 000 | 1 100 | 1 000 | 3 464 | 3 991 |
| | 51 | 0 | 0 | 500 | 700 | 800 | 242 |
| | 81 | 0 | 0 | 100 | 1 700 | 47 | 1 005 |
| | 87 | (500) | (500) | 0 | 0 | — | — |
| Octopus | 41 | (200) | (100) | (100) | (100F) | (100F) | (100F) |
| | 51 | | | | | 608 | 606 |
| | 57 | 0 | 100 | 100 | 0 | (8) | (8) |
| | 87 | 0 | 0 | 0 | (100) | (19) | (13) |
| TOTALS | | 12 800 | 14 700 | 20 000 | 35 700 | 39 122 | 24 782 |

(F = Estimated by FAO).

The bulk of the catches in recent years have been of Nototodarus sloani sloani and the build up in this fishery has been well documented by Saito (1976). After two preliminary surveys in the area, full-scale fishing was commenced in 1972/73 and the catches from this and subsequent seasons are set out in Table 7.5.

Table 7.5. Data on the fishery for Nototodarus sloani sloani off New Zealand (Saito 1976 and Nasu, unpublished MS).

| Season | No. of Boats | Catch (t) | Catch/day/boat |
|---------|--------------|-----------|----------------|
| 1972/73 | 71 | 13 424 | 3.9 |
| 1973/74 | 156 | 14 761 | 1.5 |
| 1974/75 | 152 | 18 500 | 1.6 |
| 1975/76 | 128 | 19 598 | |

At the moment this fishery is concentrated on the shelf area of the South Island and it is thought that the squid concentrations present there may be due to the effect of the subtropical convergence.

Elsewhere there has been a steady increase in the total catches although all the indications are that there is enormous scope for expansion (Voss 1973), (Okutani 1977). Although it is likely that any increases in southern hemisphere catches will occur in presently known fisheries, the speed with which the New Zealand fishery has developed indicates how rapidly an Antarctic fishery could develop once commercial concentrations have been identified and located.

7.5 Stock Assessment

The almost complete lack of information, in fishery terms, on the Cephalopods of the Southern Ocean indicates that the first priority should be to identify and determine the size of a potential fishery on these resources. Initially this is a problem of detection and catching which might be partially solved by mid-water trawlers fishing opportunistically. In the event that fishable concentrations are detected the fishing technique will have to be refined. It will only be after this stage that realistic catch and effort data will become available that will be of use in stock assessment. To improve these assessments and to enable quantitative estimates to be made earlier, catch/effort data need to be supplemented by other information including:

- a) Accurate identification of species
- b) Population structure within species, particularly those covering large areas
- c) Information on the life cycle including migration patterns
- d) Direct estimates of standing stock

8. FISH

8.1 Introduction

In most of the world's seas the fish fauna has been a subject of special study because of its economic importance. Although the value of Antarctic fish as food has long been recognised by expeditions of discovery, (one of the first fish specimens caught near to the Antarctic continent was eaten by the ship's cat before it could be properly described, Schlee 1973), it is only recently that commercial fishing has begun. There are in the literature several good reviews which include biological information outside the scope of this report (e.g., Marshall 1964, Andriashev 1965). In addition to these, Kock (1975) has prepared an extensive review which also includes an extensive bibliography, of selected species of potential commercial importance in the Atlantic sector of the Antarctic.

8.2 Species

Of the 20 000 kinds of modern fishes only about 100 have been discovered in the seas south of the Antarctic Convergence. Thus, although the Southern Ocean is continuous with the other major oceans of the world, it clearly represents quite a specialised environment. The dominant group in the Antarctic ichthyofauna is the Nototheniiformes, a division comprising five families that make up nearly threequarters of all coast fish species. Of these **five families only the Nototheniidae and Channichthyidae contain representatives of potential commercial importance.** The remaining groups include the following: Myxiniidae, Dalatiidae, Rajidae, Muraenolepidae, Zoarcidae, Congiopodidae, Liparidae, Bothidae, Gadidae, Merlucciidae, of which only the Rajidae and the last two contain species of potential major commercial importance.

In contrast to the other oceans of the world the Southern Ocean does not appear to contain dense shoals of obligate pelagic fish. The pelagic ichthyofauna is largely made up of Myctophidae in addition to the Nototheniid genera Pleuragramma and Dissostichus and the Gadoid genus Micromesistius.

The Myctophidae and other bathypelagic groups have not been included in Table 8.1 because present indications suggest that although they may well be abundant in the open ocean they do not form concentrations on which a fishery could be based. The most abundant bathypelagic species of the Antarctic according to Andriashev (1965) are:

Electrona antarctica

Gymnoscopelus braueri

Bathylagus antarcticus

Notolepis coatsi

Cyclothone microdon

A list of the species of potential importance is given in Table 8.1. Taxonomic information will be found in Norman (1937, 1938) along with good identification keys.

8.3 Distribution

As is the case with many areas that are unfished commercially, knowledge of the distribution of many species is incomplete. The information given in the maps (Fig. 8.1 a - k) will in only few cases indicate the area of abundant distribution. The information from the maps should be used in conjunction with the bathymetric information given in Table 8.2 along with a detailed contour chart in order to gain the best idea of the distribution. Pleuragramma antarcticum has been excluded from the distribution maps. This species is considered to have a high latitude circumpolar distribution, it has not been recorded in the vicinity of the Antarctic Convergence. The bathypelagic fish species have also been excluded and they are assumed to have a circumpolar distribution over more or less the whole Southern Ocean.

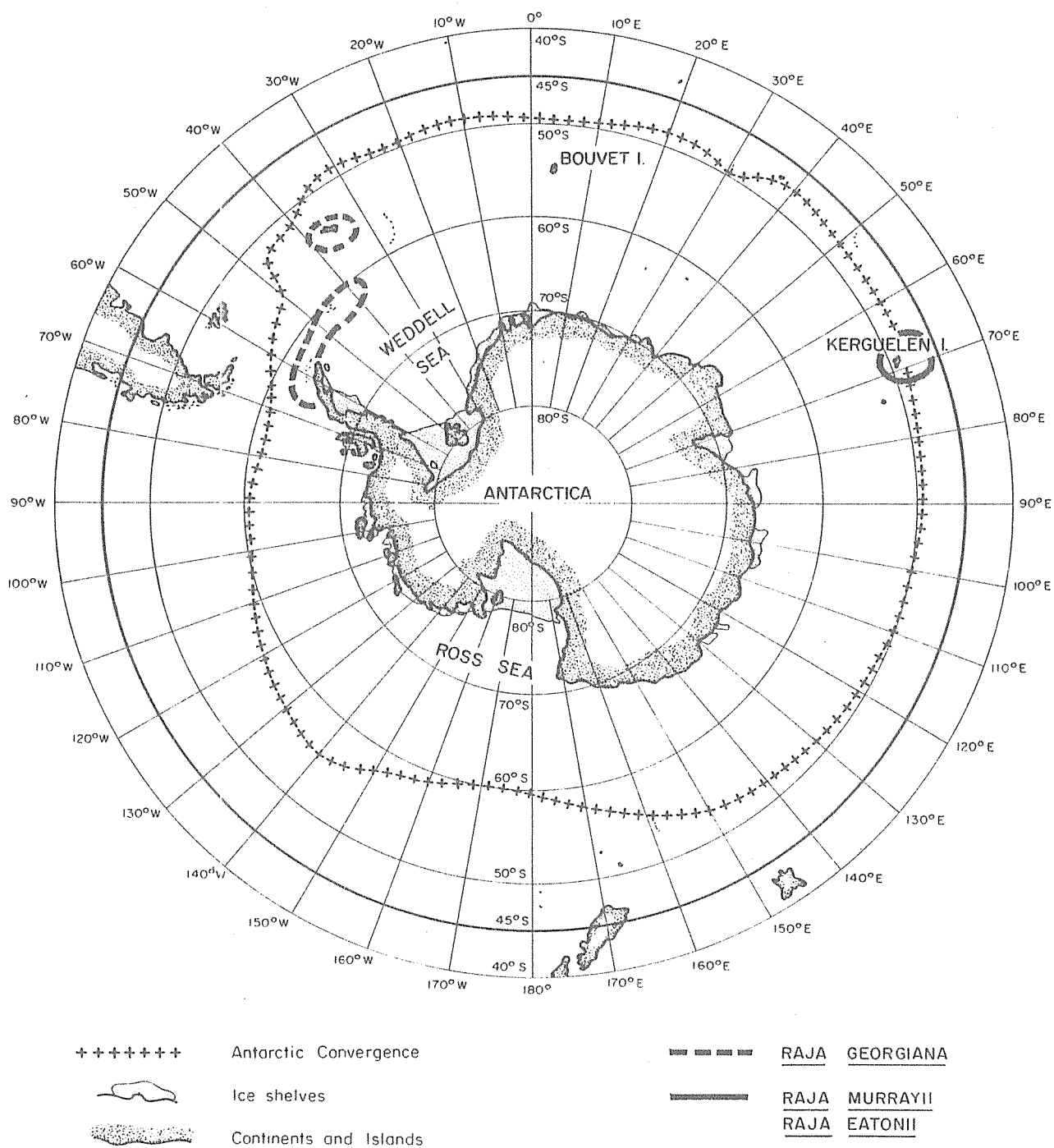


Fig.8.1 (a) Distribution of main fish species in the Southern Ocean

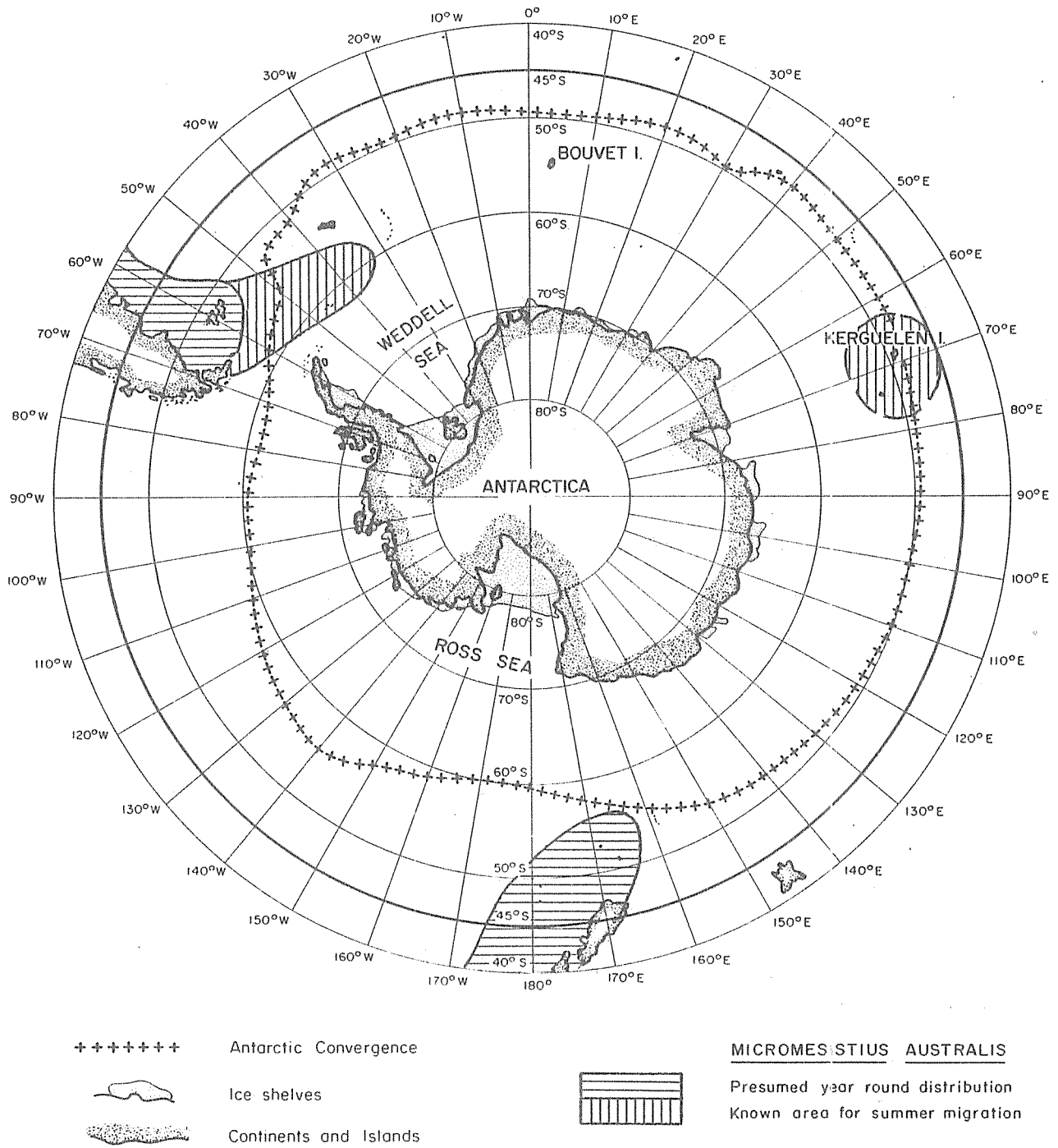


Fig.8.1 (b) Distribution of main fish species in the Southern Ocean

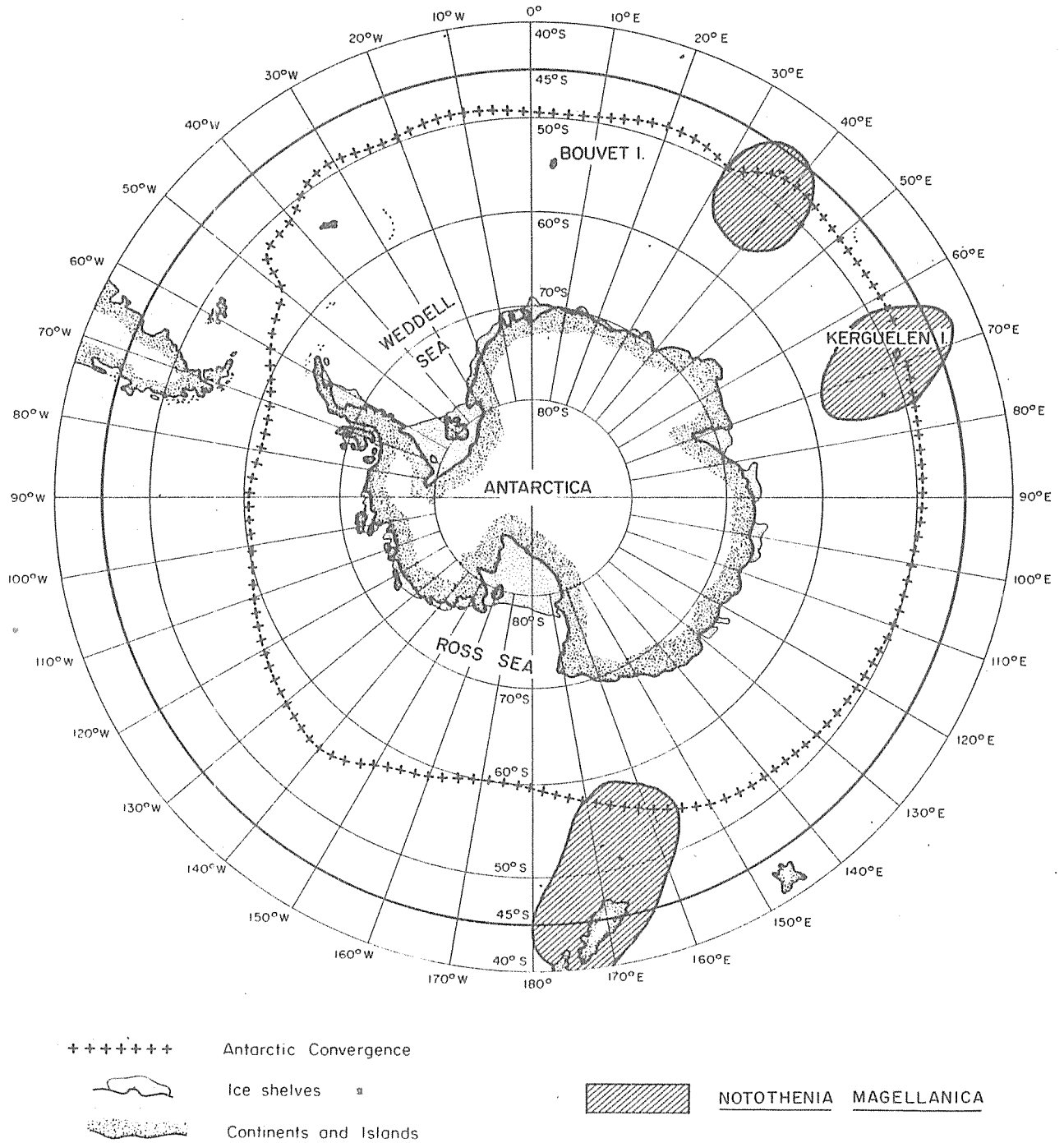


Fig.8.1(c) Distribution of main fish species in the Southern Ocean

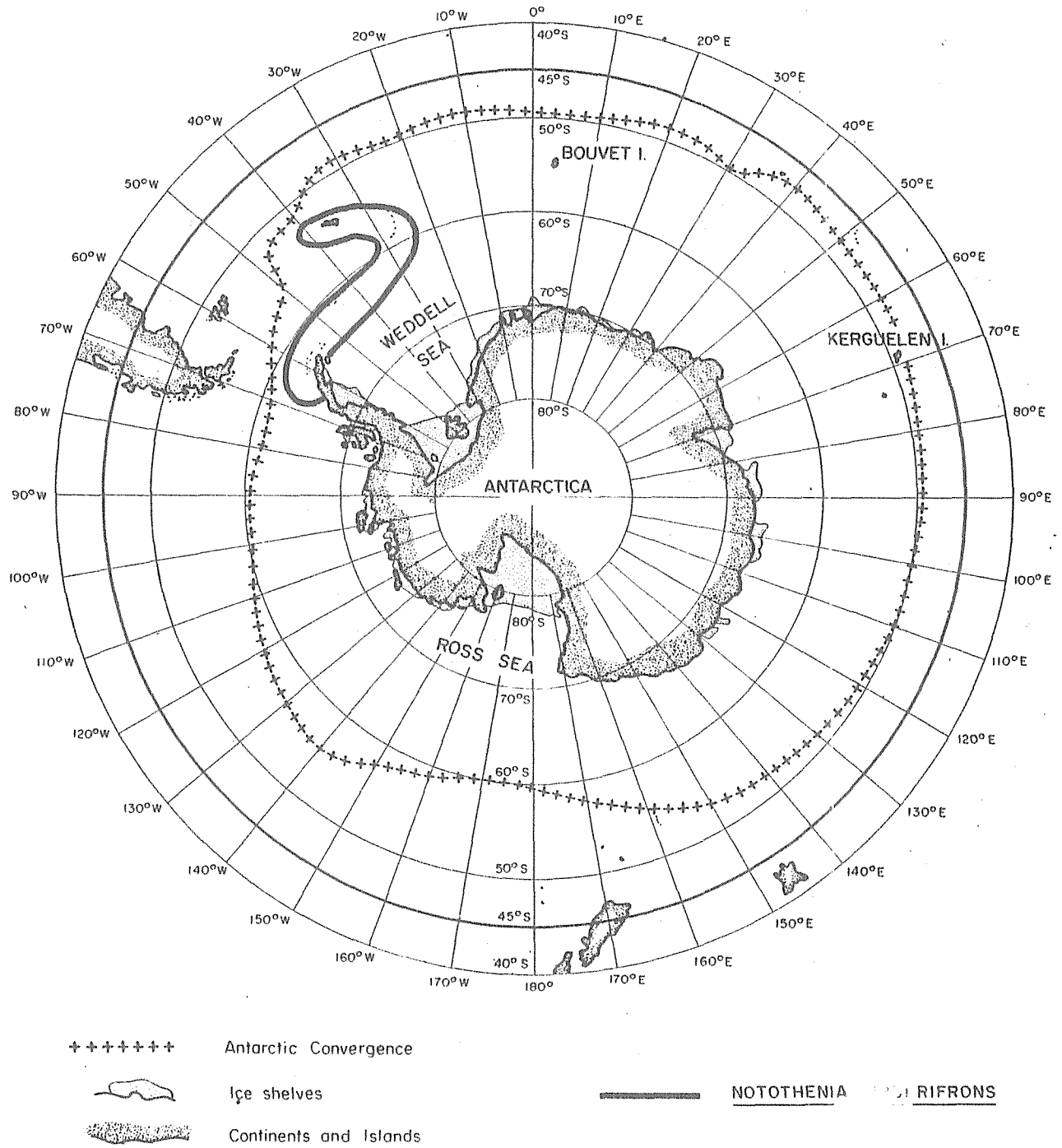


Fig.8.1 (d) Distribution of main fish species in the Southern Ocean

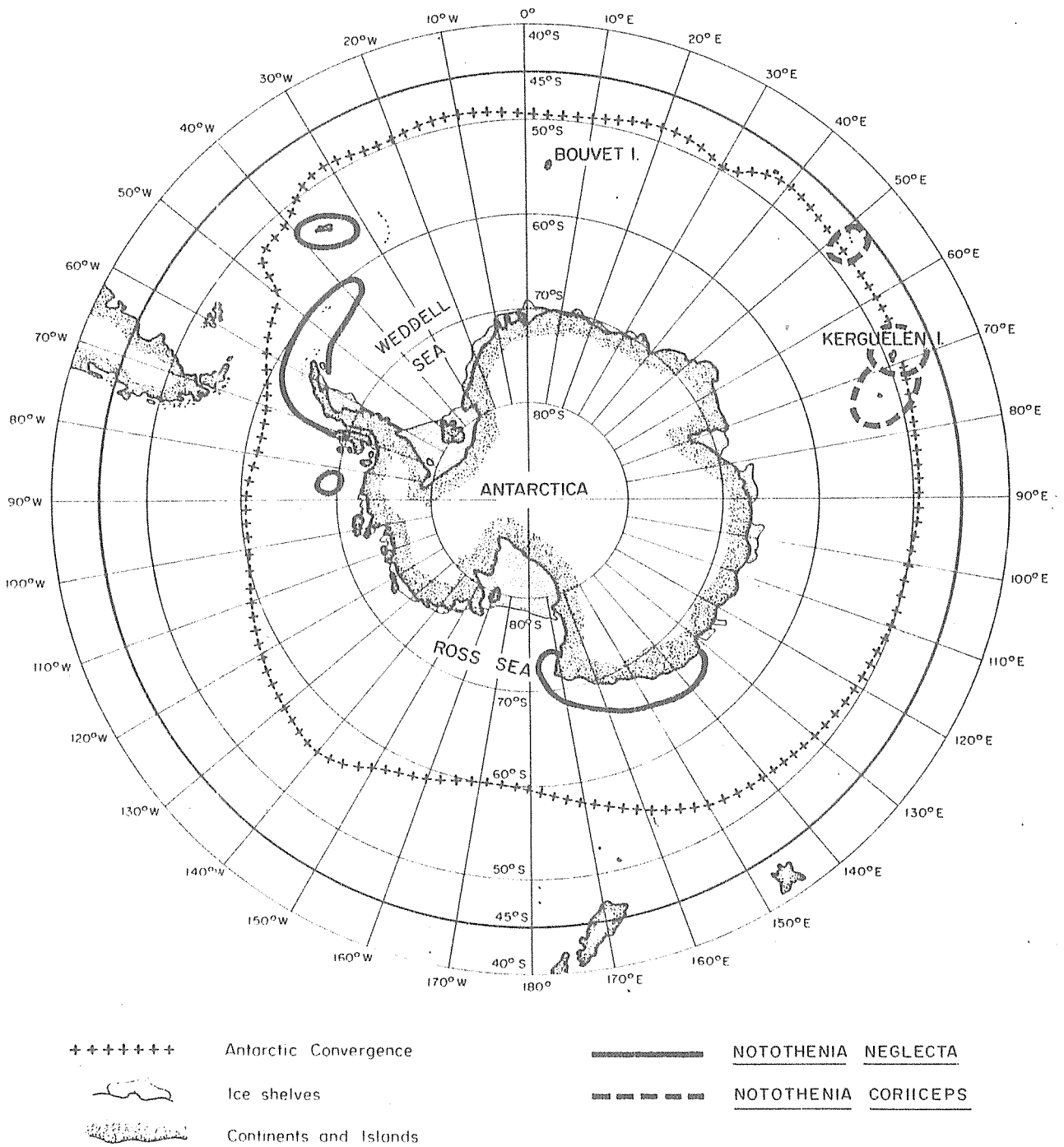


Fig.8.1 (a) Distribution of main fish species in the Southern Ocean

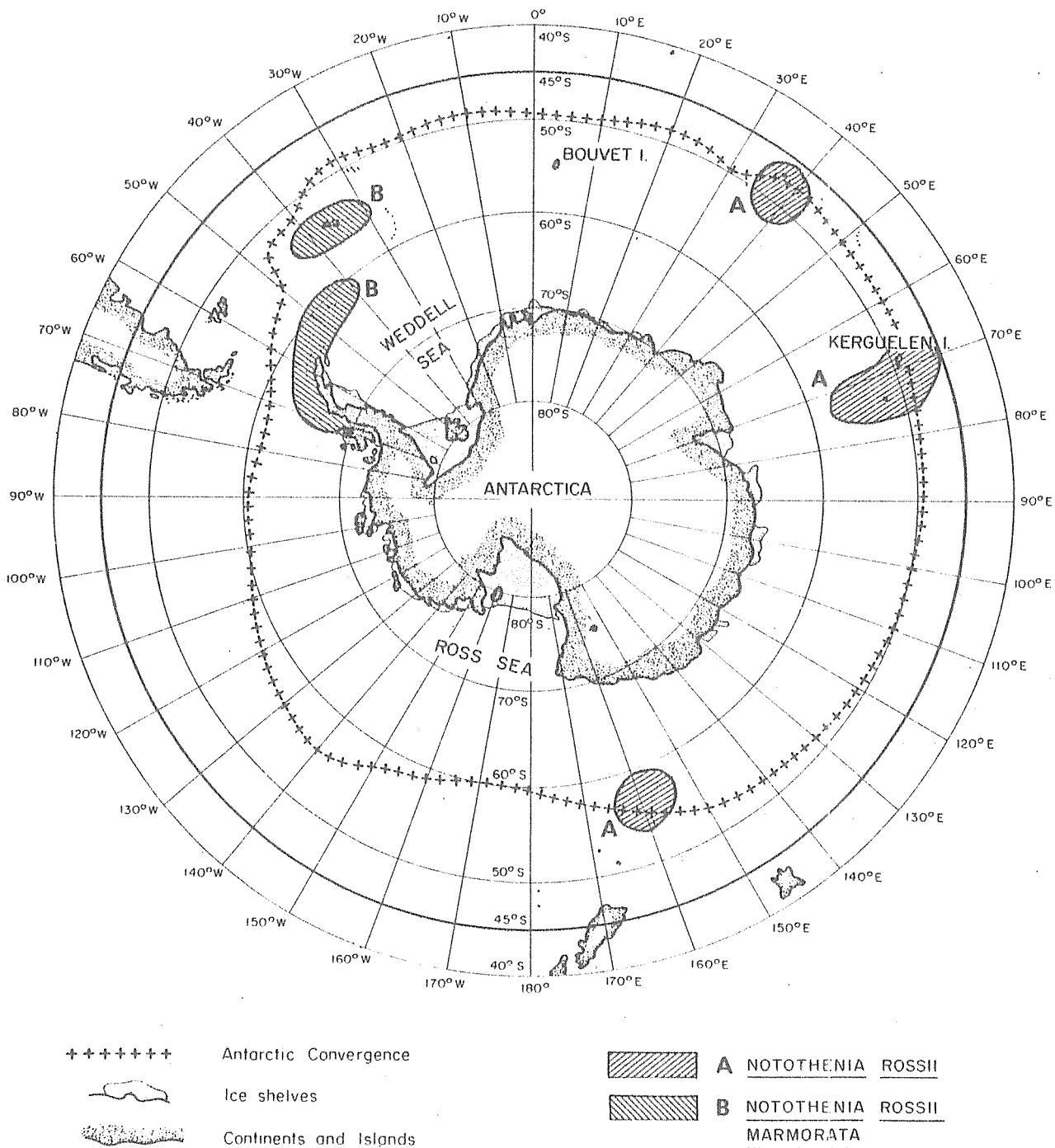


Fig.8.1 (f) Distribution of main fish species in the Southern Ocean

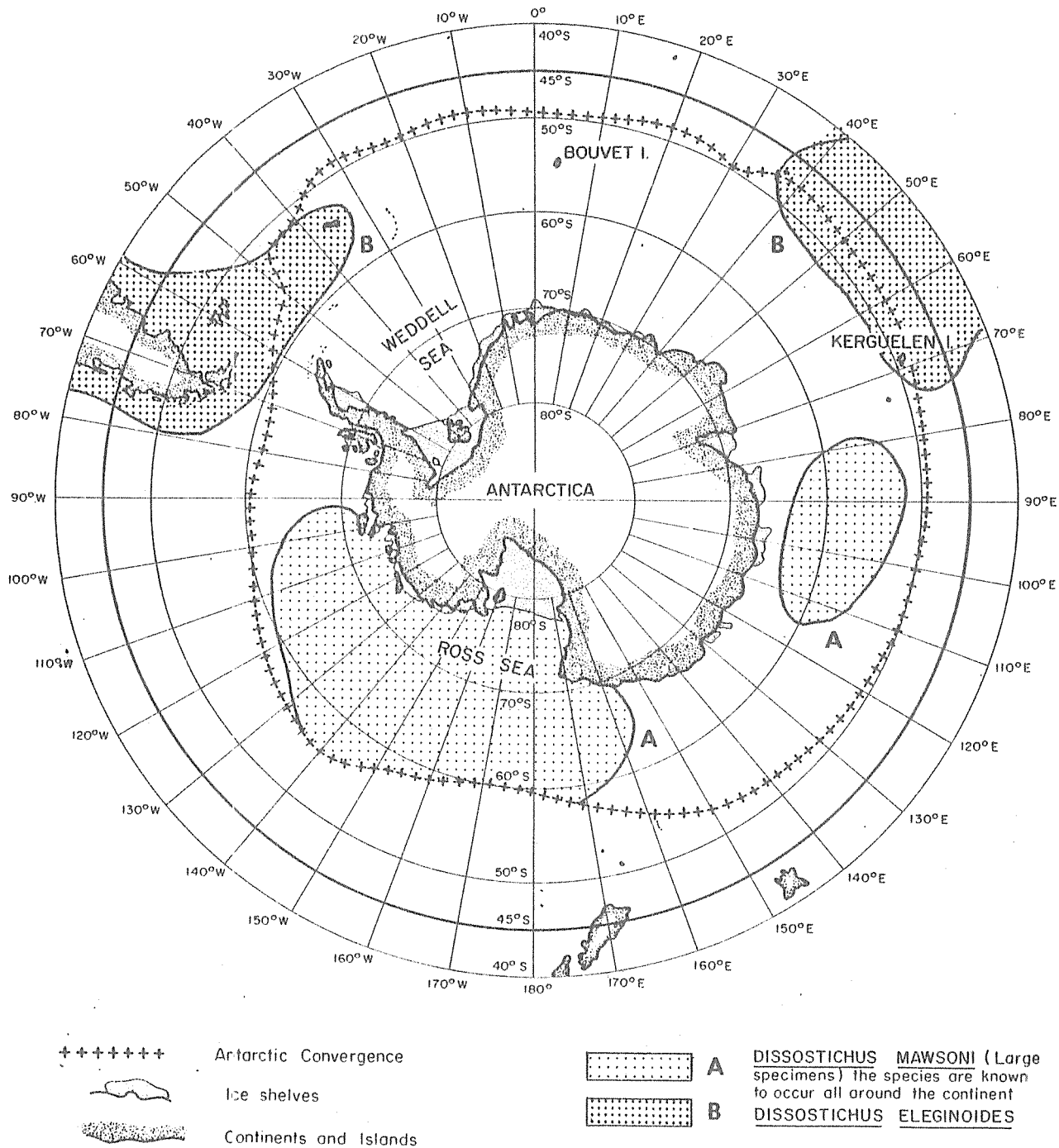


Fig.8.1 (g) Distribution of main fish species in the Southern Ocean

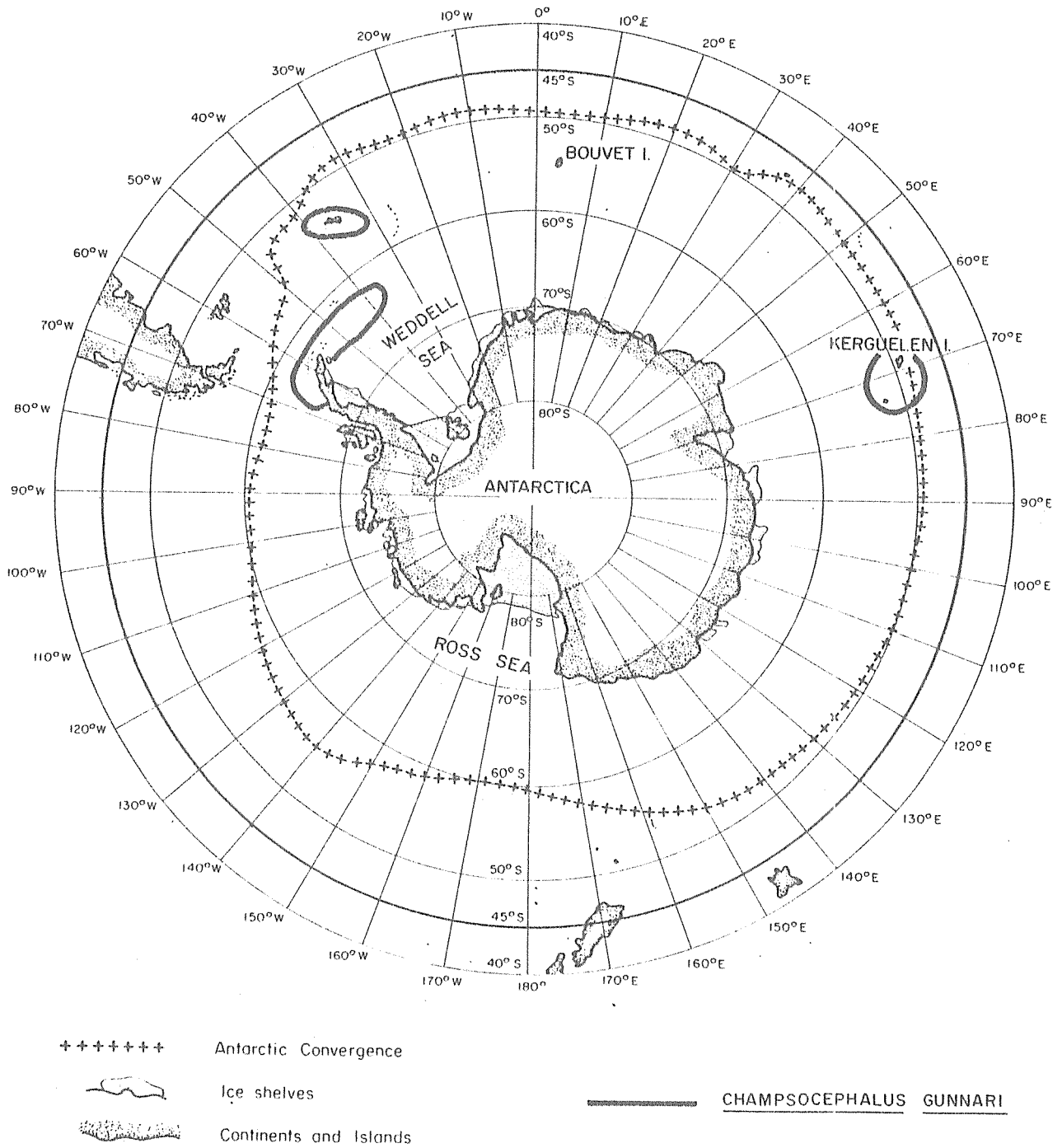


Fig.8.1 (h) Distribution of main fish species in the Southern Ocean

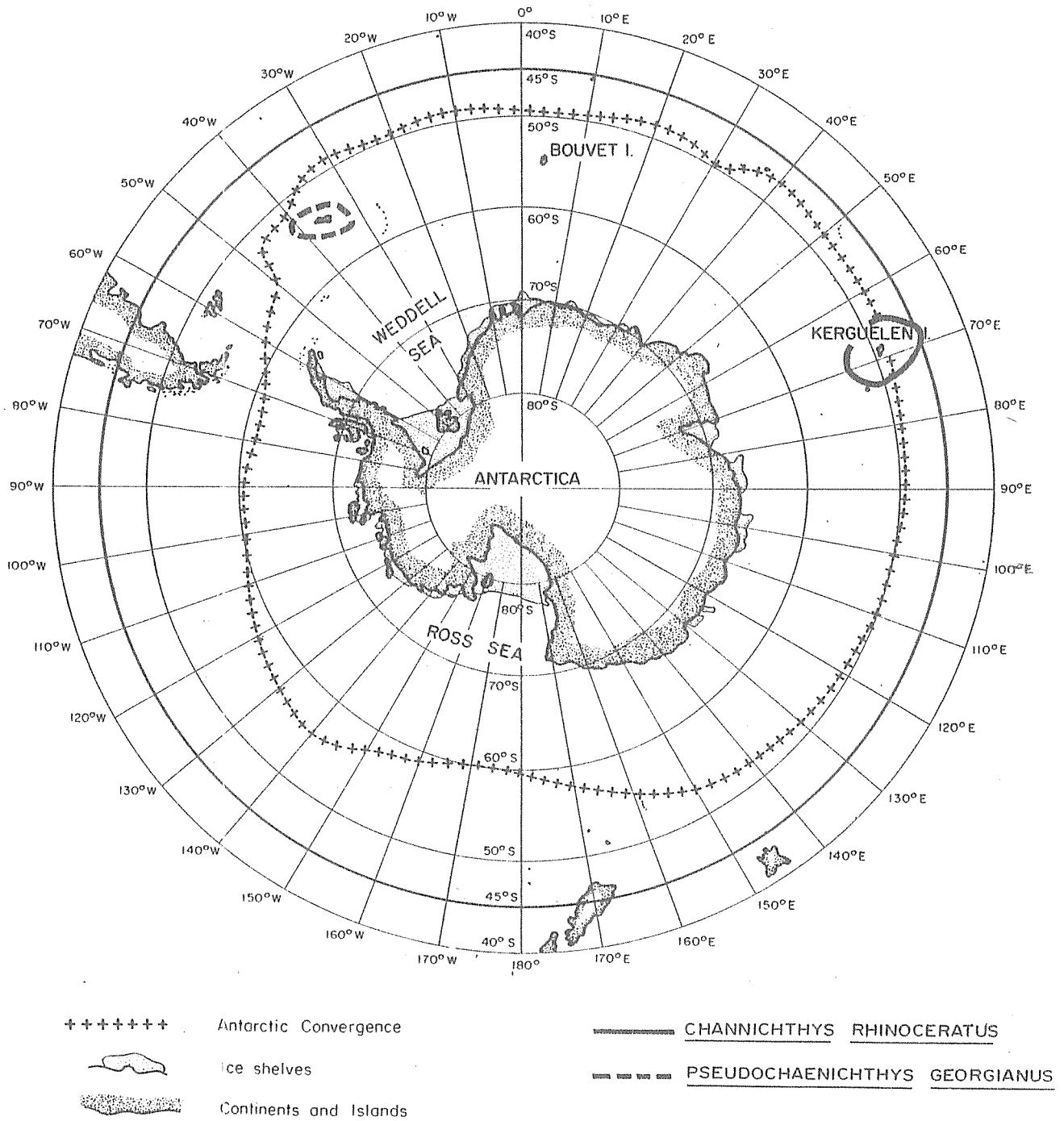


Fig.8.1 (i) Distribution of main fish species in the Southern Ocean

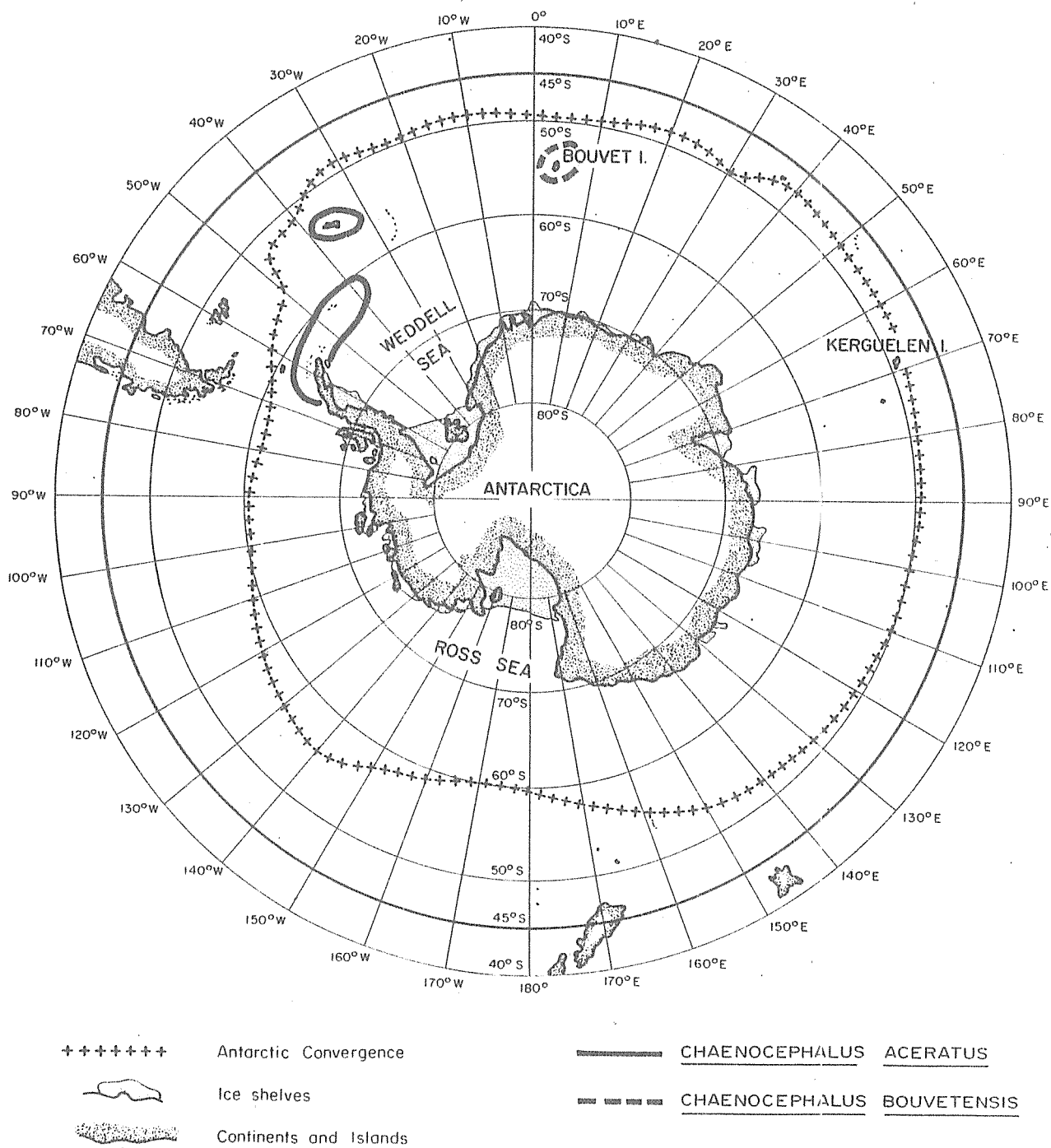


Fig.8.1 (j) Distribution of main fish species in the Southern Ocean

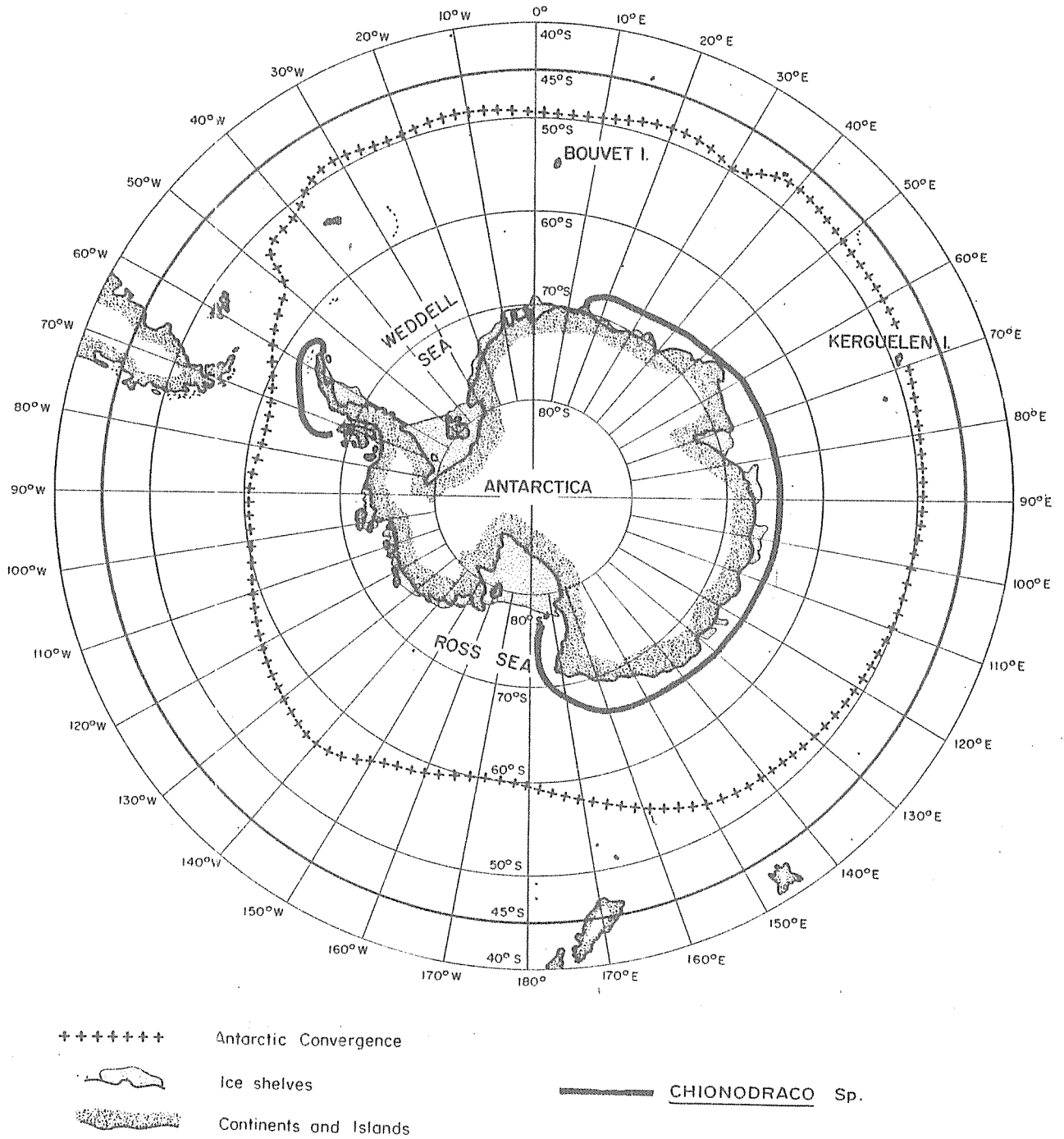


Fig.8.1 (k) Distribution of main fish species in the Southern Ocean

Table 8.1. Fish species of potential commercial importance in the Southern Ocean

| Group | Species | Common Name |
|-----------------|---|---|
| Rajidae | <u>Raja georgiana</u> <u>R. murrayi</u> <u>R. eatonii</u> | |
| Gadidae | <u>Micromesistius australis</u> | Southern Blue Whiting or Southern Poutassou |
| Merlucciidae | <u>Merluccius hubbsii</u> | Patagonian Hake |
| Nototheniidae | <u>Notothenia gibberifrons</u> <u>N. coriiceps</u> <u>N. neglecta</u> <u>N. rossii rossii</u> <u>N. rossii marmorata</u> <u>N. magellanica</u> <u>Dissotichus mawsoni</u> <u>D. eleginoides</u> <u>Pleuragramma antarcticum</u> | Marbled Notothenia Antarctic Tooth Fish Patagonian Tooth Fish |
| Channichthyidae | <u>Champscephalus gunnari</u> <u>Channichthys rhinoceratus</u> <u>Pseudochaenichthys georgianus</u> <u>Chaenocephalus sp.</u> <u>Chionodraco sp.</u> | |

Although there are several species of hake in the Southern Hemisphere, Merluccius hubbsii is the only species to have been reported from Antarctic waters (Mikheyev 1967). In this single instance fish were assumed to have migrated into the Antarctic to feed on krill. This migration is not consistent with the shoreward summer migration pattern in Patagonia described by Hart (1946), a movement confirmed by the observations of Ciechomski and Weiss (1974) who found that M. hubbsii spawned in shallow water during the summer.

The restriction of the distribution of many species to the continental shelf zone has probably resulted in the establishment of distinct stocks (even if not genetically at least as far as fishery management is concerned). Species where this is thought to be the case along with the defined localities are listed in Table 8.3.

Table 8.2. Distribution of Antarctic Fish
(See also Fig 8.1 a - k)

| Species | Habitat and Mode of Life | Depth Range | Reference |
|--------------------------------------|---|------------------|------------|
| <u>Raja georgiana</u> | Demersal, South Georgia Shelf also from a submerged elevation between S. Orkney and S. Sandwich Island (-1.44 to -1.47°C) | 180-830 | 1, 2, 3 |
| <u>R. murrayii</u> | Demersal, Kerguelen | 20-60 | 1 |
| <u>R. eatonii</u> | Demersal, Kerguelen | 30 | 1 |
| <u>Micromesistius australis</u> | In the Antarctic. Reports indicate this species is <u>generally</u> pelagic in the vicinity of the continental shelf. Has been caught in bottom trawls although larger catches have been made with pelagic trawls. | 200-650 10-70 | 2, 4, 5, 6 |
| <u>Merluccius hubbsii</u> | Reported on only one occasion Pelagic, assumed migrated to Scotia Sea from Patagonia | | 7 |
| <u>Notothenia gibberifrons</u> | Demersal in shelf area of Scotia Arc | 5-350 | 1 |
| <u>N. coriiceps</u> | Demersal, Shelf area Kerguelen, Crozet | 0-200 | 1 |
| <u>N. neglecta</u> | Demersal in Shelf area of Scotia Arc and around continent | 0-200 | 1 |
| <u>N. rossii rossii</u> and) | Juveniles demersal in shallow water | 0-30 | 8, 9 |
| <u>N. rossii marmorata</u>) | Adults demersal/pelagic in shelf area | 0-400 | |
| <u>N. magellanica</u> | Originally considered coastal species living on kelp, now known to be pelagic krill feeder | 0-80 | 1 |
| <u>Dissostichus mawsoni</u> | Mainly pelagic in open ocean | 20-220 | 10 |
| <u>D. eleginoides</u> | Mainly pelagic | 70-800 | 10 |
| <u>Pleuraagramma antarcticum</u> | Open ocean pelagic although often associated with Continental Shelf | | 11, 1, 14 |
| <u>Champscephalus gunnari</u> | Pelagic/demersal in Shelf area | 0-450 | 12, 1 |
| <u>Channichthys rhinocerotus</u> | Demersal | 0-140 | 13, 1 |
| <u>Pseudochaenichthys georgianus</u> | Demersal/pelagic in Shelf area | 0-270 | 12 |
| <u>Chaenocephalus</u> sp. | Demersal | 5-350 | 12, 1 |
| <u>Chionodraco</u> sp. | Demersal | 0-800 | 1 |

References for Table 8.2.

1. DeWitt 1971
2. Permitin 1969
3. Bigelow and Schroeder 1965
4. Merrett 1963
5. Basalaev and Petukhov 1969
6. Shuntov 1971
7. Mikheyev 1967
8. Olsen 1954
9. Hureau 1970
10. Yukhov 1970, 1971 (a), 1972
11. DeWitt and Hopkins (in Press)
12. Olsen 1955
13. Hureau 1966
14. Lyubimova et al. 1973

Table 8.3. Antarctic Fish Species for which there is positive evidence for more than one discrete management stock.

| Species | Stock Localities | Reference |
|---------------------------------|---|---|
| <u>Micromesistius australis</u> | <p>(a) Scotia Sea, probably Southern limit of Patagonian population.</p> <p>(b) Campbell Plateau</p> <p>(a) and (b) Related subspecies on morphological grounds</p> <p>(a) and (b) Not considered of sub-specific status but considered isolated</p> <p>This species has also been reported from S. W. Indian Ocean</p> | <p>Inada and Nakamura 1975</p> <p>Shpak 1975</p> <p>FAO</p> |
| <u>Nototothenia rossii</u> | <p>(a) Kerguelen, Crozet group considered of subspecific status <u>N. rossii rossii</u>, Richardson</p> <p>(b) Scotia Arc. considered of sub-specific status <u>N. rossii marmorata</u>, Fischer</p> | <p>Nybelin 1947</p> <p>Nybelin 1947</p> |

8.4 Size and Growth

In the Antarctic ichthyofauna small species are dominant, over half the species do not attain a length of 25 cm and few species attain a length of over half a metre (Andriashev 1965). It is an interesting point that most of the larger species belong to the family Channichthyidae, a group possessing neither functional erythrocytes nor any respiratory pigment. Growth rates are, with few exceptions, slow as might be expected in an environment of continually low temperatures. The limited information that is available is set out below.

Raja sp.

The South Georgia skate, Raja georgianus is one of the largest Antarctic fishes. Permitin (1969) gives the size/weight composition for 31 fish from a large sample caught in the vicinity of South Georgia (Table 8.4). No information is available on growth rate.

Table 8.4. Length/Weight information for Raja georgianus.

| Total Length (cm) | Wt.(g) | No. |
|-------------------|--------|-----|
| 20 - 30 | 146 | 3 |
| 30 - 40 | - | - |
| 40 - 50 | 860 | 1 |
| 50 - 60 | 1 780 | 3 |
| 60 - 70 | 2 680 | 11 |
| 70 - 80 | 3 800 | 2 |
| 80 - 90 | 6 015 | 4 |
| 90 - 100 | 7 690 | 4 |
| 100 - 110 | 10 850 | 2 |
| 110 - 120 | 13 700 | 1 |

Micromesistius australis

Information on growth is only available for this species from Patagonia and the Scotia Sea areas (Table 8.5.).

Table 8.5. Length (cm) against Age results for Micromesistius australis

| Locality | A G E G R O U P | | | | | | | | | | Reference |
|---------------------|-----------------|----|-------------|----------|----------------|----------|----------|----------|----------|----------|----------------------------------|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | |
| S.Orkney Is. ♂ ♀ | | | 40 45/47 | | 45/46 48/49 | 48/49 | | | | | Mikheyev 1967 |
| S.Orkney Is. ♂ ♀ | | | 46 | 45 48 | 47 49 | 48 49 | 50 50 | 50 52 | 51 53 | 53 65 | Shubnikov, <u>et al.</u> 1969 |
| Patagonia ♂ ♀ | | | 44 44 | 45 46 | 46 47 | 47 48 | 49 49 | 50 51 | - 52 | 55 58 | Shubnikov, <u>et al.</u> 1969 |
| Patagonia ♂ | 13 | 21 | 29 | 37 | | | | | | | Inada and Nakamura 1975 |
| New Zealand ♂ | 13 | 22 | 29 | | | | | | | 47 | Inada and Nakamura 1975 |

The results of Inada and Nakamura (1975) refer to fork length and the remainder (although this is not stated) probably refer to total length. The difference in size at age between results of Inada and Nakamura and those of the Russian workers is almost certainly due to gear selectivity although the possibility of its being due to interpretation of the otolith rings cannot be ruled out.

Merluccius hubbsii

Information relating size to age for this species was published by Mikheyev (1967) and is summarised in Table 8.6.

Table 8.6. Size at age information for Merluccius hubbsii in the Scotia Sea

| Length (cm) | Weight (g) | Age (yr) |
|-------------|------------|----------|
| 34 - 35 | 260 | (?) |
| 21 - 27 | - | - |
| 28 - 35 | - | 2 |
| 34 - 35 | - | 2 |

Notothenia neglecta

Results from two localities, Terre Adelie (Hureau 1970) and Signy Island, South Orkneys (Everson 1970) are set out in Table 8.7.

Table 8.7. Size at age information for Notothenia neglecta

| Age Group | Length (cm) | | | | Weight (g) | | | |
|-----------|-------------|-------|----------|-------|------------|-------|------|-------|
| | TA ♀ | Signy | TA ♂ | Signy | TA ♀ | Signy | TA ♂ | Signy |
| V | | 22.0 | 16.5(6) | 22.5 | | 311 | 107 | 318 |
| VI | 18.2(22) | 24.0 | 18.5(7) | 24.6 | 141 | 401 | 147 | 415 |
| VII | 21.4(22) | 25.9 | 20.4(20) | 26.4 | 225 | 502 | 190 | 513 |
| VIII | 24.6(10) | 27.5 | 22.3(18) | 28.0 | 338 | 607 | 240 | 612 |
| IX | 27.8(8) | 29.0 | 24.2(9) | 29.4 | 480 | 716 | 316 | 705 |
| X | 31.0(6) | 30.5 | 26.2(5) | 30.4 | 670 | 827 | 387 | 794 |
| XI | 34.2* | 31.8 | 28.1(7) | 31.6 | 890 | 939 | 500 | 879 |
| XII | 37.4* | 33.0 | 30.0(2) | 32.5 | 1 157 | 1 048 | 620 | 960 |
| XIII | 40.6(1) | 34.1 | 31.9* | 33.4 | 1 485 | 1 150 | 760 | 1 034 |
| XIV | | 35.0 | | 34.1 | | 1 245 | | 1 101 |
| XV | | 35.8 | | 34.7 | | 1 337 | | 1 161 |

() = Figures in parentheses are sample size.

* = Calculated value (The data from Signy Island are calculated values based on examination of 2 000 otoliths)

Hureau (1970) tried to fit a Bertalanffy curve to his results from Terre Adelie but could not obtain a realistic estimate for L_{∞} . He therefore derived the following alternative equations.

$$L_t = 3.2 (t) - 1.0 \quad (\text{for } t > 6)$$

$$L_t = 1.925 (t) + 6.9 \quad (\text{for } t > 5)$$

A Bertalanffy curve was fitted to the results from the Signy Island fish and the constants are set out in Table 8.8.

Table 8.8. Constants for the Bertalanffy curve derived for N. neglecta at Signy Island

| | K | L_{∞} | W_{∞} | t_0 |
|---|-------|--------------|--------------|-------|
| ♀ | 0.091 | 45.5 | 2 744 | -1.7 |
| ♂ | 0.129 | 39.5 | 1 728 | -0.8 |

Notothenia rossii

Size at age has been studied at Kerguelen (Hureau 1970) and also at South Georgia (Olsen 1954, Crisp and Carrick 1975). These results are summarised in Tables 8.9 and 8.10.

Table 8.9. Notothenia rossii rossii from Kerguelen (Hureau 1970).

| | A G E G R O U P | | | | | | | | | |
|------------------------|-----------------|--------------|--------------|--------------|-------------|-------------|-------------|-------------|-------------|-------|
| | I | II | III | IV | V | VI | VII | VIII | IX | X |
| Mean Standard Length ♀ | 11.2 (12) | 17.1 (17) | 23.5 (62) | 32.1 (23) | 39.3 (9) | 50.0 (1) | 55.0 (2) | 60.0 (2) | 64.0* | 67.0* |
| ♂ | | | | | | 48.0 (3) | 53.0 (2) | 57.0* | 61.0 (1) | 63.0* |
| Mean Weight (g) | 41 | 131 | 293 | 752 | 1200 | 1963 | 2800 | 3815 | | |

() = Figures in parentheses are sample size.

* = Estimated value

Table 8.10. Constants of the Bertalanffy curve for N. rossii rossii from Kerguelen.

| | K | L ∞ | t ₀ |
|---|------|------------|----------------|
| ♂ | 0.13 | 80 | -1.69 |
| ♀ | 0.13 | 90 | -0.62 |

Table 8.11. Size at age information for Notothenia rossii marmorata from South Georgia (Olsen 1954)

| | Age Group | | | | | | | | | | | | | |
|---------------------------|-----------|----|-----|----|----|----|-----|------|----|----|----|-----|------|-----|
| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | XIII | XIV |
| Length (cm) $\frac{Q}{Q}$ | 7 | - | 22 | 28 | 32 | 44 | 51 | 59 | 61 | 64 | 67 | 70 | 72 | 72 |
| | | | | | | | 50 | 57 | 59 | 62 | 64 | 65 | 68 | 69 |

Bertalanffy curves were fitted to the data for South Georgia with the constants that are set out in Table 8.12 (Everson 1970).

Table 8.12. Constants of the Bertalanffy curve applied to data of Olsen (1954) for Notothenia rossii from South Georgia.

| Age Group | K | L ∞ | t ₀ |
|-----------|------|------------|----------------|
| I - V | 0.15 | 75 | 0.1 |
| V - XIV | 0.29 | 75 | 3 |

The change in the growth pattern had previously been described by Olsen (1954) as being coincident to, and therefore probably a result of, the offshore migration of the fish.

The age determination methods employed by Olsen and Hureau in their studies were based mainly on otolith examination although they both examined scales as a check. Crisp and Carrick (1975), from examination of the scales from fish of known size caught at Leith Harbour, South Georgia, were able to corroborate Olsen's size at age estimates both by direct comparison and by back calculation based on the ratio of scale length to total length corrected for allometry. Their results confirm the growth pattern described by Olsen for the first few years and also indicate that this technique is of great use in obtaining the maximum amount of information from small samples.

Notothenia magellanica

The only published information on growth of this species is from fish caught at Kerguelen (Hureau 1970). The relevant information is given in Table 8.13.

Table 8.13. Size at age information for Notothenia magellanica at Kerguelen.

| | Age Group | | | | | | |
|-------------|-----------|------|------|------|------|------|-------|
| | I | II | III | IV | V | VI | VII |
| Length (cm) | 12.1 | 18.0 | 23.4 | 26.6 | 30.3 | 33.1 | 36.5 |
| Weight (g) | 55 | 178 | 374 | 565 | 642 | 886 | 1 176 |
| N | 4 | 18 | 23 | 11 | 11 | 5 | 5 |

Hureau has fitted a Bertalanffy growth curve with the following constants to these results:

$$K = 0.26;$$

$$L_{\infty} = 40\text{cm};$$

$$t_0 = 0.4\text{yr.}$$

Dissostichus mawsoni and Dissostichus eleginoides

Yukhov (1971a) has described a series of specimens obtained from sperm whale stomachs the sizes of which are set out in Table 8.14.

Table 8.14. Length/Weight information for Dissostichus mawsoni (Data from Yukhov 1971a)

| Length (cm) | Weight ♀ (kg) | Weight ♂ (kg) |
|-------------|------------------|------------------|
| 121-130 | | 24.6 |
| 131-140 | 29.5 | 29.8 |
| 141-150 | 38.9 | 37.2 |
| 151-160 | 53.0 | 49.0 |
| 161-170 | 55.0 | |
| 171-180 | 70.0 | |

In addition Calhaem and Christoffel (1969) give the following information:

| Species | Length (cm) | Weight (kg) | Notes |
|-----------------------------|-------------|-------------|--|
| <u>Dissostichus mawsoni</u> | 147 | 30 | Sp. in Dominion Museum, Wellington, New Zealand |
| | 125 | (18) | Taken from seal |

There is no information available on age determination or size at age for either species although Yukhov (1971b) has described the otoliths in detail for taxonomic purposes.

Pleuraagramma antarcticum

No information on growth is available for this species. They are reported to grow to 30-35 cm total length (300 g) (Lyubimova et al., 1973)

Champsiceps gunnari

Olsen (1955) published information on the size at age for this species at South Georgia and this is summarised in Table 8.15.

Table 8.15. Length at age information for Champsiceps gunnari data from Olsen (1955).

| | | A g e G r o u p | | | | | | | | | |
|------------------|--------|-----------------|------------|------------|------------|------------|-----------|-----------|---------|---------|---------|
| | | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
| Mean Length (cm) | ♂ N | 26.8 18 | 32.5 11 | 34.9 24 | 36.3 13 | 36.7 10 | 38.2 5 | 41 1 | — 0 | 41 1 | 42 2 |
| | ♀ N | 26.6 29 | 32.1 24 | 34.2 21 | 36.5 10 | 37.6 9 | 39.5 4 | 40.5 2 | 40 1 | 41 3 | — 0 |

Channichthys rhinoceros

Hureau (1966) has published information on size at age for this species and this is summarised in Table 8.16.

Table.8.16. Size at age information for Channichthys rhinoceros

| | A g e G r o u p | | | | | | | | | | |
|------------------|-----------------|------|------|------|------|------|------|------|---|----|-------|
| | II | III | IV | V | IV | VII | VIII | IX | X | XI | XII |
| Mean Length (cm) | 14.8 | 22.3 | 26.0 | 34.0 | 37.0 | 39.7 | 41.0 | 42.5 | — | — | 47.5 |
| Mean Weight (g) | 35 | 150 | 220 | 435 | 510 | 550 | 635 | 750 | — | — | 1 330 |
| N | 2 | 2 | 6 | 7 | 8 | 4 | 3 | 1 | 0 | 0 | 1 |

Pseudochaenichthys georgianus

Detailed information of age and size for this species is lacking although Olsen (1955) gives the following information based on examination of the vertebrae of formalin fixed specimens.

First year 6 - 10 cm

Second year 17 - 23 cm

2 - 3 years old 27 - 33

A single individual (♀) of 50 cm was aged 8 - 9 years.

Chaenocephalus aceratus

The results of Olsen (1955) for this species at South Georgia are summarised in Table 8.17.

Table 8.17. Information on length at age for Chaenocephalus aceratus

| | | Age Group | | | | | | | | | |
|---------------------|---|-----------|----|----|-----|------|-----|----|-----|------|----|
| | | IX | X | XI | XII | XIII | XIV | XV | XVI | XVII | |
| Mean Length (cm) | ♂ | 55 | 52 | 51 | 51 | 52 | 52 | 50 | — | — | |
| | N | 1 | 5 | 6 | 3 | 3 | 2 | 1 | 0 | 0 | 21 |
| | ♀ | 62 | 63 | 57 | — | 59 | 65 | — | 62 | 65 | |
| | N | 1 | 3 | 1 | 0 | 3 | 2 | 0 | 1 | 2 | 13 |

Several workers have published equations relating length to total weight for Antarctic fish (Table 8.18). Unfortunately a simple standard equation does not seem to be applicable although all are variations on the simple cubic relationship intuitively expected.

Table 8.18. Length/Weight relationships for Antarctic fish

| Species | Relationship. | Locality | Reference |
|--------------------------------------|---|---------------|--|
| <u>Raja georgianus</u> | $W = (0.21L)^3$ | South Georgia | Calculated from results of Permitin (1969) |
| <u>Micromesistius australis</u> | $W = (0.21L - 1.3)^3$ see Footnote (1) | Scotia Sea | Estimated from results of Shubnikov (1969) |
| <u>Notothenia neglecta</u> | $W = 0.029(L^*)^3$ ♀ | Signy Island | Everson 1970 |
| | $W = 0.028(L^*)^3$ ♂ | Signy Island | |
| | $\log W = 2.92 \log L^* - 4.45$ | Terre Adelie | Hureau 1970 |
| <u>N. rossii rossii</u> | $\log W = 2.76 \log L^* - 4.06$ | Kerguelen | Hureau 1970 |
| <u>N. rossii marmorata</u> | $W = 0.029L^{2.85}$ | South Georgia | Crisp & Carrick 1975 |
| <u>N. magellanica</u> | $\log W = 2.87 \log L^* - 4.20$ | Kerguelen | Hureau 1970 |
| <u>Pseudochaenichthys georgianus</u> | $W = (0.213L)^3$ | Scotia Sea | Dubrovskaya and Makarov 1969 |
| <u>Chaenocephalus aceratus</u> | $W = (0.189L)^3$ | Scotia Sea | Dubrovskaya and Makarov 1969 |
| <u>Channichthys rhinoceratus</u> | $W = 47.8 \times 10^{-6} L^{2.75}$ | Kerguelen | Hureau 1966 |

(1) This equation does not fit the results of Dubrovskaya and Makarov (1969) who worked on fish from the same hauls. An approximate conversion ratio based on their results is $W = (0.2L)^3$

W = Total Weight (g)

L = Total Length (cm)

L* = Standard Length (cm)

8.5 Reproduction

There are in the literature few published accounts of seasonal reproductive cycles but the detail that is presented in them has meant that the main patterns identified can be used to provide a reasonable description for those species for which only limited information is available.

Hureau (1964) used the factor "Relative Gonad Size" (gonad weight as a percentage of total weight) from monthly samples to describe the gross cycle in the gonads of Trematomus bernacchii. From these results and the results from several other species of Nototheniid (Hureau 1970, Everson 1970) it is possible to outline a generalised pattern for the ovarian cycle. This is indicated in Fig. 8.2. and with only slight adjustment of the (y) axes could be applied to most of the Nototheniids investigated (Notothenia neglecta (from Scotia Arc), N. rossii, N. magellanica, Trematomus bernacchii, T. hansonii). The exceptions are Notothenia neglecta at Terre Adelie which produces small diameter ova and therefore does not have such a clearly defined cycle and N. cyanobranchia for which there are two spawning periods (those maturing for the first time spawn in January and those that have spawned previously subsequently spawn in May, (Hureau 1970)).

Information on egg size, fecundity and spawning period for those species of potential commercial importance is given in Table 8.19 and this has been combined with information for all Antarctic species to describe major spawning types (Table 8.20).

It is a characteristic of Antarctic fish to produce large yolky eggs and this has been discussed by several authors (Marshall 1953, Andriashev 1965, Permitin 1971, 1973). It is generally considered that large yolky eggs spawned in the Autumn or early winter months will result in the production of post larvae in the Spring coincident with the phytoplankton bloom. These large eggs are also generally considered to be pelagic (or benthopelagic in some cases). The release of large eggs in the spring by Trematomus sp. may indicate a much slower development rate of the eggs and early larvae although there is no proof of this suggestion.

Table 8.19. Egg size, fecundity and spawning period for Antarctic fish

| Species | Egg dia. mm | Fecundity $\times 10^3$ | Spawning Period | Reference |
|---------------------------------|----------------|--------------------------------------|--------------------|----------------------------|
| <u>Micromesistius australis</u> | 0.8-0.9(P) | 50 - 100 | Spring | Hart 1946, Weiss 1974 |
| <u>Merluccius hubbsii</u> | | | December | Ciechowski and Weiss 1973 |
| <u>Notothenia gibberifrons</u> | | | Jul-Aug | Permitin & Sil'yanova 1971 |
| <u>N. neglecta</u> | 3.0(D) | 10 - 30 (12/g Total Weight) | May | Everson 1970 |
| | 3 | 10.1 - 14.7 (8-16/g Total Weight) | | Permitin & Sil'yanova 1971 |
| | 1.2 | 20-30(13-20/g Total Weight) | January | Hureau 1970 |
| <u>N. rossii rossii</u> | 3(D) | 46-53(15-17/g Total Weight) | May | Hureau 1970 |
| <u>N. rossii marmorata</u> | 4.8(D) | 20 - 120 | Apr-May | Permitin & Sil'yanova 1971 |
| <u>N. magellanica</u> | 1.2(P) | 60 -70 (50-58/g Total Weight) | Feb/March | Hureau 1970 |

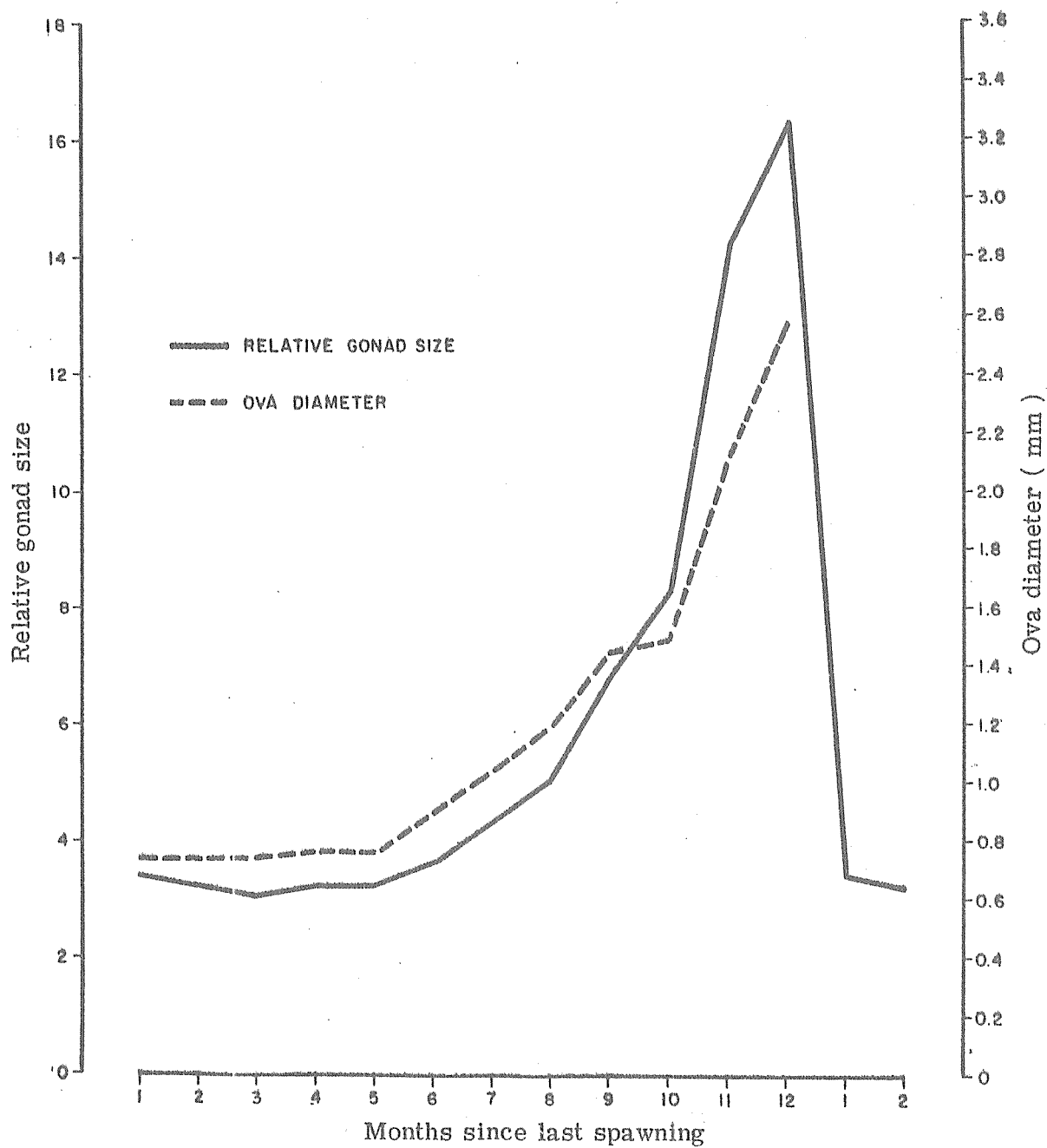


Fig.8.2 Generalized pattern of changes in the ovary of Antarctic notothenids in the pre-spawning period

Table 8.19. (continued)

| Species | Egg diam. mm | Fecundity x 10 ³ | Spawning Period | Reference |
|----------------------------------|-----------------|----------------------------------|------------------------|--------------------------------|
| <u>Dissostichus mawsoni</u> | 4-4.3(D) | | (Nov/Dec) ¹ | Yukhov 1971a |
| <u>Champscephalus</u> | 1.9-2.2 | | April | Olsen 1955 |
| <u>Champscephalus</u> | 3.4-4 | | May | Lönnberg 1905 |
| <u>Champscephalus</u> | 2.6 | 4-23 S. Georgia 8 S. Orkneys. | | Permitin 1973 Permitin 1973 |
| <u>Chaenoccephalus</u> | 4.7 | S. Orkneys | (June) | Everson 1968 |
| | 3.9 | S. Georgia | Mar/Apr | Permitin 1973 |
| <u>Channichthys rhinoceratus</u> | 4.5 | 6 - 14 | Feb/Mar | Hureau 1966 |
| <u>Pseudochaenichthys</u> | 4 | 5.8-10.9 | Mar/Apr | Permitin 1973 |
| <u>Chionodraco</u> | 3.7-5.0 | 2.5-4 | Mar/Apr | Permitin 1973 |

Notes: 1. Comparison of the process of final ovarian maturation in this species with N. neglecta from Signy Island suggests that spawning occurs in the middle of winter and not Nov/Dec.

P = Pelagic Eggs

D = Demersal Eggs

Table 8.20. Egg size and spawning time for Antarctic fish

| Spawning Period | Egg Size (mm) | Species |
|--------------------|------------------|--|
| Spring (Nov. Dec.) | 2.5 - 3.5 | <u>Trematomus bernacchii</u> , <u>T. hansonii</u> |
| Summer (Jan. Feb.) | 1 | <u>Notothernia neglecta</u> (Terre Adelie) <u>N. magellanicus</u> |
| Autumn (Mar.-June) | 2 - 4 | <u>Notothernia nudifrons</u> (<u>N. angustifrons</u>) <u>N. neglecta</u> (Scotia Arc) <u>N. rossii</u> <u>N. kempi</u> <u>N. gibberifrons</u> <u>N. larseni</u> (<u>Dissostichus mawsoni</u>) <u>Champscephalus gunnari</u> <u>Chaenoccephalus aceratus</u> <u>Pseudochaenichthys georgianus</u> <u>Chionodraco</u> sp. <u>Channichthys rhinoceratus</u> |

Hureau 1966, 1970; Everson 1970; Permitin 1971, 1973; Keysner et al., 1974

A series of subjective stages in the gonad cycle of Nototheniids has been described by Everson (in press) based on the ovarian and testis cycles in Notothenia neglecta (Tables 8.21, 8.22).

Table 8.21 Stages in ovarian maturation of Nototheniids based on the cycle in Notothenia neglecta

| Maturity Stage | Description |
|--------------------|---|
| 1. Immature | Ovaries small, firm, no eggs visible to naked eye |
| 2. Maturing Virgin | Ovaries about $\frac{1}{4}$ length of body cavity, firm, full of small eggs |
| 3. Developing | Ovaries large, contain eggs of two sizes |
| 4. Gravid | Ovary large. When opened, large ova spill out |
| 5. Spent | Ovary flaccid, contains a few large and many small ova |

Table 8.22 Stages in the testis cycle of Nototheniids based on the cycle in Notothenia neglecta

| Stage | State | Description |
|-------|------------|---|
| 1. | Immature | Testis very small and translucent, lying close to vertebral column |
| 2. | Developing | Testis small (about 1% total weight), white and convoluted |
| 3. | Developed | Testis large, white and convoluted. No milt produced when pressed or cut |
| 4. | Ripe | Testis large, opalescent white. Drops of milt produced under pressure or when cut |
| 5. | Spent | Testis much smaller and flabbier than stage 4, dirty white in colour |

The seasonal cycle in the ovary of all fish species so far studied, whereby there is a steady build up of eggs all of the same size, indicates that spawning seasons of limited duration are normal. The result of this is that it is to be expected that just prior to and during spawning the mature fish will be congregated together. That this occurs is undoubtedly the case as concentrations of mature fish have frequently been caught on the continental shelf of some of the island groups. The approximate localities and environmental characteristics of these localities are summarised in Table 8.23. It should be borne in mind that the list only includes localities where prespawning or spawning fish have been caught and obviously does not include all spawning areas. It is probably fair to assume that spawning concentrations will occur in similar circumstances to those described in the table over most of the range of each individual species.

Table 8.23. Spawning localities and environmental characteristics of spawning grounds.

| Species | Spawning locality | Environmental Characteristics | | | References |
|--------------------------------------|----------------------|-------------------------------|--------------|--|--------------------------------|
| | | Depth(m) | Temp. °C | | |
| <u>Micromesistius australis</u> | Patagonia | | | Southern part of Patagonian - Falkland Shelf | Shubnikov et al. (1969) |
| <u>Notothenia gibberifrons</u> | S.G. | 115-600 | 0.7 to 1.7 | Shelf | Permitin and Sil'yanova (1971) |
| | S.O., S.S. | 115-750 | -0.1 to -0.4 | Shelf | |
| <u>N. neglecta</u> | S.O., (SG)(SS) Shelf | 10-450 | -0.4 to -1.8 | Shelf | Everson (1970) |
| <u>N. rossii marmorata</u> | S.G., Shelf | 120-350 | 0.7 to 1.7 | North and East side of Island | Permitin and Sil'yanova (1971) |
| <u>N. rossii rossii</u> | Kerguelen Shelf | 250-350 | 1.8 to 2.0 | Rocky shelf SE of Island | Keysner et al. (1974) |
| <u>Champscephalus gunnari</u> | S.G. Shelf | 100-125 | 1.2 to 1.6 | In Fjords and shallow parts of Shelf | Permitin (1973) |
| <u>Pseudochaenichthys georgianus</u> | S.G. Shelf | 115-350 | 1.4 to 1.7 | Shelf to N,S & E | Permitin (1973) |
| <u>Chaenocephalus</u> | S.G. Shelf | 115-350 | 1.2 to 1.5 | Shelf to N,S & E | Permitin (1973) |

(S.G.: South Georgia; S.O.: South Orkneys; S.S.: South Shetlands)

Mention has already been made of the slow growth rate of Antarctic fish. A direct result of this is that sexual maturity is not reached until the fish are several years old. Information on size and age at sexual maturity is set out in Table 8.24. Precise information is not available for most species and several are estimated from the information in the literature.

Spawning migrations have been described in few species although there are indications generally based on negative evidence that several other species perform spawning migrations. Keysner et al. (1974) described a migration of N. rossii in May from the feeding ground north of Kerguelen to the spawning grounds to the south of the Island. The spawning grounds are characterised by high oxygen content and a rocky substrate. The migration itself is thought to be in the same direction as the prevailing current which in the area has a strength of 0.6 to 1.0 kt. The post spawning northward movement in August back to the feeding grounds is thought to be made in a northerly flowing current offshore of the southward flowing current of the spawning migration.

Table 8.24. Age and Size at Sexual Maturity for Antarctic Fish.

| Species | Sex | Sexual Maturity | | | Locality | Reference |
|----------------------------------|----------------|------------------|-------------------|------------|---------------|------------------------------|
| | | Age | Length (cm) | Weight (g) | | |
| <u>Raja georgianus</u> | ♀ | | 60 | | South Georgia | Permitin 1969 |
| <u>Micromesistius australis</u> | ♂ ¹ | (4) ¹ | 45.3 | | Scotia Sea | Shubnikov et al. 1969 |
| | ♀ | (3) ¹ | 46.4 | | | |
| <u>Nototothenia gibberifrons</u> | ♀ | | 35 ⁽²⁾ | 400 | South Georgia | Permitin and Sil'yanova 1971 |
| <u>Nototothenia neglecta</u> | ♂ | 8 | 30 | | Signy Island | Everson 1970 |
| | ♀ | 7 | 29 | | Signy Island | |
| | ♂ | 7 | 18 | 190 | Terre Adelie | Hureau 1970 |
| | ♀ | 8 | 22.5 | 300 | Terre Adelie | Hureau 1970 |
| <u>N. rossii</u> | ♂ | 7 | 48 | 1 700 | Kerguelen | Hureau 1970 |
| | ♀ | 8 | 55 | 2 700 | Kerguelen | |
| <u>N. rossii marmorata</u> | ♂ | 5(min) | 40(min) | | South Georgia | Olsen 1954 |
| | ♀ | 6(min) | 45(min) | | | |
| <u>N. magellanica</u> | ♂ + ♀ | (6-7) | 25 | 500 | Kerguelen | Hureau 1970 |
| <u>Champscephalus</u> | | 4 | | | South Georgia | Olsen 1954 |
| <u>Champscephalus</u> | ♂ | 4 | 21-26 | | South Georgia | Permitin 1973 |
| | ♀ | 4 | 21-25 | | South Georgia | |
| <u>Chaenocephalus</u> | | (9) ³ | | | South Georgia | Olsen 1954 |
| <u>Channichthys rhinoceratus</u> | | 5 | 34 | 435 | Kerguelen | Hureau 1966 |
| <u>Pseudochaenichthys</u> | ♂ | 4-6 | 40-48 | | South Georgia | Permitin 1973 |
| | ♀ | 4-6 | 44-50 | | South Georgia | |
| <u>Chionodraco</u> | ♂ | | 31-36 | | | Permitin 1973 |
| | ♀ | | 33-37 | | | Permitin 1973 |

- 1) This is inferred since the authors state that only sexually mature fish were caught.
- 2) In this paper mention is made only of mature fish; the size quoted is of the smallest specimen. By comparison with my own unpublished observations at Signy Island this would approximate to the size at sexual maturity.
- 3) All the fish were sexually mature and aged 9 or more.

Catch rates of Champscephalus gunnari at South Georgia clearly indicate that this species moves inshore to spawn. Olsen (1955) failed to catch any for several months during the summer but then obtained some good hauls towards the end of March. This pattern of occurrence has been confirmed in recent years by members of British Antarctic Survey fishing in Cumberland East Bay, South Georgia. A similar migration has been described for Channichthys rhinoceratus by Hureau (1966) although for this species the shoreward movement begins in February.

Both Merluccius hubbsi and Micromesistius australis outside the Antarctic zone spawn during the spring. Hart (1946) showed that Merluccius hubbsi on the Patagonian Shelf moves inshore during October and November and Ciechomski and Weiss (1973) describe spawning in December. They also state that the eggs are 0.8-0.9 mm diameter and are pelagic (Ciechomski and Weiss 1974). The plankton survey from which the above information was derived was conducted between latitudes 42° and 47°S off the Argentine coast and eggs were found throughout the region. In view of the fact that sexually mature fish have been caught in the Scotia Sea in January (Mikheyev 1967) it seems highly likely that in view of the distance between these two areas spawning occurs south of 47° although there is no direct information available.

Hart (1946) suggested that Micromesistius australis spawns during the spring and Weiss (1974) has confirmed this from examination of a collection of larvae. Weiss (1974) also considers that spawning occurs deeper than 150 m although no specific area is mentioned.

The presence of mature Micromesistius australis in the Scotia Sea during the Antarctic summer is assumed to indicate that this species migrates into the area from the Patagonian region. However, although this explanation fits the observed seasonal distribution of the species in the Southwest Atlantic, it is not confirmed as it is possible that spawning concentrations in the deep shelf zone have as yet gone undetected.

The literature on larval stages of other Antarctic fish is limited to a few papers describing small collections (e.g., Regan 1916, Nybelin 1951, Everson 1968, Hureau 1970). There is no detailed study of development rates although suitable material almost certainly exists in plankton samples.

8.6 Feeding

Although a detailed analysis of feeding is outside the scope of the present report, some comment should be made in order to gain a better idea of the position of fish in the ecosystem. Available information for those species of potential commercial importance is tabulated in Table 8.25. The preponderance of Nototheniids, a predominantly demersal group, largely explains the high frequency of benthic organisms in the diet. The presence of planktonic organisms as well indicates that for some species at least there is probably some diurnal vertical feeding migration or else opportunistic feeding on planktonic organisms migrating down. Examples of the former are probably Notothenia rossii and Champscephalus gunnari (see Fischer 1976) and of the latter, Raja georgianus and Notothenia neglecta.

8.7 Exploitation

Total Catch

In recent years the total reported catch within the FAO Statistical areas for the Southern Ocean (Areas 48, 58 and 88) has been zero. The reason for this is the two areas known to be heavily fished (South Georgia and Kerguelen) are presently included in statistical reporting areas to the north (41 and 51 respectively). In addition, of the species considered in this review only two have been reported as separate species in the FAO Yearbook of Fishery Statistics. These are Southern Poutassou (Micromesistius australis) and Patagonian Hake (Merluccius hubbsi). There is therefore no precise information available although it has been suggested (Hureau 1973 and Laws unpublished Report) that catches in some areas have been quite large. The following analysis is therefore based on interpretation of the reported catch in relation to the known fisheries of the area.

The reported catch of Southern Poutassou in recent years is set out in Table 8.26.

Table 8.25. Diet of Antarctic Fish.
Figures the percentage frequency occurrence of a particular item.

| | | | | | | | | | | | | | | | | | | | | |
|-------------------------|-----------------|-------------------------|---------------------|---------------------|-----|-----|-------|------------------|----------|----------------|-----|--------------------------|------------------------------|-------------------|--------------------|----------------|-----|--------------|----------------|----|
| Algae | | x | / | | | | | | 18 | 34 | | | | | | | | | | |
| Polychaeta | 10 | 29 | / | | | | | | 6 | 3 | | | x | | | | | | | |
| Gastropoda | | | / | | | | | | 1 | 8 | | | | | | | | | | |
| Bivalvia | | 3 | / | | | | | | x | 19 | | | | | | | | | | |
| Cephalopoda | 2 | 2 | / | | | | | | | | // | / | | | | | | | | |
| Amphipoda | 6 | 10 | // | | | / | | | 40 | 19 | | | x | | | | / | | | |
| Isopoda | 3 | 9 | // | | | / | | | 51 | 40 | | | | | | | | | | |
| Decapoda | 18 | 3 | / | | | / | | | 6 | 24 | | 7 | | | | | 10 | | | |
| Other Crustacea | | 1 | / | | | / | | | | 4 | | | 1 | | x | | | | | |
| Echinodermata | 1 | 6 | | | | | | | | | | | | | | | | | | |
| Other Benthos | | 1 | / | | | | | | | | | | | | | | | | | |
| Cinderia/ Ctenophore | 1 | 8 | / | 82 | 3 | / | / | | | | | | x | | | | | | | |
| Parathemisto | | 1.5 | | 1.5 | 3 | / | / | | | | | | 24 | xx | | | | | | |
| Euphausia | 10 | 11 | / | 4 | 30 | // | / | 6 | | // | | 1 | 38 | // | 48 | 11 | | // | // | |
| Mysideacea | 24 | 5 | / | 1 | 8 | / | | | | | | 7 | 30 | | 2 | 48 | | | | |
| Salps | | x | | | 1 | / | / | | | | | | | | | | | | | |
| Fish | 16 | 1.5 | / | | 3 | / | | | 38 | 16 | | / | 84 | 3 | | 40 | 15 | // | | |
| | SG | SG | SG | SG | SG | SG | SG | K | K | K | O | O | SG | SG | SG | SG | SG | SG | O | SG |
| | (1) | (1) | (2) | (3) | (3) | (4) | (4) | (5) | (6) | (6) | (7) | (8) | (1) | (1) | (4) | (1) | (1) | (9) | (10) | |
| | Raja georgianus | Notothenia gibberifrons | Notothenia neglecta | N. rossii marmorata | | juv | Adult | N. rossii rossii | Juvenile | N. magellanica | | Dissostrictichus mawsoni | Dissostrictichus eleginoides | Champsococephalus | Pseudochaenichthys | Chaenocephalus | | Pleurogramma | Micromesistius | |

References for Table 8.25

- | | | |
|-----|---------------------------|-----------------------|
| 1. | Permitin and Tarverdiyeva | 1972 |
| 2. | Everson | (unpublished results) |
| 3. | Tarverdiyeva | |
| 4. | Olsen | 1954 |
| 5. | Keysner <u>et al.</u> | 1974 |
| 6. | Hureau | 1970 |
| 7. | DeWitt | 1971 |
| 8. | Yukhov | 1971 a |
| 9. | Olsen | 1955 |
| 10. | DeWitt and Hopkins | (in press) |
| 11. | Permitin | 1969 |

- SG South Georgia
 SO South Orkney Islands
 K Kerguelen
 O Oceanic
 x Present but not quantifiable
 / Present
 // Dominant item

Table 8.26. Reported catches of Southern Poutassou (FAO 1976)

| Area * | (metric tons) | | | | | |
|-----------------------|---------------|--------|--------|--------|--------|-------|
| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
| 41. S.W. Atlantic | 7 900 | 5 700 | - | - | 3 200 | - |
| 47. S.E. Atlantic | - | - | - | - | - | - |
| 51. S.W. Indian Ocean | - | 4 700 | - | - | 1 900 | 2 081 |
| 57. S.E. Indian Ocean | - | - | - | - | - | - |
| 81. S.W. Pacific | - | - | 25 800 | 48 500 | 42 200 | 2 055 |
| 87. S.E. Pacific | - | - | - | - | - | - |
| TOTAL | 7 900 | 10 400 | 25 800 | 48 500 | 47 300 | 4 136 |
| U.S.S.R. | 7 900 | 10 400 | 25 800 | 48 500 | 47 300 | 4 136 |

* See attached map. No catches have been reported from the Antarctic zones (48,58,88).

The total reported catch of this species has therefore been taken by USSR but it is not clear what proportion (if any) was taken from waters which are considered Antarctic but are nonetheless north of the Antarctic statistical areas. However, since the published records of fishing for this species refer to catches made in the Scotia Sea, it is very probable that the major part of the reported catch for area 51 was made in that area. (See papers by Basalaev and Petukhov 1969 and Mikheyev 1967). It is not possible to make such a distinction

for the other areas although the reported catch for area 81 was probably taken from the Campbell Plateau (Shuntov 1971).

The reported catch in recent years of Patagonian Hake is set out in Table 8.27.

Table 8.27. Reported catches of Patagonian Hake (FAO 1976)

metric tons

| Area | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|--------------------|---------|---------|---------|---------|---------|-----------|
| 41. S.W. Atlantic | 108 100 | 116 400 | 139 300 | 187 500 | 199 400 | (152 400) |
| Nation | | | | | | |
| Argentina | 87 400 | 92 000 | 102 800 | 151 400 | 162 200 | 109 000 |
| Brazil | 16 700 | 18 200 | 24 000 | 31 600 | 33 600 | (33 600) |
| Germany, Fed. Rep. | - | - | 3 900 | - | - | - |
| Uruguay | 3 700 | 3 700 | 8 500 | 4 500 | 1 500 | 9 800 |
| U.S.S.R | 300 | 2 500 | 100 | - | 2 100 | - |

() = Figures in parentheses are estimated by FAO.

The fact that the bulk of the catches of this species were made by nations whose coastline borders the statistical area 41 suggests very strongly that only a small proportion (if any) was taken in Antarctic waters.

Concerning the other species (mainly Nototheniiforms), those catches that have been made are probably included under the general heading of unspecified demersal Percomorphs. The statistics for this group are summarized in Table 8.28.

Table 8.28. Reported catches of unspecified demersal Percomorphs (FAO 1976)

metric tons

| | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|-------------------------------|---------|---------|---------|---------|---------|---------|
| Antarctic and adjacent areas. | 450,300 | 272,900 | 152,700 | 58,600 | 160,632 | 67,185 |
| Total world reported. | 537,900 | 393,900 | 299,300 | 208,800 | 433,198 | 348,081 |

Fishing vessels of the USSR have been seen fishing in the vicinity of South Georgia (statistical area 41 S.W. Atlantic) (Laws per. comm.) and also off Kerguelen (statistical area 51 S.W. Indian Ocean) (Hureau 1973). From observations of the number of fishing and support vessels in the vicinity of Kerguelen, Hureau (1973) estimated that 120 000 tons of fish (probably Notothenia squamifrons, N. rossii, Channichthys rhinoceratus and Champsocephalus gunnari) were taken during the 1971/72 season. At South Georgia the principal fish species caught is probably Notothenia rossii (my own observations on ships visiting the islands). The reported figures for areas adjacent to Antarctica follow the known distribution of fishing vessels of the USSR in Antarctic waters which strongly suggests that a significant part of this catch is Antarctic Nototheniiform fish (Table 8.29).

In addition exploratory fishing expeditions have gone to the Antarctic from West Germany, Japan and Poland; the total catch of each is very small at the moment. It is not known whether any other nations are taking fish on a commercial scale.

Assuming the above estimates are correct it indicates the inadequacy of the present reporting systems for two reasons; firstly because two of the major fishing areas (South Georgia and Kerguelen) lie outside the present Antarctic statistical regions and secondly the catch of Percomorphs is not broken down into its specific components. An improved format for reporting has therefore been produced (See section 11.2).

Table 8.29. Reported catch of unspecified demersal Percomorphs (FAO 1974,1976).

(metric tons)

| Area | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 |
|---------|--------|--------|--------|--------|----------------------|-----------------------|-----------------------|--------|---------|----------|
| 41 USSR | 1,100 | 12,900 | 5,400 | 89,100 | 404,800 ^x | 16,300 | 2,300 | 400 | 3,900 | - |
| Total | 3,400 | 14,800 | 7,500 | 91,600 | 407,900 | 20,500 | 5,300 | 4,000 | 8,300 | (7,100) |
| 47 USSR | 1,000 | 1,600 | 10,300 | 8,000 | 9,000 | 7,400 | 11,100 | 7,000 | 7,965 | 6,816 |
| Total | 1,000 | 1,600 | 10,300 | 8,000 | 9,000 | 7,900 | 11,900 | 8,000 | 20,065 | 16,895 |
| 51 USSR | 11,400 | 5,300 | 1,300 | 900 | 12,800 | 212,300 ^{xx} | 102,900 ^{xx} | 9,700 | 87,100 | 18,449 |
| Total | 81,500 | 74,900 | 82,400 | 83,100 | 32,800 | 231,500 | 118,700 | 26,500 | 104,011 | (34,037) |
| 81 USSR | - | - | - | - | - | 10,400 | 14,300 | 18,200 | 25,800 | 5,717 |
| Total | 100 | 100 | 200 | 500 | 500 | 11,000 | 15,100 | 19,300 | 27,176 | 8,800 |

() Figures in parenthesis are estimated by FAO.

x Commercial fleets from USSR reported at South Georgia (Laws per. comm.)

xx " " " " " " Kerguelen (Hureau 1973)

Catch Rates

Published information on catch rates is summarized in Table 8.30. It is not known what catch rates were achieved by the recent West German and Polish expeditions although in the case of the former it is thought that the catch rate and maximum haul size were both at least equal to the highest figures quoted.

Table 8.30. Catch rates for Antarctic Fish

| Species | Year | No. of hauls | Mean Catch (t/hour) | Max Catch (t/haul) | Mean Haul Time (min) | Location | Nation | Remarks | Reference |
|---------|-------|--------------|---------------------|--------------------|----------------------|-------------------------------|--------------------------|--|----------------------------------|
| 1, 2 | 1964 | | | 1.5 | | Scotia Sea | USSR | Using krill net/shrimp trawl | Mikhayev 1967 |
| 2 | 1964 | 3? | | 2-4 | | Patagonia | USSR | Bottom trawl? | Mikhayev 1967 |
| 1 | 1965 | 21 | 2.4 | 10 | 85 | Scotia Sea | USSR | Mid-water trawl towed at 2.7-3.6 kn at 25-65 m depth | Basalaeov and Petukhov 1969 |
| 1 | 1970? | | | 9½ | 45 | South of New Zealand | Japan | Bottom trawl? in 100 fathoms | Anon. 1971 |
| 3 | 1970 | 17 | | 12 - 20 | | S. Georgia | USSR | Bottom trawl | Tarverdiyeva 1972 |
| 4 | 1976 | | | 17 | 15 | Obov Bank | Japan | | Anon 1976 |
| 3 | 1970 | | 10 | | | S. Georgia | USSR | Bottom trawl | Everson (unpublished BAS report) |
| 3 | 1971 | | 2 | | | S. Georgia | USSR | Bottom trawl | Everson (unpublished BAS report) |
| 5 | 1975 | 38 | 0.55 | | | Shag rocks near South Georgia | Germany, Federal Rep. of | Bottom trawl 15.5 t/h largest haul | Kock 1976 |
| 5 | 1976 | 3 | 0.008 | | | | | | |
| 5 | 1976 | 10 | 0.3 | | | | | | |

1. Micromesistius australis

2. Merluccius hubbsii

3. Notothenia rossii

4. Notothenia macrocephala

5. Dissostichus eleginoides and D. mawsoni

8.8 Biomass, Production and Yield

The very recent build-up of fisheries in the Antarctic has meant that only limited information on biomass and production is available and this is dispersed in a variety of publications. There is nowhere in the literature a detailed analysis of information suitable for fishery management decisions. The analysis which follows should be considered as a first approximation (as far as Antarctic endemic fish are concerned) that will require updating as more information from the fishery becomes available. The need for precise reporting of catches by species has been clearly understood for some time in most sea areas and it is hoped that the recommendations in Section 11.2 for the Antarctic areas will result in much improved stock estimates in future years.

The joint ACMRR/CARPAS working group on the fish stocks of South America (FAO 1974) gave information (Table 8.31) for Micromesistius australis and Merluccius hubbsii, the two species that are thought to migrate into the Antarctic.

Table 8.31. Fish Stock assessments for Patagonian species which migrate into the Southern Ocean (Data from FAO 1974)

| Species | Biomass (t) | Optimum Sustainable yield (t) | Catch 1972 (t) | 1974 (t) |
|---------------------------|----------------|-------------------------------------|----------------------|-------------|
| <u>Merluccius hubbsii</u> | 3-6 million | 200 000 - 1 800 000 | 125 000 | 190 000 |
| <u>Micromesistius</u> | ? | 800 000 or more | insignificant | 3 200 |

The working group considered the Hake as consisting of several distinct management stocks limited geographically. The above results relate to the most northern group (35 - 45°S) which represents the greater part of the present fishery. It is not clear how these figures can be applied to the southern end of the range, but in view of the slower growth rate suggested by Mikheyev (1967) the optimum sustainable yield is likely to be less in proportion to the biomass at the higher latitudes. There is no information on biomass in the Southern Ocean or on the proportion of the southern stock that migrate further south.

The estimates for Micromesistius are clearly based on very limited information and as with Merluccius there is no information to indicate the proportion of the population migrating south. This information is not likely to become available until commercial fishing takes a much larger proportion of the optimum sustainable yield. Regarding these two species since the available evidence suggests that they are migratory species it is probably best for the time being to assume that catches from the Scotia Sea area are of Patagonian fish.

There is no information on which to base estimates of MSY for stocks of Micromesistius at Kerguelen or South of New Zealand. This should become a management priority now in view of the reported catch of over 40 000 tons in area 81; this was probably taken from the Campbell Plateau area (see Shuntov 1971).

In the section 8.7 it was suggested that a large proportion of the reported catch of "Unspecified Demersal Percomorphs" in some areas adjacent to Antarctic waters was largely made up of Antarctic Nototheniiforms. There is no firm confirmation of this fact, but all available evidence indicates that this is correct.

Reported catches in Area 41 show a rapid build up to a peak of over 400 000 t followed by a rapid decline to a few thousand tons the following years. The decline in total catch can be attributed to two causes, fewer vessels and/or a lower catch rate. The very great reduction in catch rate from 10 to 2 ton/hr indicates a great reduction in stock density. This factor in itself suggests that the total catch in the first few years was something approaching the initial standing stock level. Ignoring natural additions to the population, and assuming that the change in catch rate accurately reflects an 80% drop in population, then the catch would have been 80% of the initial stock. This suggests an initial standing stock of about 500 000 t for the South Georgia Shelf area.

In area 51 (assumed to refer to Kerguelen) the more gradual decline in reported catch suggests that the highest figure was appreciably less than the initial standing stock whilst at the same time since the catches have declined from year to year they are probably still (1974) higher than the MSY. These catch figures therefore indicate an initial standing stock of well in excess of 220 000 and an MSY of less than 80 000 ton/yr.

Information on fish biomass production is available from two additional sources. Everson (1970a) in a detailed analysis of Notothenia neglecta in a small area (part of Borge Bay, Signy Island) estimated that the mean biomass was 194 kg/hectare and that annual production was 66 kg/hectare. The annual production in this study was estimated over the whole demersal phase of the lifespan.

Production by sexually mature fish was only about one third of this. Although this figure is very probably an overestimate of production by the fishable stock there is no information to indicate where a more realistic demarcation should be made. A second estimate of fish production in the Southern Ocean is given by the estimated annual consumption by predators. Estimates for fish consumption by whales, seals and birds have been made by Laws (1977) and Croxall (unpublished MS). These are summarised in Table 8.32.

Table 8.32. Consumption of Antarctic fish by Whales, Seals and Birds
(Data from Laws 1977, and Croxall unpublished MS)

| Group | Fish Consumption in Antarctic (thousands ton/yr) | |
|--------|--|----------------|
| | Initial Stocks | Present Stocks |
| Whales | 4 410 | 1 129 |
| Seals | ? | 7 685 |
| Birds | ? | 6 750 |
| Total | ? | 15 564 |

^{1/} Since preparing these estimates my attention has been drawn to a study of the fish stocks in the Kerguelen area. Hureau (in press) using results from a trawling survey estimated the standing stock of demersal fish to be about 120 000 t and their MSY to be about 20 000 t (or about 0.4 t/km² of shelf area). The disparity between his results and those presented above, is a further indication of the incomplete nature of most of the information necessary for these assessments and underlines the importance of reported catch statistics for fish stock assessments.

The total figure in Table 8.32 is made up of all Antarctic fish species and not just those of potential commercial importance. Total production by those species of potential commercial importance is therefore likely to be less than this figure although by how much is not known. The growth patterns of the fish species within the area, since most belong to the same taxonomic group (Nototheniiforms), may well follow the same sort of pattern. This being the case, the production by sexually mature fish is probably about one third of the total (i.e., about 5 million tons).

The tendency for Antarctic fish to produce large yolky demersal eggs indicates a reliance on the Continental or Island Shelf areas for at least part of their life histories. South of the Antarctic Convergence the Continental and Island Shelves cover an area of approximately $2.2 \times 10^6 \text{ km}^2$ ^{1/}. The total production estimated from consumption by predators averaged over the shelf area is 7.75 ton/km^2 .

The fact that this figure is only slightly larger than the production figure for Notothenia neglecta should not be taken as any indication of precision since both estimates are subject to considerable error because one applies to one species (the dominant one in the study area) in a restricted shallow water area and the other relates to all species over the whole Southern Ocean. The figures should be taken as only an indication that they are of the right order of magnitude rather than being truly representative of the actual situation.

If these figures of production are applied to the $36\,000 \text{ km}^2$ (approx.) of the South Georgia Shelf area, the estimated figures for that area are 230 000 - 280 000 ton production. The production figure applies to the whole demersal lifespan and since only about $\frac{1}{3}$ of this is due to sexually mature fish the production that is of interest to a fishery would be 77 000 ton/yr, and since the stock of sexually mature fish is almost certainly greater than the fishable stock these figures must be overestimates.

These estimates have been summarized in Fig. 8.3.

Erring on the side of caution and therefore taking the lowest figure, a MSY of 50 000 ton/yr is indicated for the South Georgia area.

In the absence of any more sophisticated or precise estimates of production the same estimates if applied to the Kerguelen shelf area (approx. $50\,000 \text{ km}^2$) indicate a total production of 230 000 to 300 000 tons and a production of sexually mature fish of from 77 000 to 100 000 tons. Assuming that the lower figure is a reasonable estimate of MSY this figure is approximately what would be expected from intuitively inspecting the reported catch in recent years (see Table 8.27).

It is important to bear in mind that the production figures discussed above apply, with the exception of those for Notothenia neglecta at Signy Island to all fish within the Antarctic zone. Although the Signy Island study was undertaken on only one species, it is fairly certain that within the area of the investigation Notothenia neglecta was by far the dominant species in terms of biomass. The suggested MSY for South Georgia and Kerguelen are therefore a total for all species in the particular areas. Without knowledge of the proportion of species present it is impossible to partition the MSY even between major groups.

In the absence of any further information, it is reasonable to assume that a figure of approximately 1.5 ton/km^2 (see footnote to p.110) is applicable to the other shelf areas.

^{1/} This figure excludes the major ice shelf zones.

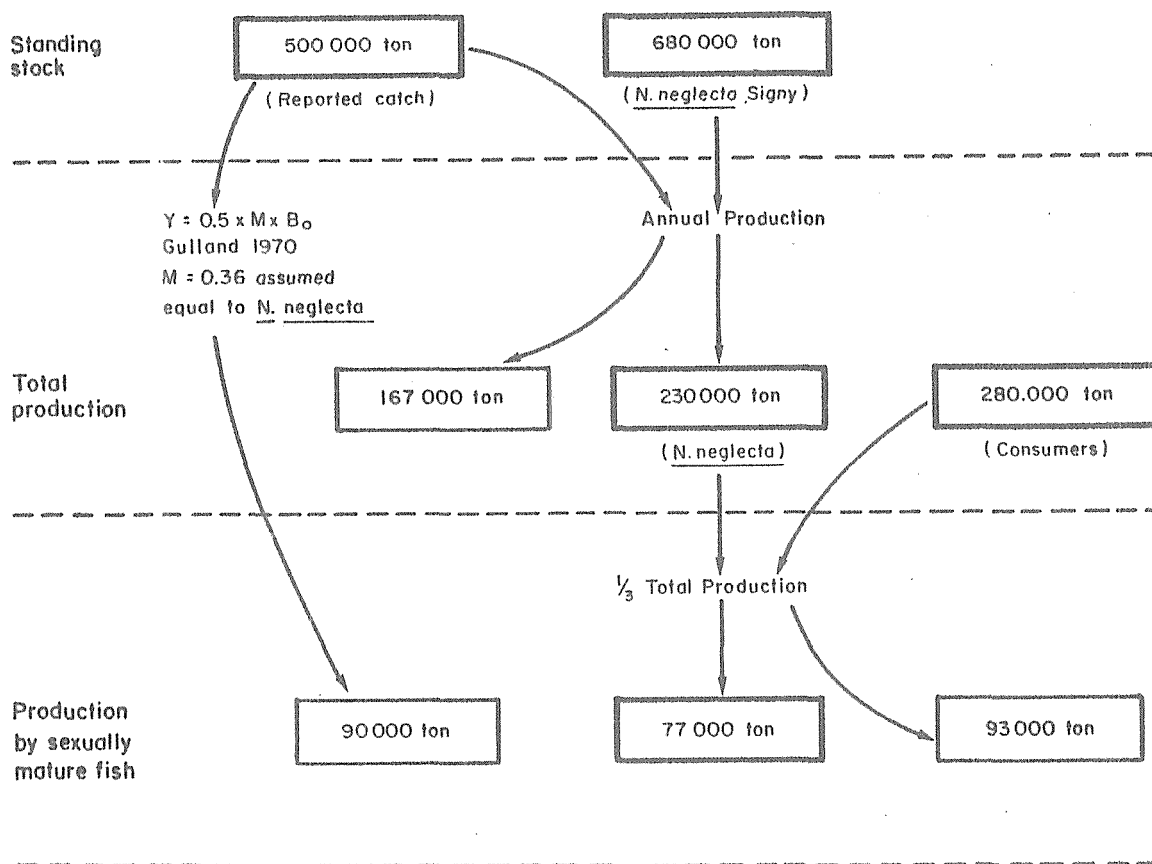


Fig.8.3 Diagrammatic estimation of biomass and production of fish around South Georgia.
(Figures in heavy-lined boxes are based on direct estimates; figures in lighter-lined boxes are based on estimates calculated by the factors shown (see text))

9. WHALES, SEALS AND BIRDS

Although a detailed review of the whale, seal and bird resources of the Southern Ocean is outside the scope of the present paper, there are certain points which should be included here in order to gain a better idea of interactions within the Antarctic ecosystem.

9.1 Whales

There is an enormous body of literature on whales as Southern Ocean resources which has been well reviewed by Mackintosh (1965) and Gambell (1976). Both of these publications contain extensive bibliographies. The species of whale that have been of greatest commercial interest in the Southern Ocean are listed below:

| | |
|--------------------------------|----------------|
| <u>Balaenoptera musculus</u> | Blue Whale |
| <u>B. physalus</u> | Fin Whale |
| <u>B. borealis</u> | Sei Whale |
| <u>B. acutorostrata</u> | Minke Whale |
| <u>Megaptera novae-angliae</u> | Humpback Whale |
| <u>Physeter catodon</u> | Sperm Whale |

Of these species the Blue Whale grows to the largest size (30 m long and 160 metric tons total weight) and was the most valuable to the whaling industry. With the decline of this species the industry turned in succession to the smaller rorquals, Fin, Sei and Minke (see Fig. 9.1), while the significant proportion that Antarctic whaling represented of the total world catch of whales is shown in Fig. 9.2. The changing patterns in the whaling industry, shown in Fig. 9.1 and Fig. 9.2, have been brought about by reduction in abundance due to exploitation rather than a change of preference by the whaling organizations. This decline in the stocks occurred in spite of the efforts of the International Whaling Commission (IWC) to regulate the whaling industry. In the Antarctic, the Commission's earlier regulations limited the length of the whaling season, established minimum-length limits for each species, protected females with suckling calves, and gave complete protection to the Southern right whale and partial protection to the Humpback whale. The Commission also limited the annual overall catch in terms of Blue Whale Units a system which served to slow down the decline in the stocks but failed to halt it because the limits were set too high and also because the system did not take account of the different degrees of protection needed by different species. The Blue Whale Unit system has now been replaced by an annual catch limit for each species. Information on the state of the stocks of the different species is given in the report of the Scientific Committee of the IWC which is published in the Commission's Annual Reports. Current best estimates for the stocks are given in Table 9.3.

The stock assessment figures given (Table 9.3.) refer only to the Southern Hemisphere since it has been shown that for the most part it is only Southern Hemisphere individuals (and then not all of Sperm Whale) which migrate into the Southern Ocean. The general migration pattern shown in Fig. 9.3 shows the importance of the Southern Ocean as a feeding ground for all the major species. The planktonic species that form a significant part of the diet of whales are listed in Table 9.2. In addition to these planktonic organisms squid and fish are also taken and Laws (1977) has calculated the amounts of each of the major food groups (Table 9.1) consumed annually by the estimated initial and present whale stocks. In Table 9.1 krill is assumed to include all species in Table 9.2 that occur south of the Antarctic Convergence and not just Euphausia superba.

The enormous reduction in the larger baleen whale stocks has almost certainly led to a relative increase in food availability for the whales and all the other consumers of krill fish and squid. Some effects of this relative increase have already been recognised.

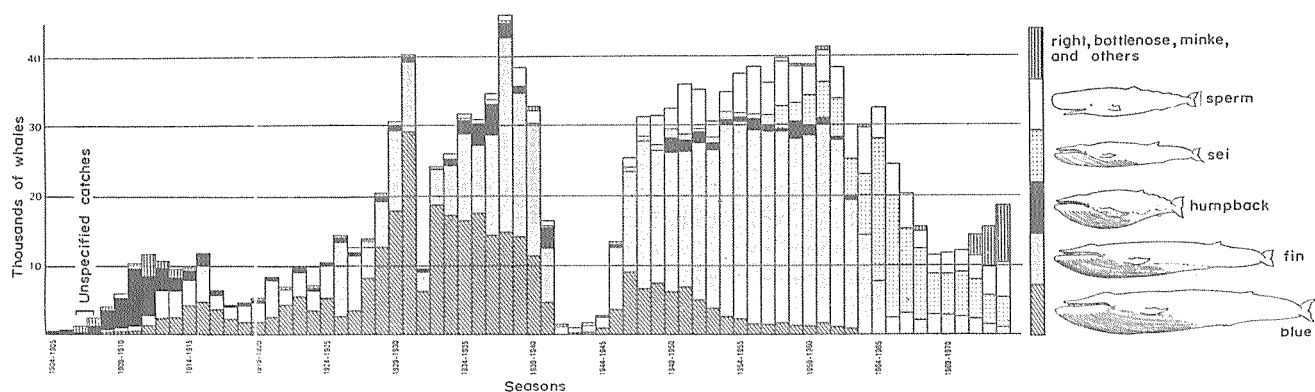


Fig. 9.1 Catches of large whales in the Antarctic (from Brown et al., 1974)

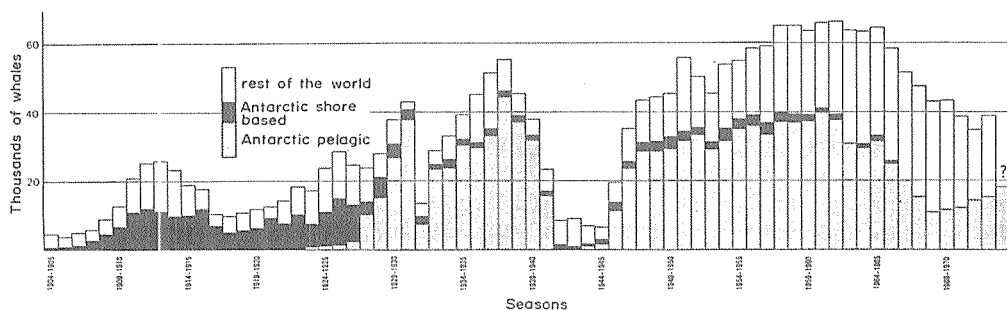


Fig. 9.2 World catches of large whales showing the predominance of Antarctic whaling (from Brown et al., 1974)

Note the sharp increase in pelagic whaling in 1929 and the great preponderance of Antarctic whaling over that of the rest of the world from then until the 1960's. Reduction of Antarctic stocks and the growth of the industry in the North Pacific, especially of sperm whaling, have now reversed the ratio. Shore based whaling in the Antarctic (at South Georgia) ceased after the 1965 - 1966 season.

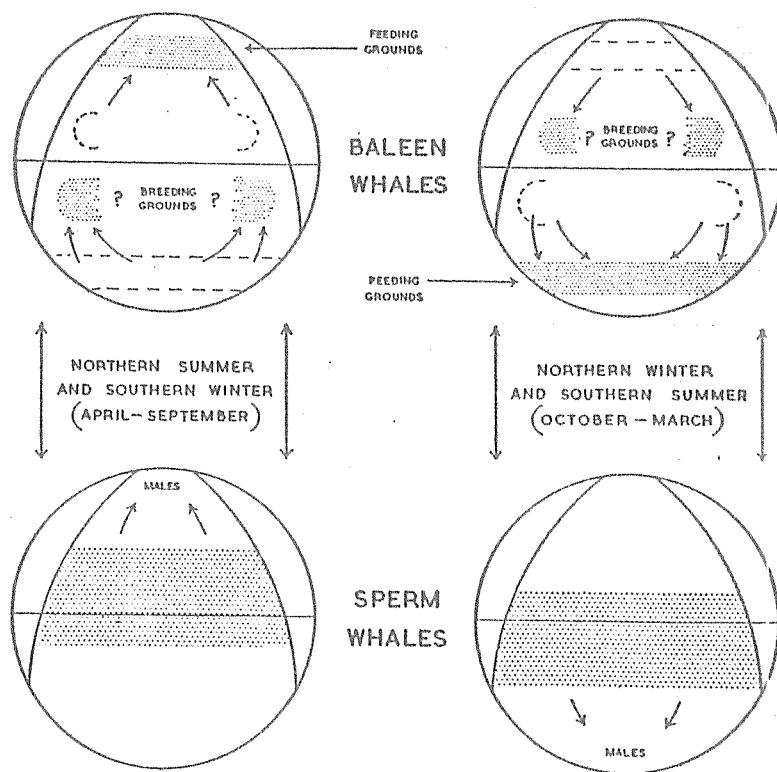


Fig.9.3 The general form of the migration of large whales (from Mackintosh (1965))

Table 9.1. Estimates of annual food consumption by whales in the Southern Ocean
(Data from Laws 1977).

('000 metric tons)

| Whale species | Consumption by initial whale stocks of | | | Consumption by present whale stocks of | | |
|---------------|--|-------|--------|--|-------|-------|
| | Krill | Fish | Squid | Krill | Fish | Squid |
| Blue | 71 700 | 1 478 | 740 | 3 400 | 70 | 35 |
| Fin | 81 500 | 1 680 | 840 | 16 400 | 339 | 169 |
| Sei | 5 700 | 116 | 58 | 2 900 | 60 | 30 |
| Humpback | 11 000 | 227 | 113 | 300 | 7 | 3 |
| Minke | 19 800 | 409 | 204 | 19 800 | 409 | 204 |
| Sperm | - | 500 | 10 200 | | 244 | 4 632 |
| Total | 189 700 | 4 410 | 12 155 | 42 800 | 1 129 | 5 073 |

Table 9.2. Planktonic food of Baleen Whales
(Nemoto 1968)

| Food Species | Whale Species | Locality |
|----------------------------|-------------------|-------------------------|
| <u>Euphausiacea</u> | | |
| Euphausia crystallorophias | Blue, Minke | Continental Shelf |
| E. superba | All Baleen whales | S. Ocean |
| E. vallentini | Blue, Fin, Sei | Antarctic Convergence |
| E. frigida | Blue, Fin | S. Ocean |
| Thysanoëssa macrura | Blue, Fin | S. Ocean |
| T. vicina | Fin | West Wind Drift |
| <u>Amphipoda</u> | | |
| Parathemisto gaudichaudii | Sei | Antarctic/Sub-Antarctic |
| <u>Copepoda</u> | | |
| Drepanopus pectinatus | Sei | Antarctic Convergence |
| Calanoides acutus | Fin, Sei | S. Ocean |
| Calanus propinquus | Fin, Sei | S. Ocean |
| <u>Decapoda</u> | | |
| Munida gregaria | Sei | Sub-Antarctic |

Table 9.3. Stock Assessments for Southern Hemisphere Whales

| Species | Original Stock size ($\times 10^3$) | MSY ($\times 10^3$) | Present Stock size ($\times 10^3$) | Authority |
|-----------|---------------------------------------|-----------------------|--------------------------------------|--------------|
| Blue | 150 | 3-4 | 5-10 | Chapman 1974 |
| Fin | 400 | 8 | 80 | IWC 1976 |
| Sei | (160) | 4 | 89 | IWC 1976 |
| Minke | 140 | ? | 122 | IWC 1976 |
| Humpback | 90-100 | 2-4 | 1.7-2.8 | Chapman 1974 |
| Sperm (0) | 225 | 7 | 112 | IWC 1976 |

Laws (1962) found that in fin whales the first few years growth was faster and that the age at which physical maturity was achieved was reduced as exploitation lowered the standing stock. More extensive data on the extent and timing of the changes in the age at sexual maturity have been given by Lockyer (1972). As has already been mentioned, there are likely to be fairly large year to year variations in krill abundance which Holt (unpublished MS) has suggested would be expected to cause variations in growth rate and age at physical maturity in the "initial" (relatively unreduced) stocks of whales. That this occurred is almost certainly true although the data available are probably not good enough to prove the point. They do, however, suggest a possible mechanism to explain the observed changes. Year to year fluctuations in krill abundance imply that as regards whale feeding there are "good" and "poor" krill years. The initial whale stocks, since they would theoretically be at or near maximum would, in the several years during which they grow to sexual maturity, experience a proportion of good and poor krill years. The reduction in the whale stocks would mean that because of the lowered feeding pressure the years during which krill abundance was low would no longer (necessarily) be poor krill years. Thus, the reduced whale stock would be likely to experience a greater proportion of good krill years. On the assumption that growth is faster in good krill years this would mean that the overall growth rate leading to physical maturity would depend on the proportion of fast growing years during that phase of the whale's life. Thus the age at physical maturity may reflect relative krill abundance during the previous few years.

Another factor that has been shown to have changed at the same time as the whale stocks declined is the pregnancy rate. With data collected before the Antarctic stocks became heavily taxed by pelagic whaling, Mackintosh and Wheeler (1929) found the ratio of pregnant to non-pregnant blue and fin whales consistent with a rate of one calf every two years. After some years of heavy pelagic catching an increase in the pregnancy rate was noted by Mackintosh (1942) who suggested it might be a reaction to whaling. Laws (1961) examined the early data in conjunction with information from post-war catches and showed that the ratio probably increased from 50 to 80 percent by 1940/41, declined during the war and returned to about 80% soon afterwards. The speed with which these changes have occurred is consistent with the ratio depending on relative food availability - the higher ratios being associated with high relative krill abundance in the past year or perhaps two.

The changes described above are discussed in relation to krill and its other consumers in a later section 10

9.2 Seals

There are in the literature several good reviews on Antarctic seals, e.g., Gilbert and Erickson (1977), Laws (1977) and Scheffer (1958). In addition major studies on individual species have been made by Stirling (1969, 1971 and 1971a) for Weddell seal; Bertram (1940) for Weddell and Crabeater seals; Laws (1953 and 1953a, 1956 and 1956a) for Elephant seal and Bonner (1968), Payne (1977) for the Fur seal. Only a brief account will therefore be given in this paper of the information relating to seals as resources and as components of the ecosystem.

The history of the exploitation of seals in the Antarctic goes back much further than that of whaling. The discovery of large colonies of fur seals on the sub-Antarctic islands almost inevitably led to their exploitation and almost total extermination. The highly lucrative fur trade during the first part of the nineteenth century was the major reason for in the rise and collapse of this uncontrolled and by present day standards particularly brutal industry. The decline of the fur seal forced the sealers to look to other resources with the result that the Elephant seal (Mirounga leonina) became the target. However, since the industry during this period was based on the extraction of oil from blubber (Elephant seal hide being useless for production of leather), a product commanding a much lower price, the industry became uneconomic before exploitation had reduced the stocks to a critically low level. With the establishment of shore-based whaling at South Georgia at the start of the present century it once again became an economic proposition to harvest seals. Although

the industry was under far stricter control than previously, there was evidence of over-exploitation which was corrected by a revised management policy effective from 1953. The history of sealing in the Antarctic is described in detail in Bonner and Laws (1964) from which the above very brief account was abstracted. The same paper also contains a great deal of useful biological information on Antarctic seals.

The only member of the family Otariidae which breeds south of the Antarctic Convergence is the Antarctic Fur Seal, *Arctocephalus gazella*. Probably the largest breeding colony of this species is to be found at South Georgia. The expansion in this stock, based on the number of pups observed on the breeding beaches is set out in Table 9.4.

Table 9.4. Fur Seal population size at South Georgia
(Bonner 1964, Payne 1977)

| Year | Stock Size |
|--------|------------|
| 1930's | about 100 |
| 1957 | 15 000 |
| 1976 | 350 000 |

The estimated stock sizes from all areas are set out in Table 9.5.

There is currently no commercial exploitation of this species although it does yield a high quality pelt. It is therefore to be expected that the stock size will continue to increase although for how long the present rate can be maintained is not known. The expansion may have been facilitated by the relatively increased abundance of krill (the staple food at South Georgia) due to the reduction in whale stocks.

A more detailed review of this species is beyond the scope of the present paper. However, further information is available in Bonner (1968) and Payne (1977).

Table 9.5. Estimated stock sizes for Antarctic Fur Seal
(ACMRR 1977)

| Locality | Stock Size | Reliability |
|--------------------|-------------------------------------|-------------|
| South Georgia | 350 000 | good |
| South Orkney Is. | 1 000 | poor |
| South Sandwich Is. | 5 000 | poor |
| Bouvetøya | 1 000 | poor |
| South Shetland Is. | 3 000 | poor |
| Isles Kerguelen | Unknown, if present probably few | |
| Heard/McDonald | 3 000 | ? |

The five species of the family Phocidae found in the Southern Ocean and their estimated stock sizes are listed in Table 9.6.

Table 9.6. Species and stock sizes of Antarctic Phocid species

| Species | | Stock Size (x 10 ³) | Reference |
|----------------|-------------------------------|------------------------------------|---------------------------|
| Elephant Seal | <u>Mirounga leonina</u> | 600 ± 100 | Laws 1960, 1973; ACMRR |
| Crabeater Seal | <u>Lobodon carcinophagus</u> | 15 000 | Gilbert and Erickson 1977 |
| Ross Seal | <u>Ommatophoca rossi</u> | (220) | Gilbert and Erickson 1977 |
| Leopard Seal | <u>Hydrurga leptonyx</u> | (500) | ACMRR |
| Weddell Seal | <u>Leptonychotes weddelli</u> | (750) | ACMRR |

The only one of these species to have been taken commercially is the Elephant Seal (see earlier section) although none are taken at the present. The large crabeater seal stock indicated that it might sustain a moderate commercial harvest although there is currently no economic market for any resulting products. While no commercial fishing now exists, arrangements have been set up, under the "Convention for the Conservation of Antarctic Seals", signed in 1972, to ensure that if any new exploitation does start, it will be adequately controlled.

The trophic relationships of Antarctic seals are of particular interest in order to obtain a complete understanding of the Antarctic ecosystem. The major food preferences and recorded biological changes are summarised in Table 9.7.

Table 9.7. Dominant food of Antarctic seal species

| Species | Food Species | Notes |
|-----------|--|---|
| Fur | Krill | Rate of increase in S. Georgia stock may be higher due to relatively high krill abundance now. |
| Elephant | Fish | Inshore waters |
| | Fish and Squid | Oceanic |
| Crabeater | Krill | Age at puberty appears to have advanced probably as a result of increased relative krill abundance. |
| Ross | Cephalopods | Probably does not compete for food with other species due to habitat preference |
| | Fish | |
| Leopard | Opportunistic predator Seal pups, Penguins, Krill and Fish | |
| Weddell | Fish | |

The food types specified in Table 9.7 may not be a fair year-round reflection principally because several species disperse during certain times of the year, to unidentified or unsampled areas. The Antarctic Fur Seal although known to be feeding on krill during the summer at South Georgia could be feeding on a variety of organisms during the winter. It is fairly certain they must be feeding during this period in order to attain peak physical condition for the pupping season although the winter feeding areas are as yet unidentified. The Crabeater seal is thought to feed for eleven months of the year on krill (Øritsland 1977) which suggests that krill swarms are a year-round phenomenon (see krill section).

The amounts of the various food types consumed by seals have been estimated by Laws (1977) and these are set out in Table 9.8.

Table 9.8. Consumption of major food components by Antarctic seals
All figures are thousands of metric tons

| Species | Krill | Fish | Cephalopoda |
|-----------|--------|-------|-------------|
| Crabeater | 63 200 | 2 017 | 1 345 |
| Leopard | 5 200 | 182 | 112 |
| Ross | 80 | 196 | 571 |
| Weddell | — | 2 232 | 463 |
| Elephant | — | 3 000 | 3 000 |
| Fur | 120 | 58 | 59 |
| Total | 68 600 | 7 685 | 5 550 |

The trophic relationships of the various seal species and their food organisms are discussed in relation to the Southern Ocean ecosystem in a later section.

9.3 Birds

The literature on Antarctic birds is very large, and since only a few features of bird biology are of direct relevance to marine resources and their exploitation, the reader is referred to the following publications for more detailed and wide ranging information. Stonehouse (1964) and Watson *et al.* (1971) for general information and Watson (1975) for the most recent detailed information on all species.

The extreme mobility of birds inevitably means that the Antarctic Convergence represents a physical barrier for few, if any, species. However, for many species the breeding localities are restricted to fairly narrow latitudinal bands which because of the very high areal ratio of ocean to land between 50°S and 65°S means that the breeding colonies are concentrated in a few small islands. It is probably no coincidence that these same latitudes encompass most of the richer feeding grounds and also tend to have continuously favourable winds. The result of this is that islands such as South Georgia and Kerguelen have the greatest diversity of breeding bird species (Table 9.9). The restriction of major breeding areas to those outlined in Table 9.9 results in the concentration of a large proportion of the population (breeding birds) in a relatively small area (Watson *et al.* 1971 suggests that most adult sea birds do not range more than a day's flight away from the nest site during breeding). The non-breeding birds can and do range over the whole Southern Ocean, a factor that Murphy (1964)

summarised by saying "Antarctic birds can feed where they wish, but must breed where they can". The breeding birds, particularly since during the middle and latter parts of the summer they will be feeding chicks, are therefore likely to have their greatest impact on food concentrations in fairly localised areas relative to the whole Southern Ocean. Whether or not this impact has an easily measurable effect on the food organisms is unknown. There is however the possibility that changes in abundance of food could result in easily measurable changes in breeding colonies. Although nobody would claim that this is the best way of monitoring the krill stocks it does give a quantifiable indication of change that could be of use in gaining a better understanding of ecosystem dynamics.

Table 9.9. Numbers of species of Antarctic bird breeding (By Locality)
(From Stonehouse 1964 Prince and Payne in press).

| Group | Antarctic Coast | Ant. Pen. North of 69oS | Scotia Arc. | South Georgia | Bouvet/ayer | Heard Is. | Kerguelen | Total Species Considered |
|---|-----------------|-------------------------|-------------|---------------|-------------|-----------|-----------|--------------------------|
| Sphenisciformes (Penguins) | 2 | 4 | 5 | 5 | 3 | 4 | 4 | 7 |
| Procellariiformes (Albatrosses and Petrels) | 7 | 6 | 8 | 17 | 7 | 9 | 23 | 25 |
| Pelecaniformes (Cormorants) | - | 1 | 1 | 1 | - | 1 | 1 | 2 |
| Anseriformes (Ducks) | - | - | - | 2 | - | - | 1 | 2 |
| Charadriiformes (Gulls and Terns) | 3 | 5 | 4 | 4 | 1 | 4 | 5 | 7 |
| Passeriformes (S. E. Pipit) | - | - | - | 1 | - | - | - | 1 |
| Total | 12 | 16 | 18 | 30 | 11 | 18 | 34 | 44 |

In spite of the fact that for various logistic reasons birds have to gather in restricted areas to breed there have been very few estimates made of the breeding stocks. Holdgate (1967) discussing the information available at that time concluded that there was a standing stock of 0.12mg of birds per square metre of sea surface. Birds are however known to be high energy users relative to their weight and so a standing stock figure is of only limited use in an ecosystem analysis. A recent analysis has been made of standing stock and food consumption by Croxall (unpublished MS 1977, and in preparation) which is summarised in Table 9.10. These figures have been derived from a literature survey in conjunction with information from a detailed research programme being undertaken by J. Croxall and P. Prince (British Antarctic Survey) at South Georgia which in part aims at studying the trophic relations of antarctic sea birds.

Table 9.10.

Standing stock and food consumption by Antarctic birds (from data supplied by J. Croxall, British Antarctic Survey).

| | Penguins | Other Species | Total |
|--|-----------|---------------|---------|
| Standing Stock (ton x 10 ³) | 487 | 48 | 535 |
| Total food consumption (M ton) | 20 - 27.5 | 6 - 8.5 | 26 - 36 |

Based on dietary analyses made by P. Prince the total food consumption figures have been divided into three major categories as follows:

| | |
|-------|-------------------|
| Krill | 14.7 - 20.3 M ton |
| Squid | 5.9 - 7.9 M ton |
| Fish | 5.7 - 7.8 M ton |

The bulk of the krill is taken by penguins which, since they have only a limited foraging range away from their nesting sites means that during the breeding season there may be very high local predation. An example of the localised cropping of krill is given in Table 9.11 in which data on the consumption of krill by Macaroni and Gentoo penguin chicks in the period, from hatching to fledging is given. Bearing in mind that the foraging birds spend no more than about 20hr travelling between their nesting site and the feeding ground the foraging area available to the penguins nesting on a particular island is quite small. The results set out in Table 9.11 are based on a current survey at South Georgia which indicates that the chicks alone consume about a million tons of krill whilst on the rookeries. This figure is very near to the standing stock of krill around South Georgia estimated by Bogdanov (1974) which, even allowing for probable errors in estimation, suggests that locally birds are one of the major predators on krill and could be useful indicators of changes in krill abundance.

Table 9.11.

Estimates of the amount of krill feed to the chicks of two species of penguin at South Georgia (Data supplied by J. Croxall, British Antarctic Survey), feed size is derived from field observations (during 8 - 11 February 1977 for Macaroni Penguin and 25 - 26 January 1977 for Gentoo Penguin) and population size from field counts by a variety of methods.

| Species | Hatching | Feed Size (kg) | Period Hatching To Fledging (Days) | Population (Pairs) | Chick Food Consumption (Tons) |
|---------------------|-----------------|-------------------|--|-----------------------|-------------------------------------|
| Macaroni Penguin | End December | 0.6 | 60 | 25 Million | 900,000 |
| Gentoo Penguin | End November | 0.8 | 87 | 250,000 | 34,800 |

10. TROPHIC RELATIONS

Descriptions of the Antarctic ecosystem have been made by several workers. Hart (1942) outlined the major qualitative relationships in the marine food web and more recently Holdgate (1967) discussed the available information on production and biomass in the whole Antarctic (marine, freshwater and terrestrial habitats). The extrapolations and in many cases almost total lack of information in Holdgate's study highlighted how little was known in quantitative terms of the ecosystem interactions. The central position of krill in the Antarctic marine food web clearly underlines the importance of understanding the quantitative relationships between the exploitable resources. A full understanding of these cannot be reached without some consideration of the other major components which underlines the need for a full ecosystem analysis as an extension of the detailed analyses necessary for the management of each resource.

The major qualitative interactions of particular relevance to resources are indicated in Fig. 10.1 which is a synthesis derived from much of the information set out in earlier sections. Although the Southern Ocean ecosystem is frequently considered a "simple" one Fig. 10.1 does indicate that simple in this context is only true by comparison with other marine areas. The representation of the food web has therefore been further simplified by amalgamating some groups and excluding those which probably only have a minimal effect on the major resources. As far as is feasible these interactions have been quantified using "present day" estimates for consumption (Fig. 10.2). The figures for production used in this figure have, with the exception of those for primary production, been based on the estimated consumption by predators, i.e., the amount of food that would be required to account for the observed consumer population production. In making these calculations it has been impossible to make an allowance for the effect of differing food availability. It is widely believed that food availability has changed in recent times due to the reduction in whale stocks, however very little is known concerning the nature and magnitude of any change, or how this change in the relative abundance of food has affected the consumer stocks. It is therefore impossible to extrapolate back to determine the consumption before whaling made a great impact on the stocks. It should also be noted that there is very little information on squid or fish. Based on consumption figures squid production is estimated to be 17.6 million tons and assuming a 10:1 conversion ratio and that the diet of Antarctic squid is 50% krill this suggests that they consume 85 million tons of krill which, on this estimate, suggests they may well be the largest krill consumer. However, the fact that the conversion factors are little more than intelligent guesses means that a figure for total krill consumed is unobtainable at the moment. Added to this the fact that there is no information to indicate the proportion of the krill production that is actually consumed by predators shows that on this basis with the presently available information it is impossible to provide a realistic estimate of krill production based on consumption by predators.

The same types of problems arise in trying to estimate krill production by reference to primary production. The large variation in the estimates of total Southern Ocean primary production puts an immediate several-fold range which, coupled with the limited information on conversion ratio and the proportion that krill represents of the herbivorous zooplankton results in an even wider range to the estimated krill production. This is set out in Figure 10.3. (See sections on krill and zooplankton for information on conversion ratio and the proportion that krill represents of the zooplankton).

Analyses of the ecosystem, considered as a whole, can provide some insight into a wide range of problems in the pure and applied fields. Practical problems include:

- (a) Estimation of production at different trophic levels.
- (b) Study of the effects of changes in predator (or prey) stocks on the stocks of prey (or predators).
- (c) Estimation of the indirect effects of harvest by man.

The medium
some main factors: Light, Circulation, Temperature

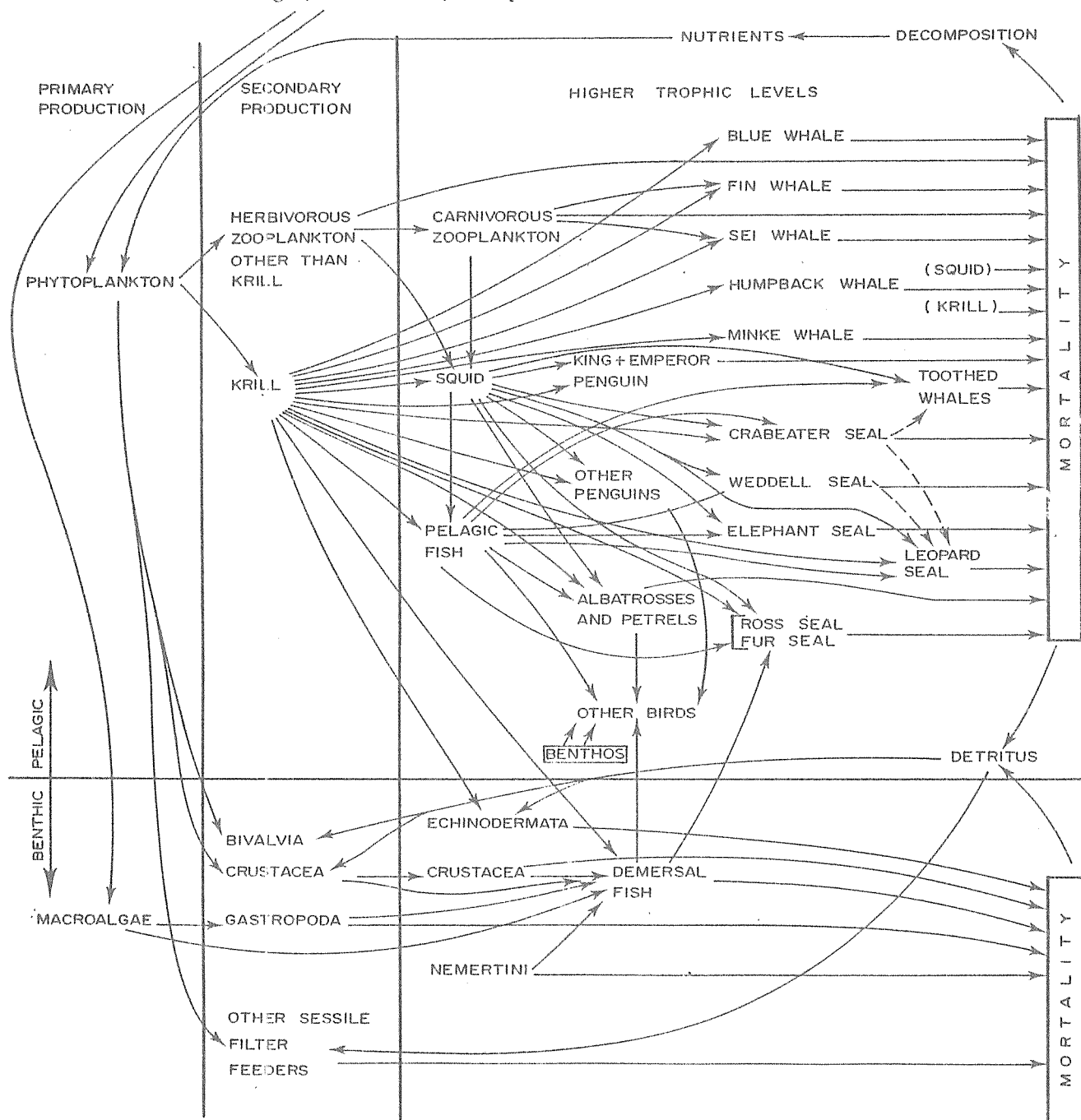


Fig.10.1 Important links in the food chain in the Southern Ocean

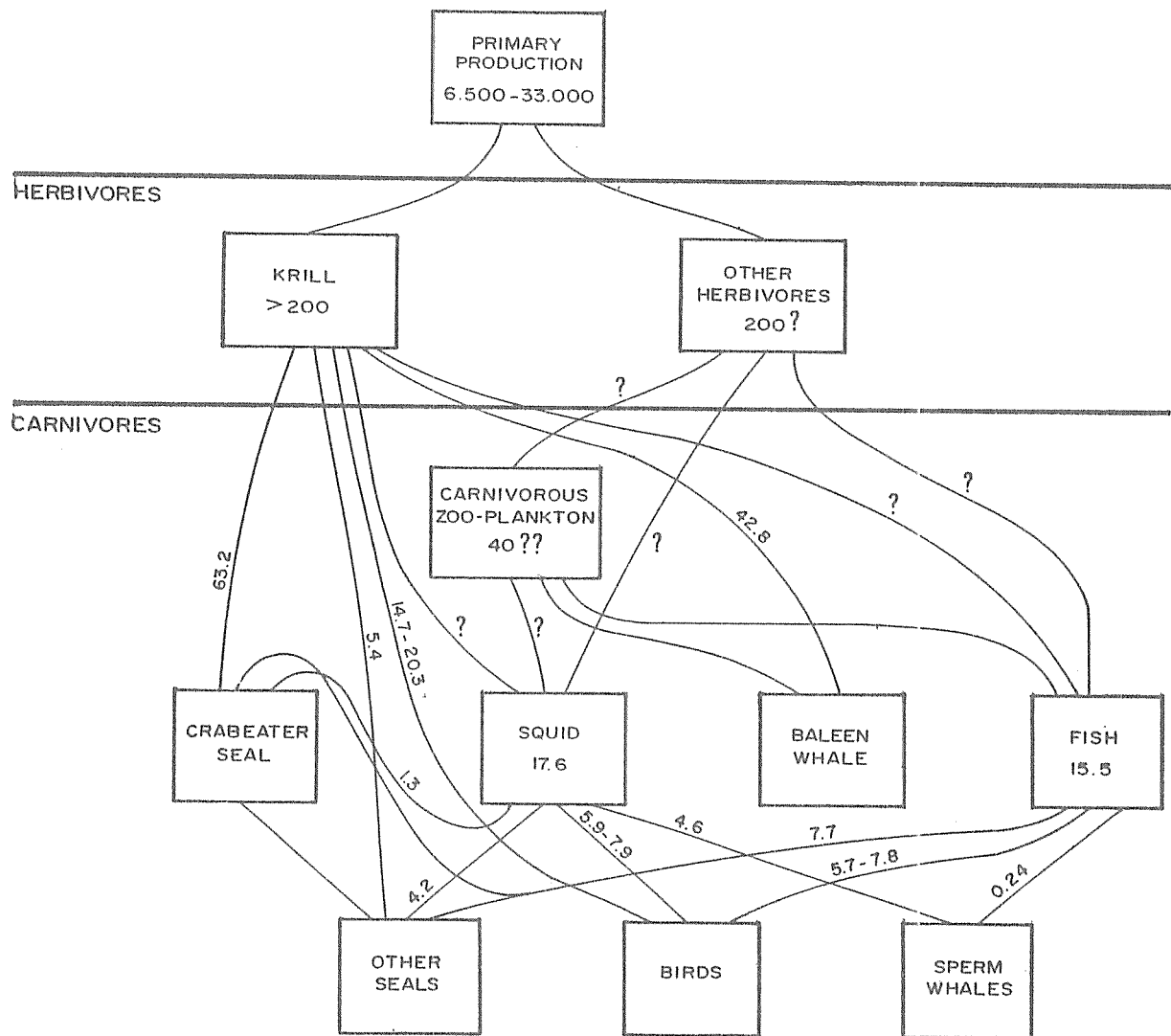
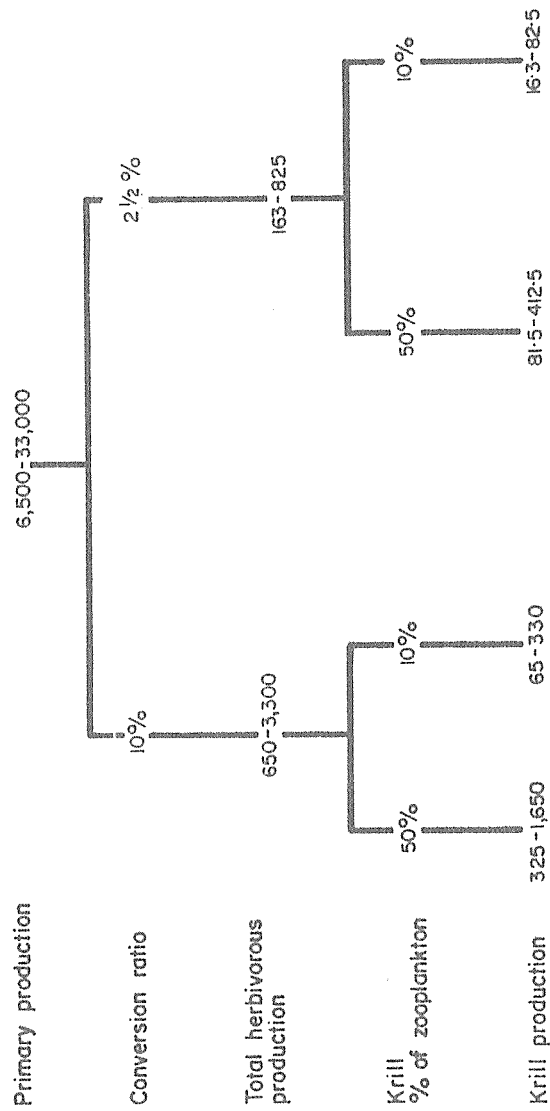


Fig.10.2 Main quantitative interactions between groups of animals in the Southern Ocean. Figures in boxes denote annual production at each stage and those alongside lines, annual consumption, in millions of tons

A. Deduction from primary production



B. Deduction from consumption

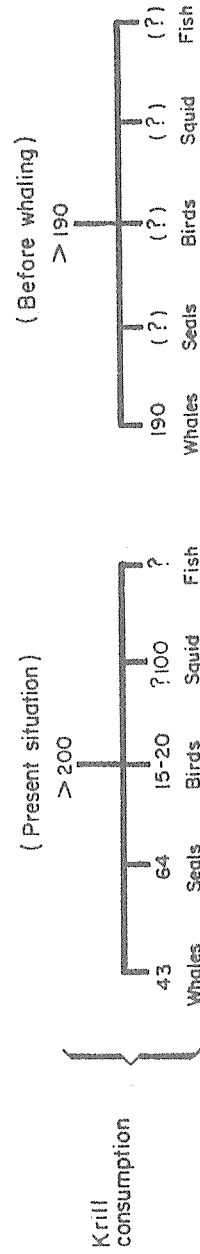


Fig.10.3 Diagrammatic methods of estimating production of krill (figures in millions of tons)

Techniques of analysis and modelling are already sufficiently advanced for models to be constructed that describe these problems, and provide quantitative results. However, the present knowledge of the form of many of the links between different elements of the ecosystem, and especially of the quantitative relations, is far from being good enough to put much reliance on the actual numbers obtained. The results of ecosystem studies at the present time are likely to be more valuable in suggesting the nature of inter-relations, and of the likely indirect long-term effects of say large-scale krill harvest. They may be particularly useful in suggesting specific observations or lines of investigation that would be needed to produce estimates that will in fact be quantitative and realistic.

In the Southern Ocean ecosystem it is probably unrealistic to attempt to refine the estimates of production at each trophic level by analysis of predation rates since even if consumption by each predator were accurately known there would be no guarantee that the final summation would be a reliable total figure. It is better to aim at quantifying production directly using either existing models or, in the case of krill, models specifically tailored to the problem.

Quantifying the effects of changes in predator and prey stocks and assessing the effects of a fishery presents rather more problems. Changes in abundance are brought about by a variety of causes and although all are important in gaining a full understanding of interactions within the ecosystem only a few are of immediate importance in determining how exploitation will affect the balance. A general description of these changes is given in Table 10.1.

Changes in abundance of the various components of the food web may be for convenience divided into two types - those concerned with interactions between the components at the krill level and above (predator/prey and fishing type interactions), for which in the first instance it will be necessary to assume krill production is constant, and those concerned with factors controlling krill production.

Considering first changes in abundance at the predator/prey level. The one group of krill consumers that are known to have changed in abundance and for which there is information on the magnitude of some of the changes are the baleen whale stocks. The consumption of krill by baleen whales is estimated to have been about 190 million tons a year around 1900 whereas their consumption of krill nowadays is estimated to be around 43 million tons. In the prewhaling era there must have been an equilibrium established between krill, whales and the other krill consumers. The whaling industry will have upset this equilibrium for a period (of at present incalculable duration) such that now the whales are consuming less krill. If now man takes x tons where $x = (\text{whale's krill consumption 1900} - \text{whale's krill consumption 1970})$ then presumably as far as food availability is concerned the other consumers are at least as well off now as they were in 1900 and whales will per capita be as well off or better than in 1900. In this simplistic approach one concludes that the whales will not decrease but on the other hand they may not continue to increase.

Although this is a reasonable initial hypothesis it does presuppose that the state of the other stocks of krill consumers is dependent on the whale stocks. However, to a certain extent the whales since they are utilising the same food will be dependent on the other consumer stocks. The two have therefore some dependence on each other and both are dependent on the krill. The question that then arises is - Is this dependence going to have a radical effect on krill consumer stocks in the event that a large krill fishery develops? In the case of the unexploited resources it is to be expected that a change in food availability will not produce a disproportionate change unless the stock size at its new level becomes more dependent on other factors such as social structure than on food availability. Thus within fairly broad limits the hypothesis would seem reasonable.

A second important shortcoming of the hypothesis is that it gives no indication of the effects of different fishing strategies on both whales and krill. The important question that remains unanswered is "How many whales and how much krill could be taken simultaneously"?

A dynamic model to gauge this has not so far been produced and yet it is essential if the resources are to be managed better than by a trial and error approach. The logical extension of such a model is to incorporate the other major krill consumers and this should be an objective of some priority.

Table 10.1. Factors leading to changes in abundance and their importance in relation to fisheries

| <u>Item in Food Web</u> | <u>Type of Change in Abundance</u> | <u>Relative Importance</u> |
|-------------------------|--|---|
| Krill | Long term trend due to abiotic factors | Minor importance initially. Will become more important in refined models. |
| | Year to year fluctuations | Minor importance initially. Could influence exploitation strategy later. |
| | Due to predation | Very important particularly with regard to consumer stock sizes. |
| | Due to fishing | Very important. Changes should be considered in relation to consumer stocks. |
| Whales | Due to abiotic factors | Minor importance. |
| | Reduction due to fishing | Important historically since this is only resource for which documentation on changes that could relate to food abundance exists. |
| | Increase following management | Important since necessary to manage whales and krill in harmony: quantify changes in relation to krill predation. |
| Other Krill Consumers | Long term trend | Important since necessary to manage resources in harmony. |

11. DISCUSSION

11.1 Past and Present Exploitation

The Antarctic ecosystem is one that has often in the past been considered relatively undisturbed. This may well be true for the greater part of the terrestrial and freshwater habitats but in the marine environment there are clear cases of major disturbance.

Soon after the discovery of the Antarctic continent in the later part of the eighteenth century an industry developed based on the Antarctic Fur Seal Arctocephalus gazella. No management policy was in operation in this industry as breeding colonies were totally cropped as they were discovered. The result was that in a very short time this industry moved systematically through the breeding colonies leaving the stocks at a dangerously low level. The failure to treat the seals as a renewable resource which could sustain a continuous harvest was clearly responsible for the collapse of the industry. The history of this industry does clearly indicate the effects of uncontrolled exploitation and, bearing in mind the time it has taken for the stocks to increase, the long-term effect of such a policy.

Whaling was the second major industry to become established in the Southern Ocean. In its early stages from 1904 until the mid 1920's shore stations and moored factory ships carried out the processing. After the introduction of floating factories in 1925-26, the catches increased enormously since the factory ships which could draw carcasses onto the deck through a slipway rapidly became independent of the land and could thus range over the whole Southern Ocean. The wider ranging activities permitted by the floating factories meant that it was possible to obtain a far higher total catch. The effects on the stocks of larger whales were to some extent controlled by a combination of the economics of operating in distant waters and the international agreement on catch limits formulated at the International Whaling Commission (IWC). The effectiveness of the latter controls have greatly increased during the last decade.

In recent years more fisheries have developed in the Southern Ocean based on krill and fish. Information on these fisheries is given in the relevant earlier sections. However, what is important in this context is the degree of control being exercised over them. The fisheries at Kerguelen and South Georgia have been almost totally undertaken by the USSR. At South Georgia there was a great reduction in stocks in a very short time whereas at Kerguelen in the following few years there has been a more steady decline in total catch (which does not necessarily imply overfishing). It is not clear what the reason is for this difference between the two regions although it may simply be a reflection of deploying the same fleet in different sized areas. In any case it is clear that any control is coming from the nation undertaking the fishing rather than through a bilateral agreement with nations claiming sovereign rights to the respective areas or by international agreement (the latter in fact does not exist). In the event that only one nation has an interest, whether that interest be exploitation or on aesthetic grounds, in the resource, and providing that changes in the resource have minimal effect elsewhere, such a unilateral approach is not necessarily bad. The history of fisheries throughout the world suggests however that distant water fisheries do not remain the interest of a single nation for long and that when several countries become interested, international agreement on management policy is essential.

The question of krill has already been raised and this is a fishery in which several nations are interested. Even though the resource may be large in comparison to current world fisheries there is still the necessity to control the fishery by international agreement so as to safeguard the resource itself and also those resources dependent upon it. Krill being at the centre of the Antarctic food web, is clearly a key resource in the ecosystem. Conservation of this resource is therefore necessary both from the resource utilization point of view as well as on environmental grounds.

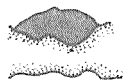
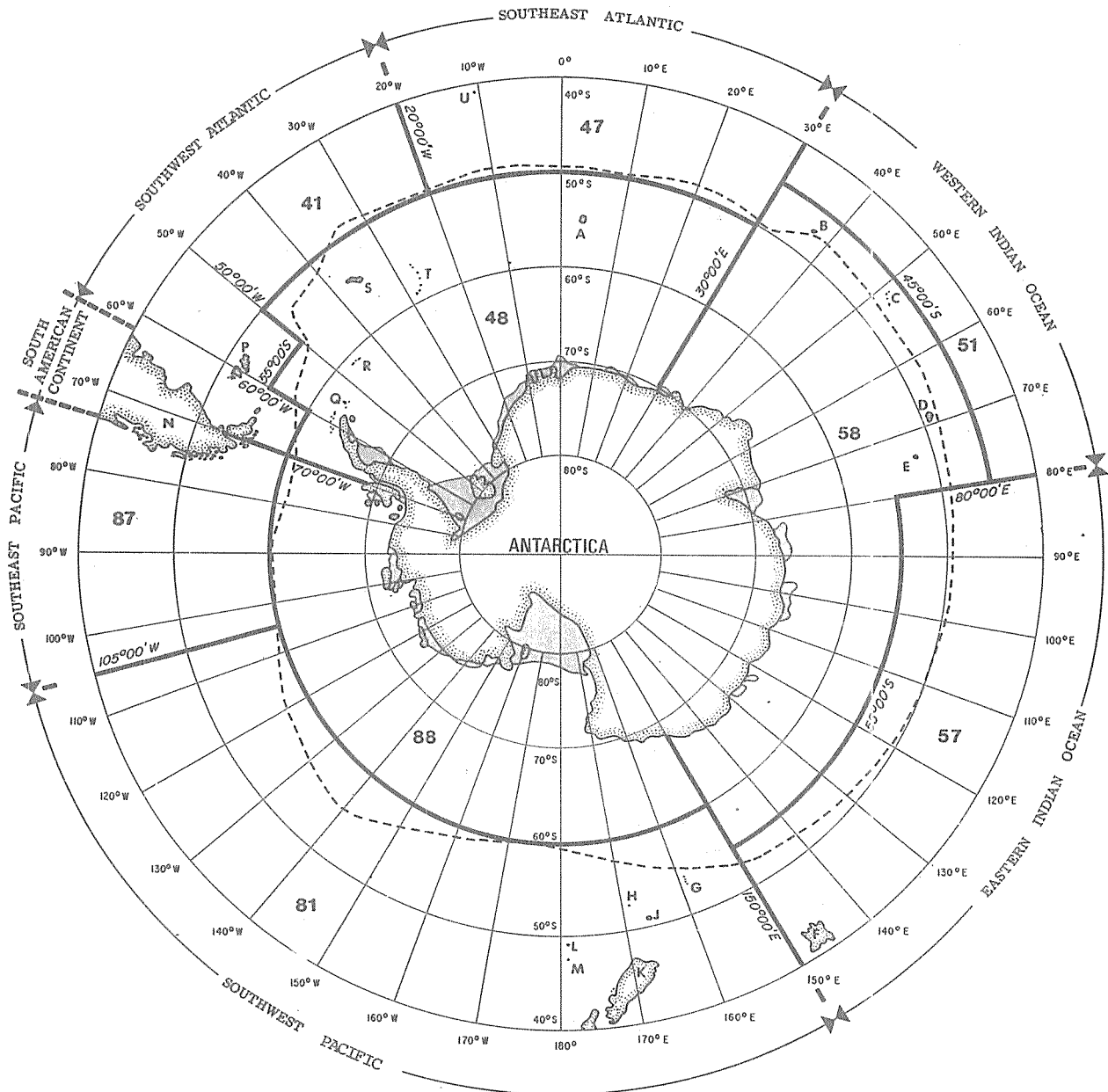
11.2. Management Arrangements

The expansion of the Southern Ocean fisheries during the last fifteen years indicates the need for the production and application of management policies for the Southern Ocean resources. The management instruments presently in force are summarized in Table 11.1 and from this it can be seen that there are major gaps particularly regarding some of the currently exploited resources.

Table 11.1 Management/Conservation Instruments for Antarctic Marine Living Resources

| Resource | Area of Application | Management/Conservation Instrument | Notes |
|------------------------|-------------------------------------|--|--|
| Whales | Global | International Whaling Commission (IWC) | Sets total catch limits. Total catch based on scientific advice from IWC Scientific Committee (allocation arranged outside IWC). |
| Seals | Seas and floating ice South of 60°S | Convention for the Conservation of Antarctic Seals (not yet in force) | No exploitation at present. SCAR Group of Specialists on Seals provides advice and updates information on resources. |
| | Land and ice shelves South of 60°S | Antarctic Treaty "Agreed Measures" | |
| Birds | Land and ice shelves South of 60°S | Antarctic Treaty "Agreed Measures" | No exploitation. Taking of birds permitted under licence. |
| | Islands North of 60°S | National Legislation | Generally modelled on Antarctic Treaty Agreed Measures. |
| | Sea North of 60°S | None | |
| Krill Fish Squid | North of 60°S | Southern hemisphere fishery commissions adjacent to Antarctic nominally managing stocks over large part of sea | No effective management policy in operation in any area. |
| | | Outside of Commission boundaries None | |
| | South of 60°S | None | |

Fig.11.1 Boundaries of the main statistical regions in the Southern Ocean



Ice shelves

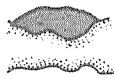
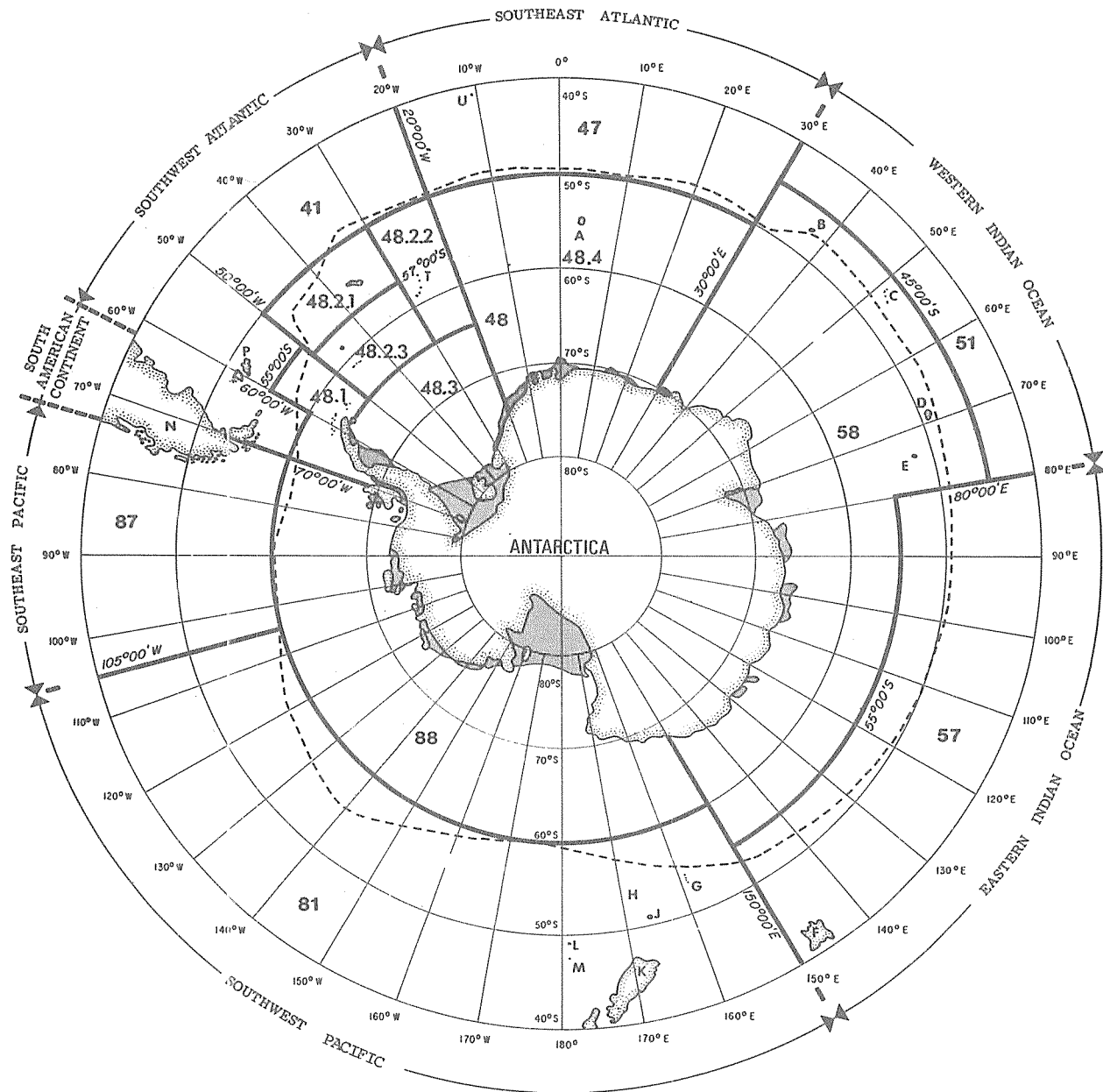
Continents and Islands

— Statistical Area boundaries

- - - Antarctic Convergence

| Code | Name of Islands and Continents | Lat. | Long. | Code | Name of Islands and Continents | Lat. | Long. |
|------|--------------------------------|------|-------|------|--------------------------------|------|-------|
| A | Bouvet | 54 S | 5 E | L | Antipodes | 49 S | 179 E |
| B | Prince Edward and Marion | 46 S | 38 E | M | Bounty | 47 S | 179 E |
| C | Crozet | 46 S | 51 E | N | South America | 51 S | 59 W |
| D | Kerguelen | 49 S | 70 E | P | Falklands (Malvinas) | 62 S | 58 W |
| E | Mc Donald and Heard | 53 S | 73 E | Q | South Shetland | 61 S | 45 W |
| F | Tasmania (Australia) | 54 S | 159 E | R | South Orkney | 54 S | 37 W |
| G | Macquarie | 52 S | 169 E | S | South Georgia | 57 S | 26 W |
| H | Campbell | 50 S | 166 E | T | South Sandwich | 39 S | 11 W |
| J | Auckland | | | U | Gough | | |
| K | South Island (New Zealand) | | | | | | |

Fig.11.2 (a) Proposed detailed statistical areas in the Southwest Atlantic sector of the Southern Ocean



Ice shelves

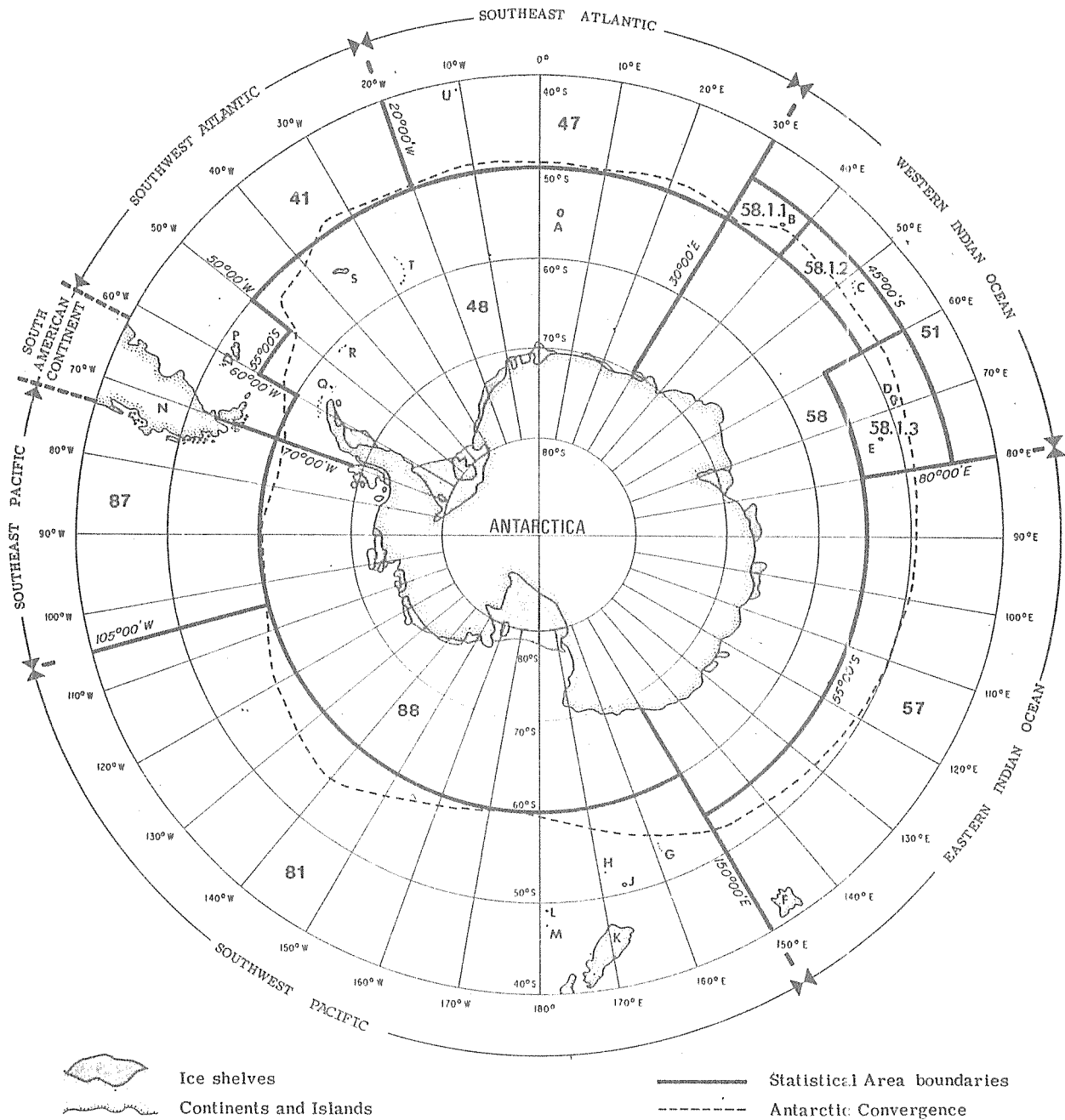
Continents and Islands

— Statistical Area boundaries

- - - Antarctic Convergence

| Code | Name of Islands and Continents | Lat. | Long. | Code | Name of Islands and Continents | Lat. | Long. |
|------|--------------------------------|------|-------|------|--------------------------------|------|-------|
| A | Bouvet | 54 S | 5 E | L | Antipodes | 49 S | 179 E |
| B | Prince Edward and Marion | 46 S | 38 E | M | Bounty | 47 S | 179 E |
| C | Crozet | 46 S | 51 E | N | South America | | |
| D | Kerguelen | 49 S | 70 E | P | Falklands (Malvinas) | 51 S | 59 W |
| E | Mc Donald and Heard | 53 S | 73 E | Q | South Shetland | 62 S | 58 W |
| F | Tasmania (Australia) | | | R | South Orkney | 61 S | 45 W |
| G | Macquarie | 54 S | 159 E | S | South Georgia | 54 S | 37 W |
| H | Campbell | 52 S | 169 E | T | South Sandwich | 57 S | 26 W |
| J | Auckland | 50 S | 166 E | U | Gough | 39 S | 11 W |
| K | South Island (New Zealand) | | | | | | |

Fig.11.2 (b) Proposed detailed statistical areas in the Western Indian Ocean sector of the Southern Ocean



| Code | Name of Islands and Continents | Lat. | Long. | Code | Name of Islands and Continents | Lat. | Long. |
|------|--------------------------------|------|-------|------|--------------------------------|------|-------|
| A | Bouvet | 54 S | 5 E | L | Antipodes | 49 S | 179 E |
| B | Prince Edward and Marion | 46 S | 38 E | M | Bounty | 47 S | 179 E |
| C | Crozet | 46 S | 51 E | N | South America | | |
| D | Kerguelen | 49 S | 70 E | P | Falklands (Malvinas) | 51 S | 59 W |
| E | Mc Donald and Heard | 53 S | 73 E | Q | South Shetland | 62 S | 58 W |
| F | Tasmania (Australia) | | | R | South Orkney | 61 S | 45 W |
| G | Macquarie | 54 S | 159 E | S | South Georgia | 54 S | 37 W |
| H | Campbell | 52 S | 169 E | T | South Sandwich | 57 S | 26 W |
| J | Auckland | 50 S | 166 E | U | Gough | 39 S | 11 W |
| K | South Island (New Zealand) | | | | | | |

In reviewing the living resources of the Southern Ocean it is clear that for the fishable resources, with the exception of whales, some fish and possibly squid, the Antarctic Convergence represents a more or less clear cut northern boundary. South of the Antarctic Convergence there are enormous areas not covered by any management procedures applicable to all the resources. In view of the speed with which fisheries can develop once a market has been identified for a particular resource this situation must clearly be of some concern. It is therefore useful to consider the probable requirements for a Southern Ocean management plan.

A management plan for the Southern Ocean should have the following major objectives:

1. To obtain information on the resources and on the basis of scientific analysis make predictions of the effects of different patterns of exploitation of each resource (including the effects on other resources).
2. To bring together all parties likely to have an interest in the resources (whether by sovereign territorial claim, current or potential future exploitation or utilization) and obtain agreement in utilizing the resources within the limits specified by the scientific advisers.

Considering first of all the provision of scientific advice. One of the basic requirements is a knowledge of the types of resource and amounts that are taken each year. In recent years a world-wide system has been developed whereby catch statistics are reported to FAO in terms of species and tonnages actually caught in designated broad statistical areas by the fishing nations. The boundaries for these statistical areas were decided upon either on biological grounds or so as to coincide with the areas of competence of the various fishery commissions. At the time that these areas were delineated there was virtually no fishing activity within the Southern Ocean with the results that the northern limits of the Antarctic fishing area were arbitrarily decided. In the absence of fishing activities there, this did not then represent a problem. However the recent increase in fishing activity in the Southern Ocean has raised certain problems in interpreting catch statistics in some of these "overlapping" areas. This has been particularly evident in areas around Kerguelen and South Georgia. To overcome this problem it has been suggested (FAO, 1976) that the Antarctic fishery statistical areas should have as their northern boundary the line of latitude (to the nearest five degrees) closest to the Antarctic Convergence (Fig. 11.1). In the Atlantic and Indian Ocean areas (48 and 58) the major areas have been further subdivided into subareas and divisions in order to give a finer breakdown of the main catching areas (Fig. 11.2). Such a breakdown will provide valuable information in the initial stages of a krill fishery. As the fishery develops it will become necessary to specify catching areas more precisely perhaps on the basis of areas included within the boundaries of one latitude degree and two longitude degrees, and to obtain other types of statistical data, especially on fishing effort.

In recent years the only catches made in the Southern Ocean that have been reported to FAO by species are Antarctic Krill and Southern Poutassou. The catches of fish certainly contain far more species and it is therefore recommended (FAO, 1976) that catches of the following should be reported by species:

GADIDAE

Southern Poutassou (Southern Blue Whiting)

MICROMESISTIUS AUSTRALIS

NOTOTHENIDAE

Antarctic Toothfish

DISSOSTICHUS MAWSONI

Patagonian Toothfish

DISSOSTICHUS ELEGINOIDES

Marbled Notothenia

NOTOTHENIA ROSSII ROSSII

NOTOTHENIA ROSSII MARMORATA

Smoothhead Notothenia

Antarctica Sidestripe

CHAENICHTHYIDAE

NOTOTHENIA NEGLECTA

PLEURAGRAMMA ANTARCTICUM

CHAENOCEPHALUS ACERATUS

CHAMPSOCEPHALUS GUNNARI

PSEUDOGAENICHTHYS GEORGIANUS

CHANNICHTHYS RHINOCERATUS

CHIONODRACO SP.

CRUSTACEANS

EUPHAUSTIIDAE

Antarctic krill

EUPHAUSTIA SUPERBA

In addition to information on catches in order to provide realistic stock assessments it is also necessary to have indices of fishing effort. For the time being it is probably sufficient to use an index based on:

- a) Tonnage categories (or engine power of the fishing vessels)
- b) Type of gear being used.

(The categories could be determined according to those set out in FAO Fisheries Circular No. 429).

Since the Antarctic fishing season is spread over the months December through to April it is logical that the "catch year" should be based on the austral summer. A split year has therefore been proposed based on an arbitrary dividing date of 1 July and that the years be included under the year on which they end (thus 1975/76 would be shown under 1976). This agrees with the practice used in reporting Antarctic whaling data.

The collection, reporting and central compilation of information on the Southern Ocean fisheries in this way should facilitate the improvement of the quality of the assessments necessary for managing the fishery.

To provide scientific advice to the decision making group will in addition require reference to ecological information on the resources. The present paper outlines ecological information available at present and has therefore highlighted many of the inadequacies. With the establishment of a controlled fishery it should be a simple matter to obtain much additional useful information. In addition there is a need for more widely based research studies. The need for such studies was recognized some years ago by the Scientific Committee on Antarctic Research (SCAR) which established a Working Group to investigate this particular field (SCAR/SCOR Group on the Living Resources of the Southern Ocean (SCOR Working Group 54)). This working group, following a meeting in August 1976 at Woods Hole, U.S.A. at which about 60 invited experts participated, drew up a proposal for a coordinated Biological Investigation of Marine Antarctic Systems and Stocks (BIOMASS) (SCAR 1977). In broad terms the objectives of BIOMASS are:

1. To provide data and information for the conservation and wise management of the living resources of the Southern Ocean.
2. To improve our understanding of the complex ecosystem on which the resources depend and to understand the flow of energy through the system.

For those resources that offer actual or potential opportunities for commercial harvest the main objectives will be to assess:

1. Standing Stock and Production.
2. Basic parameters important in the dynamics of the population (for example, growth, mortality, reproduction).
3. Trophic relationships (feeding and predation):
4. General biological and ecological characteristics, especially those needed to elucidate the preceding points.

Implicit in these objectives is the need to monitor species which although they themselves might not be exploited might be affected indirectly by exploitation, or which could indicate changes in the abundance of exploited resources. An example that has already been mentioned is birds as indicators of krill abundance in the vicinity of islands. Such considerations raise the very real problem of finance for such research work. In simple terms this may be expressed as: "If it is necessary to monitor penguins to know what is happening as krill is harvested - who pays, those who catch the krill or those who monitor penguins?" The same argument applies to other activities as for example the use of satellites to monitor krill. In the initial stages such ecological studies will almost certainly for the most part be financed by redeployment of existing research effort in the Antarctic. However as a fishery develops there will almost certainly have to be a transition to receiving finance from the industry.

The interactions between the resources are an important topic in the proposed BIOMASS programme and some of these interactions have already been discussed in earlier sections of this paper (especially 6.7 and 10). In the same way that there is a need to study the resources in relation to each other there is clearly a need for management along similar lines. Expressed in simple terms this means that the management policy should be geared to deciding on the relative socioeconomic merits taking into account a broad range of social, economic, and perhaps even aesthetic, considerations in allowing different exploitation rates for the various resources. The rates of exploitation of each resource will have to be determined in relation to what is happening to the other resources. In terms of the whale/krill choice it may be a decision between harvesting one or two million tons of whales or some tens of millions of tons of krill or, more likely, a decision on harvesting lesser amounts of both. The fact that at the moment there are both a whaling industry and a krill fishery in the Southern Ocean means that those with a major interest in one of the industries will have to take due note of the requirements and intentions of those in the other. At the moment the major whaling nations are also the leading krill fishing nations - a factor which could aid the initial discussions. The same argument applies with regard to the seal/krill interaction where although there is currently no sealing industry the stocks are being monitored in the event that one might develop. A similar argument can be applied to other resources which indicates that a management organization should contain, in addition to representatives from states claiming sovereign territorial rights to the area, representatives of each of the nations interested in the resources. Catch limits would need to be made for each resource paying due regard to the others.

11.3 State of Stocks

Currently the largest fishery relative to the production of the resource is whaling and in this industry there is an excess of processing capacity over the allowable catch. The catch limits set by the International Whaling Commission are determined with regard to the whale stocks in isolation and allow for increases in those stocks at present below MSY level.

The Antarctic fish species have been heavily exploited in certain localized areas. On the basis of information available relating to the South Georgia area it is probable that in the shelf areas a fishery taking about 1.5 tons/km² of shelf annually could be sustained. It is stressed that this is a very tentative conclusion based on limited information.

The present best estimate of total krill production, based on consumption by predators, is over 200 million tons and although this figure does have quite a large error factor it is still huge in comparison with current world fisheries. Currently the total Antarctic krill fishery is probably no more than 20 thousand tons annually which is very small by comparison to the total krill production. However, since this fishery is likely to expand and since krill is an important food organism for other resources it is important that any expansion should be monitored and its impact on the other resources carefully assessed. Currently there are several nations involved in krill fishing, several of which could rapidly expand their fishery to the point where a total catch of several million tons is a distinct possibility. Although on present estimates a fishery of this size might have a negligible effect on the stocks the fact must be faced that the effect might be of major consequence both to the resource and in the ecosystem in general. On the other hand any total catch limit should be set so as to give reasonable encouragement for capital investment in the long term. To meet these conflicting needs a management plan needs to allow controlled expansion of the fishery whilst giving some idea of long and short term potential for overall expansion. A possible solution to this would be to allow each nation to expand its fishery as fast as it wants to a certain level at a moderate rate and allow this controlled expansion to an arbitrary but "safe" level. During the build up the stocks of krill and its consumers (where possible) would be monitored to allow revaluation of the safe limit as it is approached. A possible formula for this expansion might be:

- i) Each fishing nation be permitted to expand its fishery at an unlimited rate up to a maximum catch of say 50 000 tons.
- ii) Beyond this level expansion to be limited to an increased catch of say 20% on the previous largest year's catch.
- iii) An initial "safe" limit for the total catch of all fishing nations be set at say 5 million tons.

Concerning the seal stocks there is at present no commercial exploitation and at the moment it seems unlikely that a major industry will develop in the immediate future although estimates of sustainable yield have been made (see Table 11.2).

Although squid stocks are thought to be quite large, this supposition is based on very limited evidence and until some harvesting takes place it will be impossible to define a realistic upper limit. The stocks of octopus are probably small and since they are in general restricted to the shelf area could easily be overfished. There is, however, no information available on which to base a realistic catch limit.

Information on the state of the various stocks and the proposed catch limits are given in Table 11.2.

Table 11.2. Main Southern Ocean resources, and suggested levels of total allowable catch.

| Resource | Max. Catch p.a. | Management Body | Comments |
|--------------------|-------------------------------------|--|---|
| <u>WHALES</u> | | | |
| Fin) | Zero | International Whaling Commission | Quotas set by IWC for the 76/77 Season. |
| Blue) | | | |
| Humpback) | | | |
| Sei | 1 863 | " | " |
| Minke | 8 900 | " | " Southern Hemisphere |
| Sperm ♂ | 3 894 | " | " " |
| Sperm ♀ | 897 | | |
| <u>SEALS</u> | | | |
| Fur* | NIL | Convention for the Conservation of Antarctic Seals* and National Legislation | ACMRR (1976) |
| Elephant | 20-30 x 10 ³ ton | | |
| Crabeater | (?) | | |
| Ross* | (?) | | |
| Leopard | NIL | | |
| Weddell | (?) | | |
| <u>FISH</u> | 1.5 t/km ² of shelf** | None | This paper (Section 8.8) |
| <u>KRILL</u> | 5M.tons | None | This paper. Control of fishery expansion considered vital. Resource must be managed in relation to natural consumers. |
| <u>CEPHALOPODA</u> | | None | Insufficient information. |

* Not yet in force. This convention gives complete protection to Ross and fur seals

** See footnote to p.110

12. NOTE ON STANDARDIZATION OF MEASUREMENTS

In researching the literature for this paper it has become clear that there are a variety of "standard" measurements used, all ostensibly to measure the same thing. To improve comparability of data it is clearly in the interests of all workers to use standard measures throughout, and the following are suggested as being suitable:

(i) Krill

Length - from the anterior margin of the eyes to the tip of the telson measured to the nearest millimetre below.

This measurement is not quite equal to the total length to the rostrum, a measure that has been used. However, since the eye is always very conspicuous in undamaged specimens, this measurement should be relatively easy to make under field conditions. This measurement was used by Marr and Bargmann (Discovery Investigations) and is currently being used by the Federal Republic of Germany's Antarctic Expedition.

It is suggested that 200 individuals would represent a reasonable sample size and that in large commercial catches samples be taken from several parts of the catch in case the net has gone through several swarms having different size frequency characteristics.

(ii) Fish

Length - total length to the nearest centimetre below.

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M-43

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