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RESULTS OF RESEARCH INTO DISTRIBUTION AND STATUS OF STOCKS OF TARGET SPECIES IN THE CONVENTION AREA - ATLANTIC, INDIAN AND PACIFIC OCEAN SECTORS OF THE ANTARCTIC

Abstract

The USSR has carried out coordinated fisheries research in the Antarctic since 1961. The results of more than 130 research cruises are summarised according to the three major sectors: the Atlantic Sector, the Indian Sector and the Pacific Sector. For each particular sector the review contains:

- location, period of time and main objects of research cruises,
- average annual hydrometeorological condition and its variability,
- main target species and its biological and fishery description,
- particulars of bioproductivity cycle.

The Atlantic sector has been studied more thoroughly.

The biology and fishery description includes such items as geographical distribution, population structure, life span, modal length and weight, growth patterns, length and age at maturity, sex ratio, period of spawning, fecundity, food habits, natural mortality as well as optimum fishing parameters including optimum age, length and weight, fishing mortality and recommended minimum mesh size. The analyses of data collected have shown that the entire Antarctic area may be divided into two natural zones: zone of open Antarctic waters and zone of pack ice. These zones have distinct climatic and ice conditions, physical and chemical water characteristics, distribution of biogenic elements and processes of bioproductivity. The shelf areas have the higher level of fish productivity. The necessity to continue coordinated research is underlined and some particular fields of investigation are listed.

RESULTATS DES RECHERCHES SUR LA REPARTITION ET L'ETAT DES RESERVES DES ESPECES CIBLES DANS LA ZONE DE LA CONVENTION - SECTEURS ANTARCTIQUES DE L'OCEAN ATLANTIQUE, INDIEN ET PACIFIQUE

Résumé

Depuis 1961, l'URSS mène des recherches coordonnées sur les activités de pêche en Antarctique. Les résultats de plus de 130 campagnes de prospection sont résumés pour les trois principaux secteurs: le Secteur Atlantique, le Secteur Indien et le Secteur Pacifique. Pour chaque secteur particulier l'examen comprend:

- position, durée et principaux objectifs des campagnes de prospection,
- condition hydrométéorologique annuelle moyenne et ses variations,
- principale espèce cible avec description biologique et halieutique,
- renseignements sur le cycle de bioproductivité.

Le secteur Atlantique a été étudié plus minutieusement.

La description halieutique traite de questions comme la répartition géographique, la structure démographique, la longévité, la longueur et le poids modaux, les modèles de croissance, la longueur et l'âge à la maturité, le rapport mâle/femelle, la période de frai, la fécondité, les habitudes alimentaires, la mortalité naturelle ainsi que les paramètres de pêche optimum dont l'âge, la longueur et le poids optima, la mortalité par pêche et la taille minimale recommandée du maillage. Les analyses des données relevées ont montré que toute la région antarctique pouvait être divisée en deux zones naturelles: la zone des eaux non gelées de l'Antarctique et la zone de banquise. Ces zones diffèrent par leurs conditions climatiques et glaciaires, les caractéristiques physiques et chimiques de l'eau, la répartition des éléments biogéniques et les mécanismes de bioproductivité. Les plateaux continentaux ont le niveau le plus élevé de productivité de poissons. La nécessité de poursuivre des recherches coordonnées est soulignée et certains domaines particuliers d'enquêtes sont énumérés.

РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ РАСПРЕДЕЛЕНИЯ И СОСТОЯНИЯ ЗАПАСОВ ПРОМЫСЛОВЫХ ОБЪЕКТОВ КОНВЕНЦИОННОГО РАЙОНА - АТЛАНТИЧЕСКИЙ, ИНДООКЕАНСКИЙ И ТИХООКЕАНСКИЙ СЕКТОРА АНТАРКТИКИ.

Резюме

С 1961 г. СССР проводил комплексные рыбохозяйственные исследования в водах Антарктики. Результаты более, чем 130 научно-исследовательских экспедиций сведены вместе по трем основным секторам - атлантическому сектору, индоокеанскому сектору и тихоокеанскому сектору. В обзор по каждому сектору включены следующие сведения:

- район работ, сроки работ и основные объекты исследовательских экспедиций;
- среднегодовые гидрометеорологические условия и их изменчивость;
- основные целевые виды и их биологические и промысловые характеристики;

. особенности цикла биопродуктивности.

Наиболее подробно изучен атлантический сектор.

Биологическое и промысловое описание включает такие характеристики, как географическое распределение, структура популяции, продолжительность жизни, модальные длина и масса, темпы роста, длина и возраст при половозрелости, соотношение полов, продолжительность нереста, плодовитость, пищевой режим, естественная смертность; сюда также входят и параметры оптимального режима эксплуатации, включая оптимальные возраст, длину и массу, промысловую смертность и рекомендуемый минимальный размер ячеи. Анализ собранных данных показывает, что вся Антарктика может быть подразделена на две природные зоны - зону открытых антарктических вод и зону дрейфующих льдов. Эти зоны различаются по климатическим и ледовым условиям, физико-химическим характеристикам вод, распространению биогенных элементов и биопродукционным процессам. Районы шельфовых вод характеризуются более высоким уровнем рыбопродуктивности. Подчеркивается необходимость продолжения комплексных исследований, а также указывается ряд конкретных областей исследования.

RESULTADOS DE LA INVESTIGACION SOBRE LA DISTRIBUCION Y ESTADO DE LAS EXISTENCIAS DE ESPECIES OBJETIVO EN EL AREA DE LA CONVENCION - SECTORES DE LOS OCEANOS ATLANTICO, INDICO Y PACIFICO DEL OCEANO ANTARTICO

Resumen

La URSS ha llevado a cabo investigaciones pesqueras coordinadas en el Océano Antártico desde 1961. Se resumen los resultados de más de 130 cruceros de investigación con relación a los tres sectores principales: el Sector Atlántico, el Sector Indico y el Sector Pacífico. Con respecto a cada sector el estudio contiene:

- condición hidrometeorológica anual promedio y su variabilidad,
- especies objetivo principales y su descripción biológica y pesquera,
- características del ciclo de productividad biológica.

El sector Atlántico es el que se ha estudiado más detalladamente.

La descripción biológica y pesquera incluye puntos como: distribución geográfica, estructura de población, índice de longevidad, longitud y peso modal, patrones de crecimiento, longitud y edad al alcanzar la madurez, proporción sexual, período de desove, fecundidad, hábitos alimenticios y mortalidad natural, así como los parámetros óptimos de pesca incluyendo edad óptima, longitud y peso, mortalidad pesquera y el tamaño mínimo recomendado de malla. Los análisis de los datos recopilados han demostrado que toda el área antártica puede ser dividida en dos zonas naturales: la zona del mar abierto antártico y la zona del hielo a la deriva. En estas zonas se definen condiciones climáticas y de hielo, características físicas y químicas del agua, distribución de elementos biógenos y procesos de productividad biológica. Las áreas de las plataformas tienen un nivel más alto de productividad pesquera. Se recalca la necesidad de continuar la investigación coordinada y se indican algunos campos de investigación especiales.

CONTENTS

Introduction

Following the decisions of the Second Meeting of the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources the member-countries should submit to the next meeting the analytical reviews of the results of research carried out in Antarctic waters since the beginning of work until now.

The present review of the results of the scientific research and scientific reconnaissance work is prepared by marine scientific research institutes. The data of other bodies of the USSR Ministry of Fisheries were also taken into consideration.

Since 1961 the complex fisheries research in Antarctic waters has been carried out by VNIRO, AtlantNIRO, AzcherNIRO and TINRO marine fisheries and oceanographical institutes. This research has made the greatest contribution to the investigation of the oceanographical and biological structure of the Southern Ocean and the bioproductivity of its waters. At first in the Atlantic sector and then in the Indian Ocean and Pacific Ocean sectors there were four to twelve research and scientific search cruises each year. Until now there have been more than 130 expeditions. Their areas of studies cover the entire waters of the Antarctic.

The broad-scale expedition research of the marine fisheries institutes has achieved important scientific and practical results. In the early seventies in the waters of the Antarctic region as well as in the waters of the Circumpolar current and in high-latitude waters the most productive areas were defined : the principal regularities of bioproductivity development within these areas were determined ; the structure of biological resources and the prevailing of separate groups and species in relation to environmental conditions were revealed ; the prospects of their commercial utilisation were outlined. Thus, the scientific basis of the rational utilisation of the Antarctic biological resources from the ecosystem point of view was laid down. However, it is necessary to emphasise that the quantitative description of the different ecosystem parameters can still be done with a low degree of accuracy and the population levels of the species which dominate in ecosystems are determined very roughly at present.

The material reviewed is a brief description of the results of the coordinated researches which were carried out in the Southern Ocean by the marine fisheries research institutes of the USSR Ministry of Fisheries from the beginning of work until the 1982/83 season (inclusive). The data are compiled in accordance with the traditional boundaries of Antarctic sectors :

Atlantic sector (AS)	$70^{o}W - 30^{o}E$
Indian ocean sector (IOS)	$30^{o}E - 150^{o}E$
Pacific ocean sector (POS)	$150^{o}E - 70^{o}W$

The data presented for each sector are mainly results of the original field observations on meteorology, ice conditions, hydrology, plankton, functional relationships in the plankton communities, major stages of the bioproductivity development in Antarctica, biology and geographical distribution of Antarctic fish and krill. These data have been obtained during marine research cruises. The specific patterns of these cruises are the complex approach to the investigation of environment, species distribution and, in general, to the zones of high productivity by means of broad scale oceanological, trawl and hydroacoustic surveys.

It is also necessary to note that the research in different sectors has been started separately and the Atlantic sector is the most comprehensively studied. The other two sectors - Indian Ocean and Pacific Ocean sectors are studied to a smaller extent because the period of works is shorter. The number of research cruises is not the same for all Antarctic areas. Furthermore, each scientific institute has carried out the research along its own specific direction. Thus, the data presented for each sector are different to some extent in scale and approach to the entire problem. Such differences reflect to a great extent the levels of the knowledge for particular regions and of the elaboration of separate problems.

1. Review of Research into Biological Resources of the Atlantic Sector of the Antarctic (AS)

1.1 Expedition Studies

The research in the Atlantic sector (AS) of the Antarctic was started in 1961. In the period from 1962 to 1983 (inclusive) there were 47 reconnaissance and scientific research expeditions (mainly on board the large vessels). Attention was paid mainly to the western region of AS. At the beginning the shelf waters of S. Georgia and adjacent waters of the Scotia Sea were explored. During the subsequent years, the exploration was expanded covering the shelves of the S. Orkney and S. Shetland Islands, Antarctic Peninsula and open waters of the Scotia Sea. There were searches for commercial concentrations of fish and krill ; general ichthyofauna investigation and research of commercial target species, in particular ; distribution, biology and stocks of krill and the most important target fish ; the environmental conditions.

Recently some reconnaissance and scientific research cruises were done in the eastern part of AS. There were searches for concentrations of krill, pelagic and demersal fish. The exploration covered the major part of Antarctic open waters, shelf regions and continental slope regions of the Antarctic between 35°E and 10°W.

The list of cruises, study areas, dates and the principal fields of research is provided in Table 1.

1.2 Characteristics of Long-Term Averages of Annual Hydrometeorological Conditions in the Atlantic Sector and their Seasonal Variations

1.2.1 Meteorological Conditions

The permanent extreme area of atmospheric pressure is located southward and northward from the zone of the East Winds. The stationary areas of high pressure are in the temperate zone, at the East - within the zone of the South-East Trade Winds with the

centre at $30^{o}S$; at the West - with the centre at $35^{o}S$, $40^{o}E$. The stationary area of low pressure is close to the Antarctic Circle. It extends along the latitudinal direction and encircles the Antarctic continent. These pressure areas are rather stable and they maintain their geographical positions with minor deviations all year round.

South-Atlantic anti-cyclones have a two-core structure for the major part of the year. In May-October there is one more centre of high pressure in the region of Bouvet Island (0^{o}-$10^{o}E$, 50^{o}-$60^{o}S$). The magnitude of pressure at this site is only a little lower than in the centre of the South-Atlantic anti-cyclone. In the southern part of this area there are centres of low pressure maintained, in fact, all year round. One of these centres is at about $50^{o}W$ within the region of the S. Orkney Islands. In summer the centre is located at the southern-most part of the area, in winter it has moved somewhat northward ; in autumn it has moved to the west, to Tierra-del-Fuego.

The second centre of low pressure is at $30^{o}E$ in the region of S. Sandwich Is. This centre exists all year round moving in a north-eastly direction from summer to winter. These two centres are probably related to the Antarctic field of low pressure.

The existance of stable climatic centres is reflected in some divergence in the directions of isobars from zonal distribution above the relatively uniform oceanic surface. This scheme is different from the traditional point of view that there is clearly determined zonality of pressure fields in this area.

It is possible to consider the western part of the Antarctic AS as an originating site of cyclones. The major parts of cyclones penetrate through Drake Passage from the Pacific Ocean sector. The deep cyclones usually move in an easterly direction. However, apart from this zonal movement, the meridional movement is also observed in southerly as well as in northerly directions. The

speed and trajectory of cyclone movements are for the most part dependent on the South-Atlantic cyclone. Cyclone speed is up to 700 miles per day in summer time. In winter - 1000 miles per day. The number of cyclones varies depending on the season (the maximum - during austral winter, minimum - in summer). In winter the zone of maximum cyclone occurrence spreads to the north. Cyclones develop at the ice edge along which there are substantial differences in termperature. In summer when the ice edge is moved close to the continent, the zone of cyclonic activity becomes narrower.

There is a well determined zonal distribution of the air temperature in the South Ocean AS. The maximum temperature is observed at 40°S; the temperature diminishes gradually towards the south. The warmest month is January and sometimes February, the coldest - July and August. The long-term monthly average temperature in January varies from $+1^{\circ}$C at 60°S to 17°C at 40°S; in July the temperature varies from 10°C to $+12^{\circ}$C respectively.

The seasonal variations of the temperature are within broad limits. For example, near the S. Orkney Is. it is -25°C (July) during an abnormally cold winter and 10–12°C in January-February (in warm years).

It is possible to determine the warm and cold periods for the South-East SA. The cold years were followed by warm years from 1950 in the southern part of the Scotia Sea and after 1959 in the northern part (S. Georgia). The warm years, which presumably had begun in 1950, ended in 1971-1972.

The western and north-western winds prevail in the SA of the Southern Ocean. They constitute up to 60–90% of winds. There are eastern and north-eastern winds at 55-60°S in winter time. They are caused by the northern peripheries of the low pressure Antarctic cyclones.

The distribution of the wind speed vectors mainly has a zonal pattern. However, during the transitional year seasons, the zonality is disturbed. The disturbance is apparently related to the rearrangement of large-scale atmospheric processes.

In the austral winter months the "protuberances" of the high speed wind are developed. They spread from the southern boundary of South America to the central areas of the ocean. During the same season large speed gradients are observed in the vicinity of 40°S and to the south of it. These gradients give evidence of heavy storms.

1.2.2 Oceanological Conditions

1.2.2.1 Water Mass Dynamics

The general transportation of waters in the western part of the Scotia Sea takes place in an easterly direction involving the layers up to 2800-3000 metres. Below these layers there is a near-bottom south-westerly current with a main speed of not more than 5 cm/sec. In general, this current is located in a zonal direction between 57° and 61°S. According to the water mass parameters it is a cold water flow from the Weddell Sea. Direct observations in this area do not prove the hypothesis of the existance of the powerful circumpolar counter-current below the Antarctic Circumpolar Current (ACC).

Located within the predominant water transportation to the east, are the "stripes" or cores of relatively high speeds. These cores are separated by the slow speed zones.

The first such stream from the north shore of Drake Passage to $57^{\circ}30'$S is the so-called Cape Horn current. Further in the central part of the Drake Passage there are

the streams of ACC itself. Furthermore, south of 61°S, there is one more stream in an easterly direction which is a current from the Bellingshausen Sea.

The most powerful currents are found in the central part of the passage, within the main stream of ACC, with the main speed of 35-40 cm/sec at the 0-1000 metres level and with maximum speeds up to 100 cm/sec. Below, in the 1500-3000 metres level, the main speeds are reduced 3-4 times to 7-12 cm/sec. The bottom counter-current in this area at the levels of 3200-3700 metres has a speed of 5-9 cm/sec on average.

The Cape Horn current also has rather high speeds. Thus, the main speed at the 700m level was 38 cm/sec with maximum of 100 cm/sec according to the annual series of observations.

The average speed of the Bellingshausen Sea current is below the speed of the main ACC stream. It is 13 cm/sec at the 500m level and 7 cm/sec at the 2100m level.

In the area of jet streams, meanders and eddies are created. They can cause short-term water transportations to the west in local areas.

In the Scotia Sea, behind Drake Passage, the Cape Horn current and central ACC stream merge together and then turn sharply to the north. Close to the South Antille Ridge, near 50°W, the ACC is subdivided into two branches. The northern branch goes along the ridge to the east up to 48-49°W, then again turns to the north and goes out of the Scotia Sea through the deep passage in the South Antille Ridge. The maximum speed of 30-55 cm/sec is observed in this branch.

The second, less powerful branch of ACC, goes through the central part of the Scotia Sea generally in the north-easterly direction. It comes close to the Southern Antille Ridge near S. Georgia, then turns to the north and goes out of the Scotia Sea through a relatively shallow passage at 40°W (between Shag Rocks and S. Georgia). The maximum speeds in this branch are up to 20-30 cm/sec, average speeds in the upper 0-1000m level are about 17 cm/sec.

The Bellingshausen Sea current goes out of the southern part of the area to the east including a small northern inflow with a speed of 8-12 cm/sec. In the Scotia Sea, the water masses of the current are transformed as a result of mixing with Weddell Sea waters. They flow then into the Weddell circulation system, thus leaving ACC.

The described structure of horizontal circulation maintains its patterns also at the deep levels. Moreover, the general pattern of circulation in this area remains stable in the course of time.

The seasonal variation of the intensity of the ACC system has a well determined half-year periodicity : the maximum water flow through Drake Passage is observed in January and March.

1.2.2.2 Water Masses

There are three principal water masses in ACC. Antarctic Surface Water includes the 0-(100-200)m layer. In winter in the southern and south-eastern parts of the Scotia Sea the temperature under ice is -1.8,-1.9°C. In the northern part of the Scotia Sea the temperature rises to +1.0-2.0°C near the Antarctic Convergence, which is the northern boundary of distribution of these waters. The boundary is at about 50-58°S.

In summer the Surface Water masses are subdivided into two well determined layers : a desalinated (as a result of ice melting) warm layer from summer heating and a cold residual winter layer. Warm water masses have relatively high temperatures (0.5-2.0°C) and practically stable salinity in the layer of temperature maximum (34.60-34.75°/oo). This water mass is formed as a result of the mixing of Antarctic and sub-Antarctic surface water masses. It includes the large stratum of 1500-2000m. The Antarctic Bottom Water mass is formed by means of mixing of the warm deep water and water mass which originates at the Antarctic Shelf. This water mass is marked by a constant temperature (from 0.3 to 0.9°C) and salinity (from 34.68 to 34.72°/oo).

Within these three principal water masses in AS it is possible to define several water modifications. In the first place there are cold waters of the Weddell Sea ; cold and substantially desalinated waters of the Bellingshausen Sea ($t°C = -0.1° - [-1.7°]$), $S \approx 33.0°$/oo in summer) ; ACC waters, which penetrate here through Drake Passage from the Pacific Ocean Sector ; waters of the S. Georgia shelf ; waters of the Antarctic Peninsula shelf.

There are frontal zones between the principal water masses and their modifications. The principal hydrological front of AS is the Antarctic Convergence or Polar Frontal Zone. The Polar Frontal Zone coincides with the ACC Zone of maximum speeds. It is affected by the creation of meanders. In this part of the Polar Frontal Zone the creation of eddies by means of separation of meanders from the main stream of ACC is observed. In the Scotia Sea the Polar Frontal Zone does not show any relation to the bottom relief ; it is narrow and it goes in a general direction to the east-north-east. The quasi-stationary meander is formed to the north of S. Georgia where the Polar Frontal Zone crosses the South Antille Ridge.

One more front is well determined in AS - Secondary Frontal Zone (SFZ) or the zone of merging of Weddell Sea waters with ACC waters. In the Scotia Sea, SFZ goes along the north slope of the South Orkney shelf to the east along the main direction of outflow of the Weddell Sea waters. To the east of S. Orkney, the scope of meandering in SFZ is increased. In the area of the S. Sandwich Islands the Weddell Sea water outflow turns to the north and approaches S. Georgia.

The intensity of the Weddell Sea waters outflow to S. Georgia has principal meaning for krill distribution within its areal in AS. Variability of intensity of Weddell Sea waters outflow has a broad spectrum of time scale : from inter-seasonal to a period of many years. During cold climatic ages, the Weddell Sea waters can penetrate far to the north of the Scotia Sea. In accordance with it, SFZ takes the extreme southern position. During warm years the picture is reversed : SFZ takes up postion in the south of the Scotia Sea, Weddell Sea waters outflow to S. Georgia is considerably weakened.

In terms of annual and, partly, year-to-year scale the variability of the Weddell Sea waters outflow to S. Georgia is in close relation to the intensity of zonal transportations in atmosphere of AS : under stable zonal northward transportations the Weddell Sea waters outflow to S. Georgia is intensified. The reduction of water temperature in the layer of 0-50m in the area of S. Georgia may be an indication of such an event. On the other hand, reduction of water temperature in the area of S. Georgia has a good correlation with the value of specific average of krill biomass : the lower the temperature (i.e. more intensive outflow of Weddell Sea waters) the higher the values of specific averages of krill biomass.

SFZ may be determined by means of several features : horizontal gradient of temperature and salinity ; silicon content, which is higher in Weddell Sea waters than in the Drake Passage ; absolute temperature of layers of transitional maximum and minimum (in ACC waters the minimum temperature is located in the 50-75m layer, but in Weddell Sea waters, it is at the depth of 400-500m).

Until now it was considered that SFZ had dissipated to the north of the S. Orkney Islands. However, recent cruise observations had shown that in the eastern part of ACC, particularly in the area of Bouvet Is., SFZ was very well determined as a narrow (40'-60') gradient zone ; it was observed up to a great depth and there was a lot of meandering.

AS covers the large zonal belt. For this reason, the hydrological patterns in particular regions may be significantly different. Below we consider several AS regions studied more thoroughly.

1.2.2.3 Peculiarities of Oceanological Conditions of Individual Regions

S. Georgia region

The annual variation of mean monthly temperature of shelf water in the area between 53^{o}-55^{o}S and 35^{o}-37^{o}W for 1966-1974 is given in Table 2.

Below 150-200 metres the temperature outside the shelf almost does not change, it is always 1.5 to 1.9^{o}C. At the depth of 1500-2000m there is the beginning of an Antarctic bottom water layer with temperatures below zero.

At the distance of 50-65 miles off the shore to the east and south-east, there is the beginning of a zone with prevailing water masses from the Weddell Sea. Surface temperature down there is 2.5^{o} to 2.9^{o} in February.

At the end of October-November, solar heating of surface layer commences. From December to March the seasonal thermocline is well determined throughout the water area. It reaches the maximum development towards the end of February - first days of March. Vertical gradient is as much as $0.18-0.22^{o}$C per metre. From July to September the temperature of the active layer between 0 up to 150m is the same.

Salinity variation is dependent on seasonal variation of fresh water flow from the island and on the salinity of ACC waters. Above the depth of 120-150m the seasonal variation of salinity is well determined : salinity varies between $33.80^{o}/oo$ and $34.40^{o}/oo$. In the places of bottom depressions and at the outer edge of the shelf the salinity is about $34.50^{o}/oo$, i.e. it is close to the salinity of ACC waters. The impact of fresh water flow is observed, in general, within the limits of 20-30 miles off shore. Along the south-west costline the zone of desalinated waters is narrower than to the north-east of the island.

The interaction of ACC waters with the fresh water flow has created the closed anti-cyclonic circulation in the vicinity of the island.

One of the ACC streams, approaching the island from the south, turns around it and goes to the north, north-west. Another branch, which turns around the island from the north, runs into the waters moving along the eastern shelf and slope area to the north-west. For this reason, to the north and north-east of the island there is an almost permanent complicated dynamic situation with a lot of eddies in the flow field.

The average speed of ACC close to S. Georgia is 0.60-0.90 m/sec in December-February; the speed is up to 1.0-1.5 m/sec in March-April and the highest speed is 1.5-2.0 m/sec in September-October.

S. Shetland and S. Orkney region

The coldest Antarctic waters of the Weddell Sea and the warmest waters of the Bellingshausen Sea take part in the formation of surface water masses in this region. Weddell Sea waters are located to the south from the Secondary Frontal Zone; their temperature at surface varies from 0.6° to $0.9^{\circ}C$. The dimension of homothermic stratum is from 10 to 40m. In the region of S. Orkney and to the west of it, the salinity of surface waters is $34.0-34.5^{\circ}/oo$. The minimum temperature in the cold intermediate layer is observed at the depth 100-250m and it has a value of -1.8° to $-0.3^{\circ}C$. To the east of the islands the salinity of surface waters is less to some extent : $33.9-34.1^{\circ}/oo$; the minimum temperature is observed at a lesser depth of 50-140m ; the temperature varies from -1.7° to $-0.3^{\circ}C$.

The area to the north-west of the S. Shetland Islands is occupied by Bellingshausen Sea waters with a temperature of $0.9-1.8^{\circ}C$ at the surface and salinity of $33.6-33.8^{\circ}/oo$. Minimum temperature of the cold intermediate layer is $-0.1^{\circ}C$ to $-0.7^{\circ}C$; the depth of its location is 70-100m.

To the north of SFZ and Bellingshausen Sea waters there are ACC waters. Their temperature is between $0.9^{\circ}C$ and $2.5^{\circ}C$, salinity is $33.8-34.0^{\circ}/oo$. Minimum temperature of the cold intermediate layer is usually observed at the depth of 10-120m; it varies within the limits from 0° to $-0.7^{\circ}C$ to the west of $50^{\circ}W$ and from 0.6° to $-0.3^{\circ}C$ to the east of this meridian.

In December-February, the water temperature at the surface varies from 3-4°C on the north of the S. Orkney sub-region to -1.7°C near D'Urville Island. The lowest surface temperature is observed in Bransfield Strait where it is below 0°C as a rule. In Bransfield Strait, maximum salinity of 34.60°/oo is observed. To the north-west of S. Shetlands Is. the salinity changes between 34.0°/oo and 34.5°/oo. The most variable field of salinity of surface waters is to the east of the South Orkney Islands.

The western coast of the Antarctic Peninsula to the north of 65°S is free from pack-ice from the middle of December to March. In this period of time the waters are open for navigation. The stable ice covering begins at the end of April and first half of May. Near the S. Orkney Is. the edge of pack-ice expands far to the north and in October it is at 55°S. Towards October-December, the ice edge goes down to 58-60°S and in February-March it is located near 63°S. The S. Orkney region is usually free from ice during the period from December-January to May-June.

Ice conditions of the sub-region are dependent significantly on wind conditions. South-east winds bring the fine ground ice to the area of the S. Shetland Is. South and south-east winds take pack-ice out of the Weddell Sea to the north, to the S. Orkney Is.

Central and Eastern Regions of AS

Recent complex expeditions in these regions of AS have substantially improved our knowledge on their hydrometeorological conditions. The local areas of seabed elevations and of the islands are the most studied.

Sub-Antarctic surface and Antarctic intermediate water masses are typical for the seabed mountains, Discovery and Meteor, which are located in the sub-Antarctic zone. The

waters of the Antarctic zone (the Bouvet Is. region, seabed Maud elevation and Leningrad Bay) may be subdivided into shelf waters, Antarctic surface and deep waters.

The patterns of local geostrophic circulation are dependent substantially on bottom topography : above the seabed elevations the eddies are formed mainly of a cyclonic and a quasi-stationary nature. Such an eddy, for example, is above the seabed Maud elevation where it was observed in 1977, 1980 and 1981. The same eddy is above the seabed mountain Discovery.

In the Bouvet Is. region the hydrological conditions have large year-to-year and round-the-year variability. In December 1973, April 1977 and in July 1982, in the Bouvet Is. region, there was well determined SFZ with related high speeds of water currents. The jet stream of SFZ has a lot of meanders while it is approaching Bouvet Is. In January 1981, SFZ was considerably far to the south of Bouvet Is. The patterns of dynamic topography prove it.

It appears that considerable changes in position and development of SFZ are caused by the intensity of Weddell Sea waters outflow rate. In the region SFZ it is especially clearly marked at the depth of 300-800m where its width is 50-60 miles and its horizontal temperature gradients are up to $0.2^{o}C$ per 10 miles.

1.3 Main Species under Study and their Brief Description

1.3.1 Species Composition

In AS of the Antarctic there are about 40 biological objects which may be commercially used. The most abundant species of invertebrates is Antarctic krill (Euphausia superba), the most abundant species of fish are :

Antarctic Icefish	(Champsocephalus gunnari)
Guenther's Notothenia	(Notothenia guentheri)
Bumphead Notothenia	(Notothenia gibberifrons)
Marbled Notothenia	(Notothenia rossii marmorata)
	(Notothenia coriiceps)
	(Notothenia kempi)
Wilson's Icefish	(Chaenodraco wilsoni)
Scotia Sea Icefish	(Chaenocephalus aceratus)
South Georgia Icefish	(Pseudochaenichthys georgianus)
	(Chionodraco hamatus)
	(Neopagetopsis ionach)
Antarctic Sidestripe	(Pleurogramma Antarcticum)
"Antarctic lanternfish"	(Electrona Antarctica)
and some others	

The main target species at present are Antarctic krill, Antarctic icefish, Guenther's Notothenia, Bumphead Notothenia, Marbled Notothenia and Notothenia kempi.

Below there is a brief description of each listed commercial species.

1.3.2 Brief Biological Description of the Main Species

The most abundant commercial species in AS of the Antarctic, as well as in the entire Southern Ocean (in terms of numbers and stocks), is a large euphausiid - Euphausia superba Dana, commonly known as Antarctic krill.

The northern boundary of this species areal extends rather far to low latitudes somewhere approaching the zone of the Antarctic Convergence (in particular, zonal distribution of krill in AS is especially large). The southern boundary is in fact the Antarctic coast. The vertical scope of krill biotope is also large - from surface layers (where krill aggregate in "patches") to the

depth below 1000m (during early stages of development). The adult animals inhabit in general the photic stratum. At least this is true for the vegetation season. The scope of krill diurnal vertical migration is dependent upon the depth of seasonal pycnocline.

In general, krill has circumpolar distribution but it is more abundant in the waters of so-called high latitude modification. The most extensive distribution is found to be in AS (more than in other parts of Antarctica). First of all, the main reason is the best-known and largest variation of such water modifications - the Weddell Sea waters drift - which is very much developed there. Krill is moved by these waters to the east of the Antarctic Peninsula.

Krill is more frequently found in the zone of merging of these waters with waters of low latitude modification, i.e. ACC waters (or West Wind Drift). In the western part of AS, krill are moved by waters of other high latitude modification from the Bellingshausen Sea. These waters are spread in there along the southern peripheral edge of ACC, but well before entering the Scotia Sea, they have lost their integrity.

As a result of interaction with land areas (Antarctic Peninsula, archipelagos of South Antille Arch) and also with bottom formations these two principal water streams (as well as the above mentioned merging zone) create the set of meanders. The meanders of cyclonic type, formed by Weddell Sea waters, are most rich in krill. Krill abundance is noticeably less in anti-cyclonic eddies which correspond with their area of distribution within the waters of ACC Frontal Zone. Krill aggregations also take place in the "shadow" areas of islands, in particular, S. Georgia, S. Orkney and S. Shetland Is., and also in in-shore waters of several islands of the Antarctic Peninsula.

Total standing stock (of adult animals) in the SFZ meanders of the Scotia Sea and in the adjacent waters is of the order of 12 million* tons. Krill fishing has taken place in separate areas for several years.

Krill, drifting far to the east with Weddell Sea waters, may concentrate together in separate isolated areas out of the meridian of the S. Sandwich Is. At last, separate krill aggregations are observed in littoral waters of the eastern part of AS (Lazarev Sea).

In general, it appears that krill is distributed in AS at least in two bands of high density, which are located at different latitudes. In the Scotia Sea krill becomes mature at the age of 2 years. Spawning is observed in the warm period of the year (September-April). There are specific periods of spawning and dates of mass spawning for each area.

First of all, in September the accelerated maturation and spawning begins at S. Georgia. However, there, the spawning specimens are very rare.

Near the S. Orkney Is. spawning beings in November, near the S. Shetland Is. - in September-October. The maximum number of females with spermatophores are observed in December-April. Gravid specimens are found even in October at the S. Shetland Is., but at the S. Orkney Is. - only in December. Spawning comes to an end in April in both areas.

In the S. Shetland area, it is possible to separate two peaks of spawning intensity : first (less intensive) in February, second - in April ; at the S. Orkney Is. there is one peak in February-March. The spawning may start earlier or later depending on the time of ice melting (in the south of the Scotia Sea) or on the warmth of the spring season (in the north).

* here and below : a million is 10^6

After spawning in the water the eggs sink up to 1000m of depth in open sea areas or to the bottom in the coastal shelf area. However, it is necessary to mention that the bulk mass of eggs occurs in the layer of 250-500m. The hatching occurs at the same depth. After hatching the larvae come slowly up to the surface layer, making diurnal vertical migrations and developing in size.

Larval development of krill is finished by the next spring (September-November). In summer, the formation of external genitals takes place. At this time the length of krill is up to 20-40mm. In the next spring-summer the krill become mature at the age of 2 years. The life span of krill is over 4 years. The main food of krill is phytoplankton. During the bloom of sea algae, krill become a greenish colour because their alimentary canals are overfilled by algae. Algae are green and are seen through the transparent krill shell.

The feature characteristic of krill habits is the formation of aggregations. Density of krill in such aggregations may attain several kilograms per cubic meter. The area of such aggregation may cover from several hundred square meters to several hundred square kilometres. It is in such aggregations that krill is a target for fisheries.

Antarctic Icefish (Champsocephalus gunnari)

It is the most abundant species in AS. It is distributed throughout the Atlantic, Indian Ocean and Pacific Ocean sectors of the Antarctic (Antarctic Peninsula, S. Georgia, S. Shetland, S. Orkney Is., Bouvet, Kerguelen, Crozet, Heard Is., Ob and Lena Banks). It is observed at depths from 70 to 650m. Area of habitat is near-bottom and pelagic layers.

The length of Antarctic icefish in the catches from the shelf of S. Georgia Is. is 12-69cm, weight 0.01-1.73kg ; on the shelves of S. Shetland and S. Orkney Is. length is up to 49cm, weight up to 1.2kg. Maximum age is 12 years on average, up to 9 years (S. Georgia) and 8 years (S. Orkney and S. Shetland).

Growth rate is high - in the first year length increment is 10-15cm, in the following two years - about 10cm ; then, when approaching maturity, growth rate reduces to 4-6cm and it is about 3cm at age of 6-7 years.

Weight increment is tripled in the first year, doubled in the second year and then it is 100-200g per year.

Fish growth is close to isometrical.

Von Bertalanffy growth formula is, respectively, the following :

for S. Georgia region

$$L_t = 62.97(1-e^{-0.17(t+0.69)}) ;$$

for S. Orkney region

$$L_t = 46.9(1-e^{-0.16(t+1.6)}) ;$$

for S. Shetland region

$$L_t = 47.3(1-e^{-0.15(t+2.2)}) ;$$

Transition to stage of maturity-II is at the age of two years when length is 21-23cm and higher (Permitin, 1973). First spawning is at 2^{+}-4 years when the length is over 30cm; the weight is more than 0.12kg.

Sex ratio at the time of spawning is 1:1, during other seasons it varies considerably. Females are dominant in one aggregation, males in another. Variations are from 2:3 to 3:2. Females are predominant in the centre of aggregations, but their number reduces towards the edges. During spawning, males approach spawning grounds at first, the females later.

Spawning presumably takes place on the north-east and west the shelves of S. Georgia as well as on the shelves of the S. Orkney Is. and Mordvinov Is. Near S. Georgia spawning takes place at the depth of 100-125m at 1.2 to 1.6°C. In the area of S. Orkney it takes place at the depth over 600m at -0.35 to -0.45°C near the bottom.

Spawning of Antarctic icefish occurs in May, possibly in June. In the area of S. Orkney and S. Shetland Is., it is in June-July.

Spawning is simultaneous, though asynchronism is observed in the growth of reproductive cells during the annual cycle.

Absolute individual fecundity increases with length and varies from 2.208 to 11.126 eggs. Relative fecundity is 6-12 eggs.

Hatching occurs during the spring-summer period, in August-October at S. Georgia, in October-November at S. Orkney and S. Shetland Is. During summer-time larvae stay in midwater above the depth of 100-350m in the upper 100m layer. Their distribution is only within shelf boundaries. The possibility that during late autumn the juveniles go down to the bottom layers is not ruled out. Adult fish also inhabit the littoral waters of the Antarctic Peninsula and its islands mainly in mid-water layers during the major part of the year. Larger, mature fish, which have attained the length of 40-50cm, are found in the near-bottom layer.

The Antarctic icefish is a plankton-eater. Food of adult fish consists of 91.1% of plankton : krill, mysids, hyperiids. Olsen (1955) found in stomachs the amphipoda at early stages

of development and fishes (anchovy and Guenther's Notothenia). Krill prevails in food diet and build up to 31-90%. Juveniles feed on krill and copepod larvae.

During spawning the fish does not feed. The most feeding activity is before and after spawning. Feeding activity increases towards morning and midday, then it decreases.

Parasite fauna of Antarctic icefish in the S. Georgia region consist of 11 species of parasites (1-myxosporidian, 2-trematodes, 4-cestodes, 3-nematodes, 1-crustaceans). Larvae of cestodes are parasites in the body cavity. Crustaceans are observed on the body surface. Muscle tissue is free of parasites.

Eight species of parasites were found on Antarctic icefish of the S. Shetland Is. (cestodes, nematodes, trematodes, leeches and crustaceans. Larvae of cestodes and nematodes parasite in the body cavity. On the body surface, leeches and crustaceans were observed. They did not penetrate deeply into tissues.

One species of parasite was found on Antarctic icefish of S. Orkney Is. - crustacean, which is localised on the body surface, in the mouth and gill cavities.

Seasonal migrations are carried out within the littoral zone of the islands and Antarctic Peninsula. Pre-spawning and spawning migrations took place in March-May in the S. Georgia area at the depth of 100-125m, in S. Orkney and S. Shetland areas - in May-July at the depth of 350-600m. After spawning fish migrate back to deep waters and they are distributed throughout shelf waters. Besides fish movements are observed which are related to feeding and dependent on krill migrations.

Distribution of Antarctic icefish during feeding periods of time is dependent on its main food - Antarctic krill. In periods when the pelagical krill concentrations are absent, fish

distribution in shelf waters is uniform. In the case of easterly and south-easterly winds, fish do not form concentrations because these winds impede krill entering into the area.

Fish do not feed almost completely when pre-spawning migrations begin and its distribution depends closely on temperature near bottom. Temperatures slightly below 0^{o} (from -0.35^{o} to -0.45^{o}) on the south of the Scotia Sea and temperatures above 0^{o} (from 1.2^{o} to 1.6^{o}C) on the S. Georgia shelf are considered as optimum.

Strong and stable circulations, observed on the shelves of islands and in the Scotia Sea, presumably assist concentration of Antarctic icefish larvae and prevent their transport out of the shelf area. However, in years when zones of circulation are absent, the strong stream of the north-east current can likely induce mass outflow of larvae and even their death.

All year round denser concentrations are formed at a great depth in the day-time, fish move to the surface and disperse in the night-time.

In October-November the densest concentrations near S. Georgia are observed on the east of the shelf at the depth of 240-270m ; in December-February - on the north-west at the depth of 120-400m (at the same time on the east of the shelf, concentrations are less dense and stable).

In March-July commercial concentrations of this species are also observed on the north-west of S. Georgia (first at the depth of 140-180m then 170-350m) ; on the east shelf concentrations are less dense.

In December-February on the shelf of S. Orkney Is. fish are distributed to the west and the south-west from Coronation Is. and on the south-east and north parts of Laurie Is. shelf at depth of 200-300m (10-30m above bottom during the day-time).

In March-May fish are found on the east and south-east shelf of Laurie Is. at the depth of 300-450m, and on the west slope of the shelf at the depth of 280-460m. To the end of this period pre-spawning fish move to the ice-covered areas with a depth of 300-400m. Fish stay within a water layer with temperature slightly below 0° (from -0.35° to -0.45°C). To the end of May, pre-spawning concentrations are observed at the depth of 350-500m (sometimes at the depth of 600-650m).

In June-September the shelf of the S. Orkney Is. is usually covered with ice, but in abnormally warm years (e.g. 1978) fish concentrations are found in the western region at the depth of 160-350m.

On the shelf of the S. Shetland Is. in October-November, Antarctic icefish usually remain on the west of Mordvinov Is. at the depth of 180-350m, on its northern shelf at the depth of 200-300m, and on the south-west at the depth of 320-550m. In December-February fish are recorded on the west and south-west shelf of Mordvinov Is. at the depth of 160-450m and also on the north shelf of Waterloo Is. at the depth of 280-310m.

In March Antarctic icefish remain on the west shelf of S. Shetland Is. at the depth of 220-310m and on the south shelf at the depth of 270-280m.

Natural mortality of Antarctic icefish is 0.4.

Parameters of optimum exploitation of south-georgian populations are the following : age 5.8 years, length 32.0cm, weight 0.25kg, optimum fishing mortality 0.4, optimum mesh size at 50% selectivity for fish with length 32cm - 115mm ; for south-shetland population : age 3.8 years, length 29.3cm, weight 0.15kg, optimum fishing mortality 0.4, minimum mesh size 105mm ; for south-orkney population : age 4.4 years, length 28.9cm, weight 0.17kg, optimum fishing mortality 0.4, minimum mesh size 105mm.

Guenther's Notothenia

Guenther's Notothenia occurs at the depth of 320m as near bottom as well as in pelagic layers but only on the shelf of Shag Rocks.

Fish length is 9-24cm and weight is 0.01 to 0.12kg. Specimens of 12-17cm and mean weight about 0.04kg are prevalent. Growth of Guenther's Notothenia is close to isometrical and is represented by the following equation :

$$W = 0.014L^{2.84}$$

The maximum age of Guenther's Notothenia is 7 years. Fish 3-5 years old make up the major part of catches. No substantial changes in fish length and age composition are observed.

In the first year, fish grow up to a length of about 7cm, length increment in the second year is up to 4cm, in the third and fourth years - about 3cm each year, in the fifth year - 2cm. During subsequent years, the growth rate comes down sharply.

Von Bertalanffy growth formula is :

$$L_t = 28.55(1-e^{-0.22(t-0.37)})$$

Fish become mature at length of 12-16cm (2-3 years old) and weight of 0.02-0.03kg.

Sex ratio in general is close to 1:1. The youngest size groups consist mostly of males and more adult groups of females.

Spawning of Guenther's Notothenia occurs in shelf waters of Shag Rocks presumably in August-September (possibly beginning at the end of July). There is no information on spawning conditions, at what depth it takes place and on fecundity. Eggs are probably benthopelagic. Larvae of 32.5 - 35mm in length are recorded in December.

Guenther's Notothenia is a plankton eater, second order consumer. Main food objects are : Euphausia superba, Parathemisto gaudichaudi, Amphipoda, Copepoda. In November-February, the major part of food is krill, to a lesser extent - amphipods, in May - krill, in August - krill, amphipods, ophiurans, in September - krill, amphipods, sometimes worms, ophiurans.

Daily food ration is about 5.3% of fish weight. The highest feeding activity is observed in the night; in terms of season, in October-February.

Fauna of parasites consists of two species : larvae of the thorny-headed worm, Corynosoma (in body cavity) and crustacean, Brachiella (on body surface behind pectoral fins).

Fish inhabit the littoral waters of Shag Rocks for the entire life cycle. They are distributed throughout all the shelf waters. In October-March, they form fisheries concentrations near the bottom as well as in pelagic waters at a depth of 80-130m. The best time for fishing is dusk.

Spawning, feeding and other types of migrations in the waters of Shag Rocks are not studied.

Natural mortality is 0.56.

Parameters of optimum exploitation are : age 2-9 years, length 15cm, weight 0.04kg, optimum fishing mortality 0.5.

Marbled Notothenia (Notothenia rossii marmorata)

This subspecies is widely distributed in the western part of AS (shelves of S. Georgia, S. Sandwich, Bouvet, S. Orkney, S. Shetland Is. and the Antarctic Peninsula). The fish is bathypelagic and inhabits waters up to 1000m in depth. Subspecies are represented by not less than three independent populations.

On the shelf of S. Georgia the length of fish is 24-92cm, weight 0.4-10kg, age 3-15 years. Until 1973, the major part of catches was fish of 50-77cm length and 5-9 years old; after 1973, 44-62cm length, 4-6 years old. During the first 3-4 years of life, the annual length increment is 7-10cm; in subsequent years up to the age of 8 years 4-5cm and then 1-2cm. The annual weight increment is 0.5-0.6kg on average.

On the shelf of the S. Sheltand Is. fish length is 33-80cm and age up to 20 years. The major part is specimens of 45-65cm length and 7-13 years old. In the first 5-6 years of life the annual length increment is 5-7cm, from 7 to 11 years old 3-4cm each year and older than 11 years 1-2cm each year.

Near S. Orkney Is. fish length is 39-69cm and average weight is 1.7kg.

Growth of marbled notothenia is close to isometric. It is described by the following equations :

for south georgia population

$$W = 0.0114L^{2.95}$$

for south shetland population

$$W = 0.01988L^{2.83}$$

Von Bertalanffy growth formula is as follows :

for south georgia population

$$L_t = 91.5(1-e^{-0.16(t-0.14)});$$

$$W_t = 9000(1-e^{-0.16(t-0.14)})^3;$$

for south shetland population

$$L_t = 75.5(1-e^{-0.16(t-0.96)});$$
$$W_t = 6142(1-e^{-0.14(t-0.661)})^3.$$

In general, in the western part of AS the life span of females is slightly longer than that of males.

Notothenia attains maturity (spawning first time) at a length from 40-45cm (males) to 45-50cm (females). The sex ratio is from 1:1 (S. Shetland Is.) to 2:3 (S. Georgia Is.).

Spawning is simultaneous. It is observed in May-June at the depth of 120-500m (northern and eastern shelf of S. Georgia, including Lark Rock to the east of Laurie Is. and Mordvinov Is.) at water temperatures near bottom from 0.7 to 1.7°c. Absolute fecundity varies from 20.1 thousand (first spawning fish) to 130 thousand (large fish). Relative fecundity is from 8 to 16 eggs. Eggs are bathypelgic and the largest among nototheniids fish.

Hatching occurs in August-October, larvae are about 15mm in length. In summer, they stay in pelagic waters (within the shelf and the open sea above the continental slope). In autum, the adult larvae move gradually to shallow shelf waters. Fingerlings stay at the depth of 5-15m, but towards the end of the first year, they move to the near bottom way of life.

At the age of 1-1.5 years and more than 4 years, notothenia is a plankton eater, at age from 1-1.5 years to 4 years it is a benthos eater. Main food : in pelagic waters - Antarctic krill, ctenophores, salps, hyperiids, small fishes; near the bottom - bottom crustaceans, polyhaeta, algae, fish.

In summer, the major part of food is predominantly krill, in autumn - jellyfish, salps, in winter - krill and ctenophores and in spring - ctenophores. The highest feeding intensity is observed in summer. During spawning, fish hardly feed at all. Geographical variation in feeding is slightly determined.

The daily food ration is about 10% of fish weight.

In general, fauna of parasites consist of 18 species. Only one parasite on fish of the south-georgian population is known. It is monogenetic trematodes, Pseudobenedenia nototheniae (body surface, mouth cavity). Common parasites for south georgian and south shetland populations are monogenetic trematodes (1 species), trematodes (5 species), cestodes (1 species), thorny-headed worms (4 species), nematodes (3 species), crustaceans (1 species). Besides, there are observed additionally, one species of thorny-headed worms, one species of nematodes and one of leeches on fish of the south shetland population and one species of cestodes on fish of S. Georgia.

Seasonal migrations are carried out within coastal waters of islands and the Antarctic Peninsula and are related to spawning and food searching. Migrations between islands are not likely. There is no exchange of individuals between the south-georgian population and other populations.

In March-May, pre-spawning and spawning fish migrate mainly to the east out of the shelf area to the continental slope, where spawning takes place at a depth of 300-700m. After spawning the fish move back and are distributed along the whole shelf.

Immature specimens stay in the shallow shelf waters. While maturing, they move to deeper waters close to the continental slope.

During daylight hours, notothenia stays close to the bottom and it is caught easily. During the night, it disperses throughout the water.

On the S. Georgia shelf, marbled notothenia is distributed more or less uniformly for the major part of a year. In April-June, on the north-east and south-east parts of the shelf it forms commercial concentrations (pre-spawning and spawning). Optimum depth of fishing is 250-350m.

On the S. Orkney shelf, notothenia is distributed mainly on the eastern shelf of Laurie Is.(depth 330-370m), holding waters with temperatures from -0.2 to 0^{o}C. Commercial fish concentrations were not observed on the western shelf. From July to December, the shelf and continental slope are covered with ice and they are inaccessible for study and fisheries.

Information on distribution of the species on the S. Shetland shelf is available only for November-December when, during some years, fish were dispersed in the areas to the north-west of Mordvinov Is. at a depth of 230-750m. Recently, the dispersed concentrations were observed mainly near Mordvinov, Joinville and D'Urville Is.

Natural mortality of fish of south-georgian and south-shetland populations is 0.3.

Parameters of optimum exploitation are as follows :

- for the south-georgian population : age 4.3 years, length 43.3cm, weight 1.1kg, fisheries mortality 0.3, minimum mesh size 160mm;

- for the south-shetland population : age 6.9 years, length 46.5cm, weight 1.2kg, fisheries mortality 0.3, minimum mesh size 160mm.

Bumphead Notothenia (Notothenia gibberifrons)

Bumphead notothenia is widely distributed in the western part of AS (Shag Rocks, S. Sandwich, S. Orkney and S. Shetland Is., Antarctic Peninsula) and occurs from the surface to a depth of 700m. It is a demersal fish.

In the western part of AS it is possible to separate three populations : south-georgian, south-orkney and south-shetland populations.

Fish of 15-54cm are found in catches while the size and age composition of catches is dependent on the fishing areas. The length of fish of S. Georgia is 18-54cm and age is 2-20 years; of S. Orkney, length 12-45cm, age 2-14 years; of S. Shetland, length 13-47 cm, age 2-15 years. Individuals of 36-75cm, 26-29cm and 24-28cm are predominant respectively.

Bumphead notothenia has a relatively low growth rate. For fish of the south-georgian population the length increment for the first 4-5 years is 5-8cm,, then 2-3.5cm each year. For fish of south-orkney and south-shetland populations the length increments are respectively, for the first 4-5 years : 4-5cm and 1-2cm; then 4-5cm and 1.5-2cm each year. In accordance with slow length growth, weight increment is also small, and on average, it is 100-150g for the south-georgian population, 50-60g for the south-orkney population and 50-80g for the shouth-shetland population. Fish growth is close to isometric and is represented by the following equation :

$$W = 0.0166L^{2.9} \text{(S. Georgia)}$$

$$W = 0.0032L^{3.2} \text{(S. Orkney)}$$

$$W = 0.0039L^{3.2} \text{(S. Shetland)}$$

Fish growth is described well by the Von Bertalanffy growth formula, which is as follows for the different populations :

$$L_t = 52.9cm(1-e^{-0.15(t-0.7)}) \text{ (S. Georgia)}$$

$$L_t = 49.2cm(1-e^{0.16(t+0.2)}) \text{ (S. Orkney)}$$

$$L_t = 41.4cm(1-e^{-0.12(t+0.19)}) \text{ (S. Shetland)}$$

There is a small amount of data for S. Orkney and S. Shetland Is. For this reason it is necessary to consider the obtained growth parameters as preliminary.

Bumphead notothenia attains maturity at length of 28-47cm on the north of the Scotia Sea and at length of 24-40cm on the south of the Scotia Sea. Mass maturing takes place at a length of 32-36cm for fish at S. Georgia, 30-33cm at S. Orkney and 32-34cm at S. Shetland. The age of mass maturity is 6-7 years.

Sex ratio of bumphead notothenia is close to 1:1. There might be some prevalence of females.

Spawning is simultaneous. However, along with simultaneous spawning, there is asynchronous maturation of oocytes which is a feature of fish with intermittent spawning.

Spawning takes place in austral winter-spring while in the south it occurs one month later than in the north of the area. The spawning area is the shelves of S. Georgia, S. Orkney and S. Shetland Is. Specimens with maturing gonads are observed at S. Shetland and S. Orkney Is. at a depth of 155-750m in the places with temperatures of 0.1-0.4°C below zero ; at S. Georgia at a depth of 115-600m and temperatures from 0.7 to 1.7°C.

Eggs of bumphead notothenia are demersal. The eggs have a diameter of 1.5-2.5mm. Absolute fecundity ranges from 23.6 thousand to 106.7 thousand eggs, relative fecundity - from 50 to 120 eggs, population fecundity - 3.600 eggs.

Prolarvae and larvae are found in spring (October-November) within the shelves of S. Georgia, S. Orkney and S. Shetland above the depth of 120-350m. Postlarvae also occur in shelf waters of the islands. Immature and mature fish keep together and occur in waters from the coastal line to a depth of 830m. Juveniles form more dense concentrations generally in shallow shelf waters. There are no such concentrations at maximum depths at which this species does occur.

Bumphead notothenia is usually a benthos-eater, but during some periods, plankton, such as krill, is a significant part of its diet. From the age of 2 years, as a rule, there are not any significant differences in the diet of different age groups. In summer-time, the principal food is benthos, in autumn benthos and plankton and in winter the same as in autumn, but the proportion of benthos is increased. In spring, plankton is the principal food.

Nine parasite species were found on bumphead notothenia in the S. Georgia area, 2 species for S. Orkney and 16 species for S. Shetland. Most of the parasites are localised in the alimentary canal. There are no parasites in muscle tissues.

All fish migrations take place within shelf waters of the Scotia Sea islands and the Antarctic Peninsula. On the S. Georgia shelf the prespawning and spawning migrations are carried out in easterly and south-easterly directions. After spawning, fish are distributed throughout the shelf area. During foraging, bumphead notothenia makes short migrations within population areal.

As a rule, bumphead notothenia does not form long lasting dense concentrations. The densest concentration is observed near S. Georgia at a depth of 180-350m in the north-east and south-east parts of the shelf during the aumtum-winter period and at the beginning of spring. Near the S. Orkney Is. fish are concentrated more densely in the western waters of Coronation Is. at a depth of 250-450m during summer-autumn (January-June).

Natural mortality is 0.3 and optimum fishing intensity is 0.3. Age, length and weight parameters of optimum exploitation (at the beginning) are :

for south-georgian population - 6.8 years, 32.0cm and 0.35kg;

for south-orkney population - 5.8years, 26.8cm and 0.13kg ;

for south-shetland population - 5.6 years, 2.4cm and 0.15kg ;

Minimum mesh size in trawl cod-ends is 100mm for the south-georgian population, 80mm for the other two populations.

Notothenia Kempi

Notothenia kempi is a cirumpolar species. In the Scotia Sea it occurs at S. Sandwich, S. Orkney and S. Shetland Is., but also near South Georgia and the Antarctic Peninsula.

Notothenia kempi is a demersal-pelagic species. It occurs at depths of up to 900m in areas with a rocky bottom, in bottom narrows and canyons.

According to preliminary data, it is possible to single out at least three populations in the Scotia Sea : south-georgian, south-orkney and south-shetland populations. As S. Georgia is the northern boundary of this species distribution the south-georgian population is not large and thus it is not discussed in the review.

Notothenia kempi is a fish with a medium life span. In catches off S. Shetland, specimens of 14-52cm length and 2-22 years old are found. Minimum weight is 0.04kg, maximum 1.6kg. Most of the fish have a length of 28-35cm and weight 0.24-0.60kg. At the S. Orkney Is. the length of fish in catches is 16-47cm, age 2-18 years. The majority of fish caught are 0.04-1.33kg each. The most frequent length is 34-39cm, weight 0.4-0.7kg.

For the first 5 years of life, the length increment is 5-6cm annually, then 2-3cm annually (for the south-georgian population). Weight increment is 0.03 and 0.14kg, respectively.

The growth of south-orkney fish is slower. The annual length increment for the first 5 years is 4-5cm, in the next 5 years 2cm, then within a range of 1-1.5cm.

Fish growth in both populations is close to isometric and is represented by the following equations :

$$W = 0.004932L^{3.2} \text{ (south-shetland population) ;}$$

$$W = 0.0115L^{3.03} \text{(south-orkney population) ;}$$

The Von Bertalanffy growth formula is as follows :

$$L_t = 51.2(1-e^{-0.12(t-0.68)}) \text{ (south-shetland population) ;}$$

$$L_t = 48.06(1-e^{-0.15(t-0.23)}) \text{ (south-orkney population).}$$

For the south-shetland population, the minimum length of mature males is 26-27cm, females 24-25cm. Mass maturing of males takes place at a length of 38-39cm, weight 0.6-0.7kg; for females 34-35cm and 0.45-0.50kg, respectively.

For the south-orkney population, the minimum length of mature males is 28-29cm, females 26-27cm. Most males attain maturity at a length of 38-39cm, females 32-33cm. All females become mature at a length of 42-43cm, males 44-45cm.

The sex ratio, in general, for both populations is close to 1:1. However, a small prevalence of females is found (49% and 51%) in the south-orkney population and of males (51.6% and 48.4%) in the south-shetland population. In younger age groups, females prevail in both areas, in older age groups, males.

Spawning takes place in the austral spring-summer (November-December) and lasts 1-1.5 months. Spawning is simultaneous and occurs within the areal of habitat of the species (on the shelf of South Antille Arc Islands).

Spawning, hatching and larva growth occur in the Scotia Sea at temperatures from -2° to $3-4^{\circ}$C. Nevertheless, there are different temperature conditions for spawning in the warm waters of S. Georgia and in the "colder" waters of S. Orkney and S. Sheltand Is. In the north, spawning takes place one month earlier than in the south. It is explained by differences in the advent of spring. Eggs of Notothenia kempi are benthic and sticky. Ova diameters at the beginning of stage IV of development are 0.6-1.3mm (mean diameter is 0.99mm). Absolute fecundity ranges from 17.6 to 161.0 thousands of eggs. Population fecundity is 3013 eggs.

Underdeveloped larvae of 9.2-11.6mm length are found on the S. Orkney and S. Shetland shelves above a depth of 200-800m, in the surface 100m layer in the period from January to March. Developed larvae of 46.5-47.5mm length are found in December above the depth of 200-1000m in the surface 50m layer. Juveniles of 2 years and older occur in the same area as adult fish. On the shelf of the S. Shetland Is. and adjacent waters of the Antarctic Peninsula, adult fish are found in bottom-trawl catches in the area between $60^{\circ}40'$ - $66^{\circ}40'$S and $53^{\circ}30'$ - $70^{\circ}00$W at depth of 100-700m.

Usually fish are not found in spring to the west of 60°W. In summer fish are distributed more widely than in spring, from $60^{\circ}40'$to $66^{\circ}50'$S and from $53^{\circ}30'$ to $70^{\circ}00$W. In autumn as in summer, fish are distributed in all parts of the area at a depth of 180-500m. At S. Orkney, fish are found in the waters between eastern and western parts of the shelf slope at a depth of 100-700m. In autumn, fish are distributed at the same depth as in summer. In winter-spring, it is in fact impossible to study fish because of heavy ice conditions.

The main food of Notothenia kempi is krill. At the same time, ctenophora, salps, polychaeta and fish make up a significant part of its diet. In summer Notothenia kempi feeds mainly on krill. In autumn, on the S. Shetland shelf, the principal food is krill and fish ; at the S. Orkney Is. - ctenophora, salps, the proportion of krill is less, the proportion of fish is rather large. Adult fish do not migrate beyond the bounds of the two above-mentioned areas. All migrations take place within the shelf and its slope. Drift migrations of larvae occur also within the same bounds.

At S. Shetland, the most dense concentrations are observed in spring on the west and south-west of Mordvinov Is. at a depth of 350-400m. Moreover the density of concentrations diminishes while approaching the surface. In summer, the dense concentrations are observed at the same places, but at a depth of 370-420m.

At S. Orkney, dense fish concentrations are observed in the west of the area in the places of deep warm water inflows with temperatures of 0-0.2°C, at a depth of 350-600m. In autumn, the most dense concentration is formed east of Laurie Is. at a depth of 330-360m.

Natural mortality of Notothenia kempi is 0.3-0.4. Parameters of optimum exploitation of the S. Orkney population are : age 6.4 years old, length 28.8cm, weight 0.26kg, optimum intensity of fishery 0.3. It is necessary to use a minimum mesh size in trawls not less than 80mm.

The following regulatory measures meet the requirements of rational exploitation of the S. Shetland population : fish age for the beginning of exploitation 7.3 years, length 27.9cm, weight 0.25kg, intensity of fishery 0.3, minimum mesh size in trawls 80mm.

1.4 General Conclusion on the Characteristic Features of Bioproductivity Formation

1.4.1 Biogenous Elements

The specific ratio in the biogenous elements concentrations is observed in sub-Antarctic Surface Waters : very low concentration of selicic acid and rather high concentration of nitrates and phosphates. Conditions of phytoplankton mineral nutrition in this region is favourable for all groups of algae, with the exception of diatoms, the development of which would be limited by silicon shortage.

Antarctic Surface Waters are the richest waters in World Oceans in principal biogenous elements which ensure the conditions of optimum nutrition for all algae groups. During periods of algae "bloom" the maximum values of reduction of mineral salts concentrations, due to consuming by algae, are : for nitrates - 7-6 times, for phosphates, 2-2.5 times and, to a lesser extent, for silicon - up to 1.3 times. Only concentrations of nitrates in local sites have been reduced to values which limit the development of phytoplankton.

The reduction in contents of biogenous elements in Antarctic Surface Waters, especially of nitrates, down to the values, which are not usual for these waters, and simultaneous oversaturation of waters with oxygen up to 105-120%, take place as a result of mass phytoplankton development. These patterns may be chemical indicators of high productivity areas.

1.4.2 Light Conditions

According to the data of 320 sets of daily records of light intensity for the spring-summer periods of 1979-1983, the monthly summary values of incident radiation were calculated for zonal belts to the north of 40°S, between 40° and 50°S, between 50° and

60^{o}S, to the south of 60^{o}S. The differences were shown in seasonal changes of maximum light intensity, summary values of incident radiation and length of the daytime for the zones. It was revealed that abnormal low indices of light conditions for summer 1981 were related to prevailing of cloudy days. The lowest light conditions are a characteristic feature of the zone between 50^{o} and 60^{o}S. During spring-summer periods, light is not a limiting factor for photosynthesis. However, as it was observed, the excess of light might inhibit production especially where diatom algae were prevalent. In winter, 1982 (June-July), in the zone between 52^{o} and $60-61^{o}$S, the value of primary production at the level of 150–250 mgC/m^{2} per day was observed. This is evidence of sufficient light for photosynthesis in phytoplankton even in winter.

1.4.3 Phytoplankton

Diatom algae are prevalent in phytoplankton of the Antarctic region. This is a characteristic feature for waters rich in biogenous elements. In spring, a large amount of small flagellates is also observed. During a year, the quantitative patterns of algae development are changed substantially as a result of variations in oceanographic conditions.

First of all, spring development of phytoplankton takes place in the northern zone of Antarctica (between the Antarctic Convergence and about 55^{o}S). The period of intensive vegetation usually lasts from October until May, having two peaks of development : the principal peak in December and the second (lower) peak in April. Southwards, the vegetation period decreases and periods of peaks are shifted to later dates. In the intermediate zone (about 55^{o} to 60^{o}S), the vegetation period covers November-May, the spring peak is observed in January and a small increase in algae abundance also takes place in April. South to 60^{o} the vegetation period is not long (December-April), short-term "bloom" takes place at the end of January-February.

The described scheme of seasonal development of phytoplankton may be affected substantially by environmental conditions (periods of ice-melting, local dynamic conditions and the position of the Secondary Frontal Zone, etc.) which prompt or inhibit the development.

At S. Georgia the spring peak may occur earlier than in the northern part of Antarctica, usually in November-December. During this period, the abundance of algae is over 100 million cells per m^3. In general, phytoplankton vegetation lasts from October to April, and in autumn the abundance of algae may increase up to 20 million cells per m^3. The maximum values of quantitative indices of phytoplankton development are observed in the Secondary Frontal Zone. This zone is a zone of high productivity in accordance with those indices.

At S. Shetland and S. Orkney, which are located at the boundary between the intermediate and the southern zones of the Antarctic, the vegetation period is the same as the ice-free period : from November-December to April-May. Favourable conditions for algae development are created under permanent high contents of biogenous elements and appropriate amounts of light due to dynamic factors (surface water stratification, interaction of ACC with bottom topography). Maximum development of phytocenosis takes places in January-February.

Area of Underwater Elevation - Maud is placed in the southern zone of the Antarctic. According to the general scheme the phytoplankton development lasts from December until April with a peak in February. In an abnormally warm summer, 1983, in the middle of January, the abundance and standing stock of algae were 234-330 million cells/m^3 and 1.2-3.7g/m^3, respectively. At the end of January to the beginning of February, directly above the elevation, a concentration of phytoplankton of up to 82 million cells/m^3 and biomass of 300mg/m^3 was observed which was related to intensive upwelling at the edge of an anti-cyclonic meander. At

the end of February to the beginning of March, inside the zone of cyclonic circulation, up to 42.2 million cells/m^3 and 685 mg/m^3 were observed. Maximum values (over 90 million cells/m^3 and 1000 mg/m^3) were found inside the zone of the circulation which was formed by the interaction of upwelling and the north stream of the warm current. Reduction of algae abundance and biomass was observed in the waters of the Weddell Sea Drift. In April the abundance and biomass had reduced to 5-60 million cells/m^3 and 50-400 mg/m^3, respectively. The highest values were recorded at the ice-edge which had been moved to the north.

The area of Bouvet Is. is placed at the junction of northern and intermediate zones of the Antarctic. The vegetation season of phytoplankton lasts from October to April in the north (up to 55°S) and from November to May in the south. There are two peaks of vegetation in December and in January, respectively. In December, 1979 mass development of algae was observed to the east of the island (155.3 million cells/m^3 and 396.5 mg/m^3) and above the underwater mountain "Shpis" (138.9 million cells/m^3 and 395.4 mg/m^3). These sites corresponded with the position of upwelling zones, the first of which was related to cyclonic circulation, the second to meandering of an eastward current stream. In January, 1981 mass vegetation (over 100 million cells/m^3 and 300 mg/m^3) was observed at 53°-55°S in the zone of cyclonic circulation and at 57°S at the edge of anti-cyclonic circulation.

A unique survey of the area (in terms of scale and time) was carried out in June-July, 1982. The values of quantitative indices of phytocenosis development were more than 6 times less than in spring. Increased values of abundance and biomass are characteristic features of ACC waters. Maximum development was found in the frontal zone between ACC and the Weddell Sea waters (over 80 million cells/m^3 and 290 mg/m^3). Inside ACC and Weddell Sea waters, phytocenosis is developed more weakly (not more than 3 million cells/m^3).

In Leningradbukta (Bay), (southern zone of the Antarctic), the vegetation season lasts from January to March with the peak in February. At the end of January-February 1983, the quantitative indices were as much as 100-194 million cells/m^3 and 200-315 mg/m^3. Vegetation becomes weaker in March : abundance is about 5 times less, biomass more than 10 times less). Such short-term spring "bloom" is observed in inshore areas of the Pacific Ocean and the Indian Ocean Sectors of Antarctica. It is possibly a characteristic feature for the entire southern zone.

Vertical distribution of phytoplankton during spring "bloom" has a distinctive pattern - maximum abundance of phytoplankton in the surface layer. As a rule, abundance decreases as depth increases. The appearance of the second (deep) maximum is apparently caused by sinking of the algae after "bloom". Within the areas of anti-cyclonic meanders, the deep-laid development of phytoplankton is possible also in spring.

If thermocline is not developed or weakly determined there is a gradual slow down of phytoplankton development against depth. Well determined thermocline and a high degree of vertical stability are favourable for algae concentration in the surface 0-50m layer. In spring, when thermocline is not sufficiently developed, the closest relationship between abundance and stability is usual for the surface layer. Down to the depth the influence of stability is decreased. In spring, when thermocline is well determined, the close relationship of algae abundance with thermocline vertical stability remains only in the layers where abundance is maximum. In the layer of highest stability, the abundance of phytoplankton usually is not large. It appears that even small (by absolute value) stability gradients keep algae within the photic zone. This is apparently related to the weighted mean value of volume of algae cells in the particular areas.

1.4.4 Chlorophyll

The seasonal variation in chlorophyll-A concentration and distribution is well determined in the southern zone of the Antarctic AS. Such a variation is dependent on seasonal variation of phytoplankton development.

In January-February, ACC waters are of mesotrophic type according to their chlorophyll concentration. In some local places they are eutrophic. In April, all AS waters are oligotrophic according to this index.

Chlorophyll-A content in the photic layer has a linear relationship with summary production and biomass of phytocenosis. Increased content of chlorophyll as in a unit of water volume (as well throughout water column) is a reliable index of high availability of primary food.

In January-April, 1983, for the first time in scientific-reconnaissance practical work, the "Impuls fluorescence meter with continuous action" was successfully tested. The meter registers fluorescence of phytoplankton pigments and of dissolved organic materials continuously aboard the sailing vessel. Obtained data were calibrated taking into account observations on chlorophyll and quantitative indices of phytoplankton development as well as results of comparison with distribution of hydrologic and hydrobiologic conditions. After calibration, this method was recommended for use in complex expeditions dealing with the study of ocean biological productivity and, in particular, with search of zones with increased bioproductivity.

1.4.5 Primary Production

Appraisal of the daily dynamics of photosynthesis at stations in the 43°-69°S zone had shown that intensity of photosynthesis did not change proportionally with the amount of light. In 4 hours, immediately after dawn, about 42% (on average) of primary

production is formed, in mid-day time (8-10 hours) under the condition of maximum light intensity - 37.4%, in 4 hours before sunset - 20.8%. Photosynthesis active radiation (PAR) was subdivided according to these intervals as 12%, 80% and 8%. It was suggested that light during mid-day had an inhibiting action. It was found, by experiment, that simple doubling of half of the daylight production resulted in a 23% increase of daily production during the period from dawn to noon and in a 24% decrease in mid-day.

The level of primary production was assessed in relation to light intensity and temperature ; the equation was developed for calculation of production through algae biomass, rate of cell growth, light intensity and temperature. Such a calculation gives rather reliable results. Efficiency of photosynthesis increases in accordance with the increase of water nutrient capacity. It is 0.71-3.76% of PAR (on average 1.83%). It allows us to speak of the high degree of utilisation of solar radiation by Antarctic phytoplankton.

Primary production ranges within wide limits from 2 to 150 mg^c/m^3 per day at the surface and from 70 to 7600 mg^c/m^3 per day in the photic layer. The average level of primary production, calculated on the basis of records at 196 stations in 1979-1983, is 312.1 mg^c/m^3 per day. The highest values were observed at S. Orkney Is. (7.6g^c/m^3/day) in February, 1984 ; at S. Sandwich Is. (6.7-7.2g^c/m^3/day) in January-February, 1984 ; in Leningrad Bay (1199.3mg^c/m^3/day) in January, 1983; on the area between 35°S and the underwater mountain "Discovery" (1130.0mg^c/m^3/day) in December, 1979 ; in the area of underwater elevation Maud (884.4mg^c/m^3/day) in January, 1983 ; at Bouvet Is. (615.3mg^c/m^3/day) in December, 1979 and (895.0mg^c/m^3/day) in January, 1981. In other cases primary production usually was not over 500mg^c/m^3/day.

On the basis of our own and published data, the vegetation seasons and peaks of phytocenosis development were determined for all regions.

The space and time variability of location of zones with increased bioproductivity were determined in accordance with results of observations in three testing areas for which the most complete data were obtained.

In the area of the underwater mountain "Discovery" the general feature was dynamic turbulence of water mass as a result of interaction of ACC northern peripheral streams with bottom topography. It promoted the creation of favourable conditions for phytoplankton development (inflow of biogenous elements from below-laid layers, the mechanical effect of water head and algae concentration). At the end of March-beginning of April, the average level of production in the surface layer was twice as high as the value in December, 1979 (about 20 $mg^c/m^3/day$). The intensity of photosynthesis had increased, on average, 4.5 times at the surface. It relates to seasonal rearrangement of phytocenosis (small "peridinial" algae replaced the predominated diatoms) and to change of light conditions (inhibition of surface photosynthesis by light excess was ceased). During the period from December to March-April, the production in photic layers was 1.6 times less (on average from 485 to 303 $mg^c/m^3/day$) under almost equal value of the efficiency rate of photosynthesis. In January, 1983 the production was 613.3 $mg^c/m^3/day$.

There is definitely a seasonal feature in changes of production and area of the zone. A survey in December corresponded with some drop after the spring/October peak of phytocenosis development, second survey - with the beginning of autumn/April peak. The level of primary production changes in relation to seasonal variation in light intensity and seasonal rearrangement of phytocenosis under the same location of the zone of increased productivity in December and March-April.

Bouvet Is. area. In December 1979, the indices of increased bioproductivity were recorded just around the island. In January 1981, the large water area on the east of the island had an increased bioproductivity. Differences in zone location are

related to distribution and characteristics of circulation systems which are not constant and dependent on directions of ACC principal stream close to bottom elevations as well as on position of SFZ between ACC and Weddell Sea waters. In January, higher values of production (300-895 and 156-615 mg^c/m^3/day, respectively) and of phytoplankton biomass (140-240 and 70-195 mg/m^3) were observed. Photosynthesis intensity was reduced to some extent. It is related to a significant increase of average size of cells (on average from 680 to 8390 mμ). During both surveys diatoms were prevalent in phytocenosis (in December they made up about 90%, in January over 93%, in carbon units of biomass). It is necessary to consider these surveys as one-season surveys. The differences in production indices have regional and intra-seasonal features.

Underwater elevation Maud has a feature of permanent relatively closed circulation - large scale cyclonic water drift around the elevation. The zone of increased productivity in January covers a wider area while the primary production is 3 times higher than in February-March and 4.5-5 times higher than in April. As the amount of light decreases and the seasonal thermocline is destroyed, the zone moves to near the ice-edge area.

The population and biomass of phytoplankton are at their maximum in January, when the community consists of a great variety of species. The mean size of the algae cells does not change significantly. Diatoms are permanently predominant. Only in April do Peridinea (up to 30-45% of biomass in „C" units) and Coccolithophoridae (5-11%) appear in noticeable amounts. This indicates the beginning of biological autumn. In general, changes in the production level and in the extent of the productive zone, exhibit seasonal and year-to-year variations.

Equations were developed to relate primary production and efficiency of photosynthesis to 14-16 independent variables. The closest relationship of production is between algae numbers and biomass, their species diversity and total amount of radiation. Intensity of photosynthesis depends, to the greatest extent, on algae cell size and light conditions.

In January-February, the seasonal variations in environmental factors upon which phytoplankton development depends, are greatest in the southern zone of the Antarctic, while in the northern areas they are not apparent. The determining feature of the production process in the Antarctic - is a good supply of mineral nutrients - and upset by a deficit of silicon only in the northern part of the sub-Antarctic. Conditions of mineral nutrition deteriorate locally, and for a short period of time during algae "bloom" as a result of nitrite consumption, to an almost limiting degree.

Solar radiation varies from optimal to excessive over the whole period of time throughout the study area, while daylight period decreases from January to April by a factor of 1.5-2.

The ratio between the mixing layer and the layer of photosynthesis is maintained at the same level to the north of $60^{o}S$ and restricts the development of phytocenosis. To the south of $60^{o}S$, in January, it is favourable for development of phytocenosis which has a "bloom" stage at this time. Later, the stability of the surface layer is destroyed and algae vegetation is limited by this factor.

The relatively moderate indices of phytoplankton development are explained by a low growth rate in cold water and by the negative effect of deep mixing. However, these indices are also dependent on the seasonal condition of the whole plankton community. In the area between 40^{o} and $60^{o}S$, during the study period, the community was in the stage of summer development when the quantity of phytocenosis is limited by predation of zooplankton under the conditions of optimal mineral nutrition and light intensity. To the south of $60^{o}S$ the peak of development in January is dependent not only on maximum density stratification of surface waters but also on the spring stage of planktocenosis development when the absence of zooplankton predation is a characteristic feature. The decrease in phytoplankton abundance from February on occurs under constant parameters of photo-synthesis (efficiency of photosynthesis, food assimilation rate per hour, and per day). It proves that predation is a major factor.

Analyses of the data demonstrate that in summer the level of primary production in the Antarctic depends on the magnitude and stability of surface water stratification. It allows us to consider this characteristic feature as a principal pre-requisite for increased bioproductivity water zones during growth periods. In the Southern Ocean, water stratification is dependent on the interaction of factors which control water temperature, ice melting and air circulation. The factors have a large variability in time and space.

Table 3 shows the results of calculations of annual primary production, total biomass of zooplankton and euphausiids which can be maintained by the yield of photosynthesis.

Measurements of bacterial production in the spring-summer seasons of 1979-1983 have shown that, in general, it was at the same level as primary production. It was found by ecological and toxicological experiments on phytoplankton that in the Antarctic area algae have practically no adaptation to pollution but revealed high tolerance to oil products, heavy metals, polychloric biphenyls and to their different combinations. It is connected with the low temperature, a high concentration of biogenous elements and the small mean size of the cells.

1.4.6. Zooplankton

The principal group of zooplankton in the Antarctic is copepods. They make up to 60-75% of zooplankton in number and biomass. The following copepod species predominate : Calanus propinguus, Calanus acutus, Rhincalanus gigas, species of genuses Metridia and Oithona, and the Pseudocalanidae family. The distribution boundary of Antarctic fauna used to be along 60^{o}S. Almost all principal copepods species are phytophagous or euryphagous (except the g.Oithona).

Seasonal development of plankton throughout the area has the same pattern, the only differences are in timing of the same stages of the life cycle. Local differences in zooplankton numbers are dependent on the conditions of algae development (principally by the vertical water stability) and also on abundance and age composition of wintering zooplankton stock.

In the Western part of AS the S. Orkney and S. Shetland Is. are in the zone of the Weddell Sea waters distribution. It is possible to suggest that the principal patterns of the plankton community formation and the dynamics of their development are much the same.

Seasonal status of planktocenosis, biomass distribution and timing of growth season in this area are strictly dependent on ice condition. The spring season in the shelf waters of the S. Orkney and S. Shetland Is. is in October-December. During the first part of the season, zooplankton is in winter or early spring state. About 60-75% of biomass is distributed in the 200-500m water layer. In the 0-100m layer, biomass is 111 mg/m^3. To the north-east of S. Orkney, biomass is less than 100 mg/m^3 and to the west it is above 130-150 mg/m^3.

In December, in the desalinated waters of the islands, the patches of "bloom" algae are observed under conditions of intensive water heating and ice melting. Wintering stock of zooplankton begins to move up to the surface layers. As a result of increased abundance and biomass of zooplankton in the surface layers, the first peak of zoocenosis development is observed.

Towards the end of December and in January, biological spring is in full swing in the area. Reproduction of zooplankton is intensive and results in a rapid growth of biomass : up to 1-2 g/m^3 in the 0-25m layer, 100-400 mg/m^3 in the 100-200m layer and 20-30 mg/m^3 in deeper waters. The second peak of zooplankton community development is usually observed in February. It is caused by the

appearance of the new generation. The major part of plankton organisms are distributed in the 0-100m water layer where areas of very high biomass density may be found (up to 12g/m^3). The maximum indices of zooplankton numbers at this time are found to the east of the S. Orkney Is. At S. Shetland biomass averages 500 mg/m^3.

At the end of March and in April, the community begins to change to its autumn status and sinks to deeper layers.

The distribution of zooplankton in March-May, in many aspects, resembles distribution in June-August. Within the surface layer, about 18-25% of biomass remains. Zooplankton density is not more than 1000 mg/m^3 (this value would be much less without large salps and euphausiids - 200-300 mg/m^3). From June to October, the community is in the wintering stage and its characteristic feature is a maximum density of adult organisms in deep layers.

In island waters of the Scotia Sea the mean zooplankton biomass within the 0-100m layer is increased from July to December almost 5 times (up to 580 mg/m3). In March, this value is halved.

In the Eastern part of the AC the species composition of zoocenosis has the natural trend of the smooth change from warmth - requiring forms to cold-resistant forms.

The main species which occur only in the sub-Antarctic are Rhincalanus nasutus, Calanus tonsus, Candacia maxima, Calocalanus styliremis. In February-April there is also Calanus simillimus. Oithona frigida is also always present.

Fauna consists mainly of groups of typical species and forms. Among copepods the species of largest size are more important : Rhincalanus gigas, Calanoides acutus, Calanus propingus, Metridia gerlachei ; while the more abundant species (up to 97% of total numbers) were Paracalanidae, Microcalanidae, Oithona similis and species of g. Oncaea. These species are widely distributed in

Antarctic waters though their ratio is not constant. In April, instead of large size copepods, the principal position is occupied by small sized organisms.

Among other species of Antarctic zooplankton the Amphipoda, Chaetognatha and Polychaeta species are not numerous but they are important. The importance of these species increases towards April and at the same time, the importance of Copepoda decreases.

Time and space variability of zoocenosis was calculated on the basis of analyses of zooplankton distribution. The variability is more noticeable when the study area is subdivided according to N.M. Voronina's divisions of the Southern Ocean.

In January, the highest quantitative indices of zooplankton development are observed in the sub-Antarctic. In terms of trophic relationships, the phytophagous species is predominant (up to 60% of total biomass).

At the same time, in the northern part of the , the amount of zooplankton is much lower. It appears that mass spawning of Copepods is finished by that time and the development of a new generation takes place. For the intermediate and southern zone of the Antarctic, the relatively high level of numbers and biomass is a characteristic feature dependent on the spring movement of wintering stock to the surface. Euryphagous species take the chief position in trophic structure. Mass spawning of copepods begins (concentration of eggs in some areas was up to 34%).

In February, the center of maximum zooplankton development shifts to the northern Antarctic. Phytophagous species are predominant during that period of time.

In March, the "peaks" of zooplankton development move to the intermediate and southern zones of the Antarctic, though they begin 2-3 weeks later (in the intermediate zone in the first part of March and in the southern zone in the second part).

In April, the summer development of phytoplankton ends. Low values of quantity indices and changes in trophic structure (the importance of predators is increased) are evidence of this.

In June-July, the plankton community is in a state of winter depression with the prevalence of older age groups. In accordance with the winter state, predators numerically and euryphagous species (by biomass) take the principal position in the zooplankton community. The major part of zooplankton (84%) stays above the 500m level.

Species distribution in peripheral parts of the region depends, in principle, on the hydrodynamic situation which is extremely variable. Increased numbers and biomass correspond with the upwelling zones.

Energy flows through the krill population and the mesopelagic group were compared and relative assessment of krill and mesoplankton roles done for the austral winter. Calculations are based on data collected in May-June 1982 (between $4^{o}W$ and $20^{o}E$) from the Antarctic Convergence ($52^{o}S$) to the ice-edge ($60-61^{o}S$) at 70 stations. The role of mesoplankton was evaluated on the basis of copepods only because they form the major part of the mesoplankton in AS. The basic indices were production, food consumption and food assimilation in terms of $Cal/m^{3}/day$ at the surface of the 0-100m layer. Within the study area, two water modifications were determined. They were subdivided by the secondary frontal zone. To the north of it are the transformed ACC waters and to the south, Weddell Sea waters. The plankton communities of these areas are considerably differentiated. The big difference in effectiveness of energy transformation is a characteristic feature of the plankton communities compared. Thus, the production at second trophic level and effectiveness of utilisation of primary production at this level is almost five times larger than in ACC transformed waters.

The function of the second trophic level of biocenosis of the ACC transformed waters is completely dependent on the group of "peaceful" copepods who transform more than 90% of energy at this level. On the other hand, in the Weddell Sea waters, the major part of energy is transformed through the krill population (64%).

2. Review of Research into Biological Resources of the Indian Ocean Sector of the Antarctic (IOS)

2.1 Expedition Studies

There is a shorter history of research in the Indian Ocean Sector (IOS) than in the Atlantic Sector. Nevertheless, experience of work in the Atlantic Sector assisted with the undoubted success of the further research described below. A list of cruises and basic data for IOS is provided in Table 4.

Research into fish resources available for commercial fisheries began in IOS in 1968 aboard RS/V "Alelita". In 1968-1983 research was carried out in several large areas : the shelf of the Crozet Is., the shelf of the Kerguelen and Heard Is., Ob and Lena Banks and peripheral Antarctic seas. To obtain chronological accuracy, the research and fisheries search studies, as well as other questions are described in review in accordance with the abovementioned areas.

The Crozet Is.

This area was studied to the least extent. Research had been carried out in 1968, 1970-1973 and in 1978. In general, there were 12 expeditions in waters of the Crozet Is. (7 research and 5 research/fisheries search expeditions), but none of the expeditions had spent over 20 days in the area. In most cases there were 10-30 bottom trawlings and related oceanographic stations in each expedition. Only

in September 1973 RS/V "Skif" had carried out the detailed complex oceanographic survey and trawl survey (91 trawlings). Relatively low fish productivity in this area was found. Later, after expansion of research on the shelf of the Kerguelen Is. and the establishment by France of the 200-mile economic zone (in 1978), there was no more research at the Crozet Is. There were no evaluations of fishing ground areas.

Ob and Lena Banks

Research on the Ob and Lena Banks was started in 1971 during the third scientific-research cruise of RS/V "Skif". In general, there were 32 expeditions on banks from 1971 to 1983.

Since 1980, after the 16th cruise of RS/V "Skif", relatively systematic fisheries research was begun on the banks. Such research was carried out in August-October, 1980 ; April-May, 1981 ; May-August, 1982 ; April-May, August-September, November-December, 1983.

The total area available for trawling on Ob and Lena Banks is 360 sq. miles and 850 sq. miles, respectively.

Kerguelen Is.

Studies of the commercial fish resources on the shelf of the Kerguelen Is. were commenced in 1968 aboard RS/V "Aelila". Relatively systematic scientific-research and fisheries search studies were started by RS/V "Skif in 1969. They had been carried on until June 1978 (i.e. before establishment of the economic zone around the islands). After the USSR-France agreement on licence fishery in the Kerguelen waters was concluded (1979), there were only search studies (in 1983 there was not even a search cruise). In general, there were 31 expeditions (10 scientific/research, 10 scientific/fisheries searches and 11 fisheries search expeditions). Only 4 expeditions were considered to be complete. During the expeditions, the complex of fisheries research was done (RS/V "Skif" cruises number 2, 10-12). A sufficient amount of data was obtained on oceanography and fishery ichthyology in those expeditions.

In October-December 1981, a survey of fishing grounds and their areas was carried out. All fishing grounds with good catches were on north-eastern, eastern, south-eastern and southern parts of the shelf. Their area was 878 sq. miles.

The shelf and continental slope of Antarctica

Studies along the coast of Antarctica were started on the first scientific-research cruise of R/V "Chatyr-Dag" (December 1972-April 1973). In general, there were 24 expeditions in ten years of research of fisheries resources in the area. Up to 1978, the research was directed, first of all, at krill resources. A large-scale complex oceanological survey and trawl survey in surface waters to fish krill aggregations was carried out. In this period of time, 7 expeditions, 7 bottom and 17 off-bottom trawlings were undertaken to find fish aggregations. Almost all expeditions up to 1981 had their efforts concentrated on the Commonwealth Sea area. Fish resources study was started in February-March 1978 in Prydz Bay aboard RS/V "Fiolent". Short-term investigations (up to 30 days) were undertaken in 1979-1982 (R/V "Chatyr-Dag", "Kara-Dag" and "Mys Ostrovskogo"). Directed study of fish resources available for fishery on the shelf and continental slope of Antarctica was begun in the navigation season of 1982/1983 by a complex expedition involving 5 vessels (3 research/search vessels and 2 scientific research vessels). Area of study was considerably increased. Promising results were obtained for the following coastal seas : Lazarev, Riisen-Larsen, Cosmonaut (to the west of Commonwealth Sea) and Davis and Mawson (to the east of Commonwealth Sea).

The largest-scale work on aggregations of Antarctic sidestripe, Pleurogramma antarcticum, was done in 1978 aboard R/V "Fiolent".

2.2 Characteristics of Long-term Averages of the Annual Hydrometeorological Conditions in the Commonwealth Sea

2.2.1 General Remarks

The navigation season (December-March) for the Commonwealth Sea area has the following characteristic features of principal meteorologic conditions (see Table 5).

The thermohaline structure of the Commonwealth Sea may be described by means of traditional oceanography subdivisions of the water column into structural zones : surface, intermediate, deep and bottom zones. The surface zone is directly dependent on processes in the atmosphere and on solar radiation. In winter, the surface zone is uniform in terms of temperature and salinity layer with a depth of 80-100m. In summer, the relatively warm and wide-spread surface layer is formed with a depth of 50-70m in the northern part and of 10-20m in the southern part. The temperature in this layer ranges from 2.9°C in the north to -2.0°C in the south. The zone of maximum horizontal temperature gradients is fixed at 60-62°S and near the ice-edge ; the zone of maximum salinity gradients - near the ice-edge and in the area of intensive ice-melting. The salinity ranges from 32.10°/oo at the ice-edge to 33.90-34.10°/oo in the north.

Below the layer of homothermal waters, there are cold winter waters with temperatures from 0.0° to -1.75° and salinity 34.00-34.40°/oo. The vertical temperature gradient between layers is 0.05-0.20°/m. The low boundary of this layer as well as of the entire surface Antarctic water mass is at 150-200m depth in the south and at 75-90m depth in the area of the Antarctic Divergence.

The intermediate Antarctic water mass is in the layer between 200 and 1800m depth. A characteristic feature of the water mass is the increasing of temperature with depth up to 2.0° and of salinity - up to 34.70-34.80°/oo. Its core is tracked up to 300-450m depth.

Below, there is a circumpolar water mass with a temperature of 0.0-0.2° and salinity 34.65-34.70°/oo. The layer below 1000m, as a rule, is not studied in fishery expeditions.

2.2.2 Year-to-Year Variations according to a Series of Hydrometeorological Observations

A systematic oceanographic survey in the Commonwealth Sea was started by the AzcherNIRO Institute in 1972. Since 1973, the seasonal standard survey is carried out in January-February including sections along 55°, 60°, 65°, 70°, 75°, 80°, 85° and 90°E up to the ice-edge. Stations are located along the sections 1° apart. The comparable sets of oceanographic data were obtained for each year excluding 1974 and 1976 (Table 6). Mean temperatures of the surface layer throughout the survey area (to), mean minimum temperature of cold surface water stratum (tmin) and mean maximum temperature of intermediate warm water stratum (tmax), were calculated to evaluate year-to-year variations. These figures are in Table 6.

Other oceanographical characteristics appeared to be useless for evaluation of year-to-year variations. In particular, parameters of salinity for the 0-500m layer actually have differences only within the range of 0.01 units.

2.3 Characteristics of Bioresources of IOS

2.3.1 Antarctic Krill and Structure of Plankton Communities in Antarctic IOS

Fisheries and scientific research on krill in Antarctic IOS have been carried out from 1973 to 1984.

During this period, there were 14 expeditions directed on search and study of krill (see Table 4). At the initial stage in 1973-1975, there was only a minimum of oceanographic work accompanying krill research. Hydroacoustic surveys and fishing of krill aggregations by commercial trawls and Isaacs-Kidd nets was the basic work of that time. Actually, the whole area of IOS was explored. Krill aggregations were found in different parts of the area, the largest in the Commonwealth Sea region.

On the basis of results obtained since 1977, the krill fishing stock in the Commonwealth Sea was determined at the level of 20 million tons (70 million tons for the entire IOS).

Simultaneously, a complex research of the area has been started to obtain correct stock assessments (and their variations) by means of direct surveys (hydroacoustic and trawl surveys) and on the basis of study of the plankton community structure and its energy balance. With this purpose in mind, and since 1977, the complex field and experimental work is carried out annually. Data on waters productivity, distribution of krill and its stock, functional meaning of distribution areal, plankton community structure and energy balance were collected. Systematically, the recommendations on krill catches were provided for the fishing industry on the basis of results obtained for this traditional krill fishing ground.

The principal parts of the krill areal are shallow coastal waters differentiated by circulation systems. It was discovered on the basis of research on distribution of krill eggs, larvae and adult specimens. In such places the current system is stationary, spawned eggs do not drift into deep waters and hatch on the bottom. Concentration of krill is dependent directly on physical forces and indirectly through food availability and on the existence of stationary current systems. Favourable conditions are the most likely in stationary anti-cyclonic circulations and less likely in cyclonic circulations. In the zones of storms and uniflow currents, the dispersion of krill concentrations is observed.

By experiments, the diet and energy balance is studied for krill of 16.0-50.0mm length. By means of approximated equations the quantitative ratios of these parameters with size (weight) of animals were found. On the basis of experimental data, the K_2 indices were calculated for different size groups ; index ranges from 0.64 to 0.21 for krill of 16 to 50mm length. Experimental results serve as a background for subsequent calculations of krill length increments, food consumption etc.

On the basis of experimental data and the results of the study of length-weight stock composition, it was calculated that krill weight increment for the post-larval period ranged within limits of 20-60% of krill biomass and, in general, for the whole population it was 30-35%.

Total krill biomass in the region between 60° and 90°E, in the Commonwealth Sea, and in commercial krill concentrations has seasonal and year-to-year variations. Thus, in summer 1977-78, the data of two surveys in the region between 60°-75°E (northern boundary of krill areal is at 60-62°S) provided the following stock assessments : in January, 57 million tons and in February, 17 million tons.

Weighted average of krill biomass in the region ranged in different years from 11.7 to 100.0 g/m^2 with an average of $46g/m^2$.

Plankton communities in the studied area are developed inside current systems, presented by ACC and West Coastal currents, and inside the hydrological structure, consisting of surface Antarctic, intermediate, deep and bottom water masses. The picture of water circulation is most complicated in the zone of the Antarctic Divergence of hydrometeorological and orographic conditions. Cyclonic and anti-cyclonic circulations follow each other in a meridional direction.

There are sinoptic, seasonal and inter-years variations under the influence of air circulation.

The large variety in plankton composition depends on the complicated hydrological structure. Up to 160 species and varieties of phytoplankton and over 120 of zooplankton were determined. At the same time, similarity of the biotopes throughout the major part of space (within the Antarctic water masses) in the summer season leads to the existence in plankton of small amounts of species of Antarctic, sub-Antarctic and temperate-warmwater complexes. Among algae, the diatoms prevail (about 70% of species and 95% of biomass), among animals - copepods (over 80% of species) and Antarctic euphausiids - Euphausia superba (40% to 75% of biomass),

The level of development of plankton components in the region undergoes clearly determined seasonal and inter-years variability related to appropriate macroscale changes of oceanographical conditions. The mean level of primary production in the vegetation season in different years ranges within limits from 4 to 6 mg^c/m^3 in the photic layer ; mean level of residual algae biomass - from 400 to over 1200 mg/m^3 ; mean level of mesozooplankton biomass - from 40 to 90 mg/m^3 in the layer 0-1000m.

Seasonal variations in the level of mesozooplankton development, (on average - four times), are correlated with changes in the trophic structure : in summer the amount of potential carnivores is relatively the same as filter-feeders ; in winter their amount is two times more.

A characteristic feature of plankton components is the unbalanced trophic relationship in the vegetation season. Daily algae production is considerably higher than daily food requirements of phytophagous mesozooplankton and Antarctic krill. It results in the accumulation of a considerable amount of phytoplankton residual biomass. The other results of unbalanced trophic relationships are permanent high contents of suspended organic materials - from 1.4 to 4.0 $mg/_l$ (weighted in dried condition) dependent on time of observation in the vegetation

season ; high level of bacterio-plankton development (4-8 thousand mg/m^2 in the photic layer) and of their production (about 0.5-1.0 thousand mg/m^2) ; and intensive development on this basis of microzooplankton - first of all, dinoflagellate - about $20mg/m^3$. Fifty to 90% of energy consumed by heterotrophic organisms is a share of bacterium and zoo-flagellate (due to their relatively high activity and high abundance).

Thus, the krill share is 15 to 40% of energy, consumed by heterotroph organisms (macro- and mesozooplankton and bacterium) ; the share of primary production, comsumed by krill, is from 15 to 80%, depending on the level of krill abundance in the region, on average, about 30% in summer.

2.3.2 Main Species under Study and their Brief Biological Description

On the shelves of the Crozet Is. and Kerguelen Is.and on Ob and Lena Banks, the main objects of fisheries research are Marbled notothenia (Notothenia rossii rossii), Scaled notothenia (Notothenia squamifrons), Patagonian toothfish (Dissostichus eleginoides) and also Antarctic icefish (Champsocephalus gunnari) on the Kerguelen shelf. Below there are brief biological descriptions of each species.

Marbled notothenia (Notothenia rossii rossii)

This fish was a major part of catches in the shelf waters of the Kerguelen Is. in 1970-1973. It also prevailed in catches on the shelf of Crozet Is. As a by-catch, it is observed on Lena and Ob Banks.

Fish may attain over 90cm in length and over 9kg in weight. At the beginning of the fishery, the major part of catches were fish of 45-75cm length and of 0.5-8.5kg weight (1970-1971).

Marbled notothenia attains maturity at 40-60cm length at the age of 4-7 years. Spawning takes place in May-July (it is observed in all study areas in IOS) on the south-eastern part of the Kerguelen shelf. Eggs are large and benthopelagic-pelagic. Spawning is simultaneous. The diameter of the eggs ranges from 2.8 to 5.8mm (on average - 4mm). Absolute fecundity of fish of 50-75cm length ranges from 12 to 63 thousand eggs. The linear correlation is observed between length, weight and age of fish and their fecundity. Egg development takes over two months (in the laboratory - 76 days).

Spawning concentrations in 1971-1973 were on the north-east shelf of the Kerguelen Is. in September until May. In 1981 spawning concentrations were observed on the south and west of the shelf. In May, fish migrate along the slope to the south-eastern part of the shelf (spawning ground). Fish concentrate in dense aggregations on the spawning ground from the second part of May until the first ten days of July (inclusively). In July-August, backward migration takes place to feeding grounds on the north-eastern part of the shelf.

During feeding and spawning mirgrations, sharp daily variations in catches are observed and patchiness of aggregations is clearly determined. Catches during the day-time usually are 4-5 times higher than at night. During the spawning period, catches used to be stable.

It is necessary to underline that Marbled notothenia is the most studied species of the Kerguelen Is. In particular, the migration patterns were studied by multiple tagging experiments. There are no such detailed data for other commercial species.

Scaled notothenia (Notothenia squamifrons)

Fish may attain 64cm length and 2.2kg weight. The major part of catches are fish of 30-40cm length. The fishery is based on 4 year old fish and over, while fish of older age groups (9-14 years)

are prevalent in terms of weight as well as numbers. The length of these fish range within the above-mentioned limits. Fish attain maturity at length of 24-30cm (6-8 years). In different regions, spawning is observed at different times : on the Kerguelen Shelf, in August-October ; on Ob and Lena Banks, in September-November, February-April. There is only indirect information on spawning time because scaled notothenia does not form a spawning concentration on grounds and depths accessible for observation. For this reason, periods of spawning are shown in accordance with dates of observations of the highest numbers of post-spawning fish.

Egg diameter is 1.2-1.7mm. Absolute fecundity ranges from 25.5 to 138 thousand eggs. Eggs are benthic. Period of development is unknown (there are no published data). Fecundity is related to fish length and weight. Marbled notothenia is euryphagous (principal food - macroplankton).

Feeding concentrations are formed in austral spring-summer (observed at the Kerguelen Is., Ob and Lena Banks). On the Kerguelen shelf the principal spawning concentrations (accessible for fishing) were recorded on southern and south-eastern parts of the shelf. In 1981-1982 spawning concentrations were observed on the western part of the shelf.

Actually, this species had not been utilised in the first years of fishing at Kerguelen Is. In the middle of the seventies, catches of scaled notothenia attained considerable levels (in some years it built up to 85% of catches). There was not, in fact, any scaled notothenia fishing in years when Antarctic icefish was being fished successfully because scaled notothenia are a more active and a more difficult object to catch. On Ob and Lena Banks, scaled notothenia is always a major part of catches (80-95% of total catch).

Patagonian toothfish (Dissostichus eleginoides)

This is the most valuable fish in the Southern Ocean from a gastronomic point of view. However, its share in catches is negligible. It is 0.5 to 5% of the total catch (on average - 1%). Actually, it occurs in all trawl catches on the Kerguelen and Crozet shelves, Ob and Lena Banks. Fish length in catches ranges from 20 to 150cm, weight from 170g to 26kg. The major part of catches is fish of 30-50cm length, 550-1300g weight. The age of fish caught is 1-8 years. Fish of 3-4 years predominated in catches. Actually, all analysed fish had gonads at stage II of development (i.e they were immature). It was observed that only the largest females had gonads at stage III of development (the beginning of trophoplasmatic growth).

Patagonian toothfish is the only distinct carnivorous species in ichthyocenosises of sub-Antarctic islands and underwater elevations.

No variations were observed in catches of Patagonian toothfish. Single catches of 1.3 or even 8 tons were recorded (the last such catch was obtained aboard RS/V "Chatyr-Dag" in October 1980 on the western part of the Kerguelen shelf). Tagging in May-August 1982 (18th cruise of R/V "Skif") on Ob and Lena Banks did not give any results. Until now, there have been no tags recovered.

Antarctic icefish (Champsocephalus gunnari)

This species is recorded only on the Kerguelen shelf and on the banks of the underwater Kerguelen Ridge (Skiff, "Esox", New and Middle Banks). Fish are absent on the Crozet shelf, Ob and Lena Banks. At first (in 1970-71), fish were found as a by-catch in marbled notothenia fishery although absolute catch of Antarctic icefish ranged from 10 to 30 thousand tons yearly.

At present, Antarctic icefish, together with scaled notothenia, are the principal part of catches on the Kerguelen shelf.

Specimens of 12-14cm length and 11.7-400g weight are found in catches. The major part of catches is fish of 22-35cm length. The age of analysed fish was from 2 to 11 years. During all years of the fishery, fish of 4-6 years old were the principal part of catches. It was found that fish length decreased when depth of trawling increased.

Fish attain maturity at 4-5 years old when their length is 22-28cm. Spawning takes place in April-May although single mature specimens are observed even in March and July. It is suggested that fish move to shallow waters for spawning. Spawning is simultaneous. Fecundity of fish of the Kerguelen population ranges from 4 to 11 thousand eggs. Eggs are smaller as compared with eggs of another Chaenichthyidae - diameter is 2.2-3.0mm. Eggs are benthic. Hatching occurs in November-December.

Accessible for trawling fish, feeding concentrations are formed in the austral spring-summer on the north-eastern, eastern and south-eastern parts of the Kerguelen shelf. In winter, fish disperse actually throughout the whole shelf; they do not form stable dense concentrations.

Recently, in waters adjacent to Antarctica, two other abundant fish species were found : Antarctic sidestripe (Pleurogramma antarcticum) and Wilson's icefish (Chaenodraco wilsoni). Concentrations of Antarctic sidestripe are, at present, found in the Riiser-Larsen Sea (Gunnerus Bank), the Commonwealth Sea (Enderby Land and Prydz Bay) and the Mawson Sea.

Catches of bottom and midwater trawls in IOS of the Southern Ocean indicate several prospective fish species (Trematomus spp., Pagotenia spp., Chionodraco, g. Neopagetopsis, Macrourus whitsoni).

Antarctic sidestripe (Pleurogramma antarcticum)

Fish of 7-26cm length and of 1.9-165g weight are found in catches. In catches on the shelf (Prydz Bay, Drygalski Is., Enderby Land, Cosmonaut Sea), the modal fish group is 11-15cm ; in catches on the upper part of the continental slope (Mawson Sea) - 14-18cm. Fish attain maturity at 6-7 years when they grow up to 15-18cm in length. Apparently, spawning takes place in the austral winter-spring, hatching in December-January. Eggs are pelagic. Spawning appears to be simultaneous.

Antarctic sidestripe is a circumpolar Antarctic species. Feeding concentrations are, however, formed only under particular environmental conditions, namely : gradient zone in the near-bottom layer and a gap in seasonal pycnocline surface waters. If only one factor exists, the concentrations will be stable. There would be no concentrations if both factors are absent.

Wilson's icefish (Chaenodraco wilsoni)

Fish were found only in the Riiser-Larsen Sea (Gunnerus Bank) in 1983. There were fish of 11-24cm length (on average - 17.5cm) and of 11.5-111.6g weight (on average - 43g) in the catches. There were only immature fish (gonads at stage II of development) in the fished concentration. In the Cosmonaut Sea (41-47°E) mature fish were recorded, but there were not any concentrations. In Prydz Bay (Commonwealth Sea), in catches of bottom trawls, there were also mature fish of 21-36cm length (on average - 27cm) and of 130-680g weight (on average - 248g). However, there also, concentrations of Wilson's icefish were not observed. It appears that additional research is needed in shallow waters of the Antarctic coastal seas to study the details of species distribution.

In accordance with published data, hatching takes place in December-January, larva length is 34.3-40.8mm (for S. Shetland and S. Orkney Is.).

In 1983/84 waters above Gunnerus Bank were covered with ice and planned research was not done.

3. Review of Research into Bioresources of the Pacific Ocean Sector (POS) of the Antarctic

3.1 Expedition Studies

The Pacific Ocean Sector (POS) of the Antarctic is one of the less explored regions of the World Ocean. Weather conditions, specific ice conditions and little information on bottom topography prevent the development of research and establishment of fisheries down there.

In 1967-1971 TINRO Research Institute carried out complex expeditions in POS. The expeditions were of reconnaissance nature and were carried out throughout the large area from the Bellingshausen Sea to the D'Urville Sea. A multipurpose observation program (pinnipeds, whales, krill, fish) and an extensive study area were not favourable to obtain detailed data, in particular, to determine and assess krill and fish stocks in the Antarctic. Nevertheless, they were the basis for further, more directed research and they had also shown future prospects of exploration of this sector of the Southern Ocean.

Systematic research of biology, distribution and resources of krill in the western part of the Antarctic POS has been carried out since 1972. A great deal of attention was paid to carrying out a complex of hydrological and hydrobiological work. Since 1979, the directed research of biology and distribution of Antarctic fish, primarily, Antarctic sidestripe was carried out.

During previous years, a large number of complex sea expeditions had been completed. A list of expeditions is provided in Table 7. These expeditions provided the basic data on bioresources of POS, their distribution and general biological description of species. These data are of particular interest from a practical point of view.

3.2 Hydrometeorological Characteristics of Regions

3.2.1 Meteorological and Ice Conditions

Formation of air circulation and weather conditions in POS depend on the interaction of the Antarctic anti-cyclone (having a core at about 80-85°S and 70-90°E) with a zone of low pressure (which is circumpolar and covers the zone between 60° and 70°S). Areas of krill habitat are to the north-west of the centre of Antarctic atmospheric activity - the depression above the Ross Sea and inflow of cold air from the continent causes a noticeable acceleration of cyclonic activity. Mean speed of cyclone movement is 55 km/hour; maximum speeds may be as high as 110 km/hour. The most probable are cyclones with pressure in the core of 980-989 mbar : 75% of all cyclones have a depth ranging in between 970 and 989 mbar.

The continuous cloudiness of middle and low layers is always observed in this area. Clouds are stratified or stratified-cumulus. Frequence of recurrence of days with continuous cloudiness in the Ross Sea is 40-75% (layers of low clouds are prevalent).

To the north of the area (60-33°S) west winds prevail all-year-round (more than 50%), while to the south of 63°S, the inconsistency of wind direction is a characteristic feature. Winds of 3-10 m/sec prevail. Winds of 10-20 cm/sec are observed considerably rarely : it is only 30-35% of such winds in the northern part and about 15% in the southern part (from 63°S to ice-edge).

In the Ross Sea the southerly winds prevail (50% and more). Winds of 4-7 units (on the Beaufort scale) have 50-65% frequency, storm winds of 8 and more units - 10-20%.

In the northern part of the region, in summer, the most probable range of temperature is 2-4°C, in the northern part - 0-10°C. The most probable range of temperature in the ice-edge area (20-35 miles width) - within a range of -0.5° to -1.0°C.

At Balleny Is. air temperature throughout the summer season, in general, is below 0°C. The isotherm line of 0°C on average for season takes place close to the northern part of Young Is., isotherm of -2°C - to the south of Sturge Is. For the major part of the year the study area of the Southern Ocean is covered with pack-ice (in January-March the free of ice area is the largest).

To the west of Balleny Is., there is the so-called Balleny ice-massif. At the end of January, the west boundary of the ice-massif extends to about 145°E, northern - 66°S, eastern - from the Balleny Is. to the south to Cape Adare. The position of the northern edge at the meridian of Leningradskaya Station ranges from 64° to 67°30'S in different years. Movement of the ice-edge is not over 60 miles per season.

Icebergs are frequent in all of this area. Their numbers increase to the south. The northern boundary of iceberg distribution at the Balleny Is. extends to about 63°S.

3.2.2 Hydrological Conditions

Thermohaline conditions of the region are formed, in general, under the influence of water circulation, heat radiation flow and pack-ice melting.

Water temperature in POS of the Antarctic ranges from 3-4°C in the north to -1°-0°C in the south. Maximum heating of surface waters (0-30m) is attained at the end of January-beginning of February. In the southern part of the isotherm of 1° repeats the boundary line of Balleny ice-massif, 60 miles from its northern boundary in a period of maximum water heating. In March, there is a decrease of surface temperature to 0.3°-0.8°C in comparison with a period of maximum heating. In the south-west part the cooling is more intensive.

Salinity in the western part of the region between 135 and 150°E does not actually change from south to north. At the same time salinity does significantly change along the meander area of ACC to the east of 150°E. The desalination effect of the Balleny ice-massif is traced to the north to 62°S and to the east to 167°E. Limits of salinity variation are 33.2 to 34.2°/oo. Average long-term year-to-year isotherms on water surface at Balleny Is. are orientated from north-west to south-east.

Depth of the quasi-uniform surface layer is of 30-50m on average. The maximum depth of this layer (up to 80m) is in the south of the region where there is no seasonal thermocline. Vertical termperature gradient is 0.05° per meter within the thermocline zone. In the central part of the Ross Sea, the area of water with temperatures above 0°C (1.0°C in some years) may be formed in short summer season because the area becomes clear of ice early. On the other hand, in the eastern part and in coastal waters, temperatures are usually below 0° and it is -1.0° to -1.5°C.

Salinity of surface waters in Ross Sea is relatively high and it is up to about 34.4-34.5°/oo.

Several frontal zones are observed in POS. The Secondary Frontal Zone (SFZ) separates ACC waters from High Latitude Modification waters (HLM), and as well, the Local Front separates waters of the Balleny ice-massif (desalinated by ice-melting) from

other adjacent waters. The location of SFZ in the area of 139-150°E is observed most clearly by horizontal gradients of silicon contents in surface waters. In this area, ACC is close to the coast and SFZ is the zone about 100 miles in width.

Waters in this region are under the influence of ACC south periphery, the southern branch of which follows the continent coastline between 132-150°E. The current in this area flows to the east; its speed is small (1-5cm/sec). At about 150°E, the southern branch of ACC is subdivided. The southern ACC branch itself turns to the north-east while a small part continues movement to the east along the ice-edge of the Balleny ice-massif. The system of circulations is formed in the central part of the Somov Sea as a result of meandering in the southern branch of ACC above the underwater plateau.

A zone of strong currents is located in the north-east part of the region. Maximum speeds there are up to 20-25 cm/sec. Acceleration of the current takes place above the top of the South Pacific Elevation (SPE). Between SPE and Balleny Is., there is anti-cyclonic circulation. The main pattern of large-scale circulation usually does not change from year-to-year. The dynamic field around Balleny Is. is a complicated area of interactions of anticyclonic and cyclonic vortexes having a scale of the order of several tens of miles (10-100 miles). Speed of vortex movement is apparently not less than 10 miles/day. The north-west current to the east of the islands is the most stable.

The general pattern of geostrophic currents in the Ross Sea does not change significantly from year to year. It is a slightly noticeable cyclonic water circulation. Complicated circulation, the most turbulent current field, is observed at the boundary of the shelf and continental slope.

Drift currents at boundaries of the Ross Sea and open waters of the Southern Ocean are of a continuous nature and they have a north-westerly direction.

3.3 Description of POS Bioresources

3.3.1 Antarctic Krill

Within the western part of POS, the main area of krill habitat is the Coastal Antarctic Current, high latitude waters of which mainly cover the shelf and are close to slope areas. In waters of the southern periphery of ACC, krill occur, in general, in small amounts with the exception of places where waters of the Antarctic coastal currents intrude in this current due to a system of coastal cyclonic circulations. Usually, the krill aggregations are found in the surface 50-100m layer but sometimes krill aggregations are observed at a depth of up to 200-400m. These krill aggregations generally coincide with bottom elevations where many local current vortexes are observed. In the Ross Sea krill aggregations are found in the east and south-east parts, in the Somov Sea - at Balleny Is. and in the south-east part in the D'Urville and Mawson Seas - almost throughout the area. There are seasonal changes in krill distribution. In summer and at the beginning of spring, principal areas of the krill habitat are covered with ice. To the end of spring, in summer and at the beginning of autumn, the major part of krill habitat areas is free from ice.

Spawning takes place mainly in January-February; sometimes in March-April (second peak). The principal spawning grounds are the shelf and close to slope areas at Balleny Is. Usually, spawning occurs in near-bottom layers or, in any case, below the pycnocline layer. Krill spawn at least twice during their life - at third and at fourth years. Absolute fecundity ranges between 4-12 thousand eggs depending on krill size. At early stages of development the larvae inhabit the bottom layer at a depth of 700-2000m (depending on the actual depth of the site).

At stages of calytopsis - furcilia larvae, in general, are found in the surface 100-200m layer. The older the larvae, the greater the degree of their concentration in surface water layers. Juvenile krill mainly inhabit the surface 50-100m layer. Both larvae and juvenile krill are observed mainly in the more southern part of the region.

From stage calitopsis-I, krill larvae feed mainly on small phytoplankton. The principal food of juvenile and adult krill is phytoplankton. There is no specific species. Krill feed on any abundant species of plankton algae.

At the last stage of larva development, krill grow up to 13-16mm in length. In trawl catches both juvenile (up to 36-39mm) and adult (40-65mm) krill are observed. In general, weight of juvenile krill is not higher than 0.5g, of adult - 1.5-2.0g. Usually, krill attain maturity at a length of more than 36mm at the third year of life. Mean life span of krill in POS is 3-4 years. In catches of commercial trawls, specimens of 20mm and longer (to 60mm) are usually found. These sizes correspond with ages of 1+ to 3+ years.

3.3.2 Biological Characteristics of Studied Fish Species

Among Antarctic fishes, only some species may be of commercial importance. Below there are results of research into principal biologic features of such species.

Antarctic Sidestripe (Pleurogramma antarcticum)

Length-age structure Specimens of 6-33cm length are presented in catches. In the eastern part of the region (Ross Sea) fish of 12-20cm length are prevalent (modal group - 16-18cm, average length for several years - 16.2cm). To the west, in more northern seas (Somov Sea) fish of 10-18cm length are more frequent

in catches (modal group - 15-16cm, average - 14.2cm), in region periphery (D'Urville Sea and adjacent waters up to 135°E), specimens of not more than 13.7cm on average are prevalent (modal group - 12-13cm).

It is possible to obtain a knowledge on growth patterns of Antarctic sidestrip from direct observations and by back calculations. As for most fish, the Antarctic sidestripe has the most intensive growth in the first year of life. At the age of 1+, fish length is 5cm. In the second year intensive growth continues; fish attain 8.0cm length. Decreasing of annual length increments in the third year and, in particular, fourth year, is dependent on the maturity process. Fish begin to attain maturity at that time. At the length of 15-17cm (close to 5 years old) the immature fish are nearly not found in the population. In sixth and seventh years, the length increments are still rather high - 2.1-1.6cm (Ross Sea) and 1.9-1.5cm (D'Urville Sea) respectively. In the eighth and ninth years, length increment is 1cm annually (eastern seas) and 0.9-0.8 (western periphery). Lineal growth may be described as uniform and referred to as parabolic.

Specimens of 1.7-150g weight are found in catches. Mainly, fish have a weight of 30-60g (Ross Sea), 7-45g (D'Urville Sea), 8-38g (western periphery of areal). Their share is 72.2, 85.0 and 69.1%, respectively. Where the length increment decreases with age, the weight increment is of a different kind : the weight of fingerlings is only 0.5g ; at the age of 1+ fish weight is three times higher (on average 1.7g), weight of two year old fish is 2.5 times higher than in the previous year, and so on with annual growth. The largest weight increment is observed in fish of 5 years old (13.0g) ; it relates to maximum length increment at this time. From then on, absolute weight continues to increase intensively but increments slow down and it is about 12g for fish of 8 years old. Mean weight of Antarctic sidestripe, according to data for several years of observation, is 42.5g (for eastern parts of the region) and 36.7g (for western parts).

Spawning It is impossible to observe Antarctic sidestripe during spawning. The earliest period of time to observe the accessible areas of the shelf (D'Urville Is.) is in the middle of November. However, observations are absent for this period and it is only possible to get an idea on spawning dates by retrospective analysis. Thus, in December-January, the post-spawning fish with gonads at stages II, II-III of maturity, are observed in considerable amounts. Only individual fish have stage IV. It provides the background to assess only fecundity of this species which is 12-14 thousand eggs on average. In summer time, in February, in krill catches of surface trawling, the juveniles of Antarctic sidestripe 2.0-2.7cm in length are observed. By means of back calculation of growth rate, it was determined that hatching took place in August-September and, in general, spawning was rather extended throughout different parts of the areal.

Antarctic sidestripe is one of the few bentho-pelagic fish of the Antarctic. Such a statement is true for the adult part of the population. Early larval (0+) and juvenile (1+-2+) stages of development take place in pelagic waters. Juveniles migrate into deep water and bottom layers as they become older.

Feeding In shelf areas of the Ross, Somov and D'Urville Seas, adult Antarctic sidestripe of 15-23cm length, feed on plankton and also on fish eggs and juveniles (cases of cannibalism are recorded).

The principal food of Antarctic sidestripe is krill (at different stages of development from larvae to adults), which is certainly prevalent in meso- and macroplankton. Krill build up to 85-90% of total food diet of Antarctic sidestripe. Secondary food objects are fish juveniles (mainly Myctophidae), fish eggs (in general 8%) and also Copepods (6%). All other food components are casual : amphipods, pteropods, polychaeta, tunicates and chaetognathes (in general not more than 11%). Abundance of Antarctic krill - the principal food of Antarctic sidestripe, is an

indication of good food supply all year round. This factor is also favourable for fish concentration. Relatively high fatness (up to 12-13%) of sidestripe is dependent, among other factors, on such good food supply. Indices of stomach fullness in summer-autumn are rather high and they are 2.30-2.80 units.

Distribution Antarctic sidestripe is a circumpolar species in the Antarctic waters. It appears that fish do not make any substantial migrations along the continental shelf. For this reason, fish distribution is located in particular areas of Antarctic waters. In general, larger specimens inhabit higher latitude areas, whereas the smallest specimens and juveniles inhabit the most northern peripheral parts of the Antarctic continental shelf. Sidestripe distribution is from surface to deep layers over 700m, the highest density is within waters with a depth of 350-470m. Maximum density is recorded in near-bottom layers, 5-15m off bottom. In general, small specimens are close to the shelf (250-350m), adult specimens are observed down to the depth of the upper part of the continental slope (over 700m). It is impossible to analyse sidestripe distribution in relation to seasons due to specific conditions of the region : in particular, areas of shelf waters are free from ice and accessible for exploration not more than 40-150 days each year in the austral summer-autumn (the largest area is in December-beginning of April). For this reason, the scientific data are limited and related to that period.

Migrations There are not any substantial migrations. Seasonal movements (mainly in summer-autumn) are observed from high-latitude areas, northwards. Such movements are most usual for the Ross Sea. In other seas the movements are not so clearly determined because the shelf is narrow there.

Feeding migrations begin in the first part of March. To the end of February, fish usually disperse throughout a large area (not less than one-fourth of the Ross Sea area). Dispersed fish concentrations take up positions above shelf areas of 200-500m

depth ; during the daytime fish concentrate in ribbon-shaped shoals of 10-40m in depth and up to several miles in length. Migration patterns along the shelf are very variable. Locations of concentrations with highest density vary to a considerable extent. They depend on rates and patterns of formation of seasonal hydrological situation. The area of shelf slope in the north-west part of the Ross Sea in summer-autumn of individual years (1980, 1982), might be considerably affected by oceanic waters having temperatures above $0^{\circ}C$ ($0.3-1.2^{\circ}C$). This is a thermic barrier for sidestripe migration into the area. Optimum water temperature is $1.3-1.8^{\circ}$ below $0^{\circ}C$.

Trematomus newnesi

All species of g. Trematomus belong to high-latitude Antarctic fauna. Trematomus newnesi is the most abundant representative of the genus. It is rather widespread in the Ross Sea. It inhabits coastal shelf parts. Also, it builds up a major part (up to 90% of species composition) of trawl catches at Franklin and Beaufort Is. Small immature fish form dense concentrations in coastal littoral waters at a depth of 15-30m. Mature fish inhabit coastal shelf areas with a depth of 130m and over.

Spawning takes place in summer and it continues until the beginning of autumn (January-March). At that time, the amount of pre-spawning fish (stages III-IV and IV of gonads) is about one-fourth of the mature part of the population. The amount of spawning fish (stages IV-V and V) is about 18%. Eggs are benthic, but larvae and juveniles are found in surface layers.

The commercial part of the population consists of fish of 8-30cm in length (on average - 19.5cm); prevailing size group is 14-22cm (about 85%). There are no considerable differences in the growth rate of medium size males and females (on average 19.46 and 19.51cm, respectively).

Intensity of feeding during spawning is rather high (2.74 units) and it remains practically the same in summer. Fish juveniles, molluscs and to a lesser extent - krill, are the principal parts of the food ration.

Trematomus centronotus

Trematomus centronotus is not a dominant species of benthic ichthyofauna of the Ross Sea (not more than 2.3% of total biomass). In summer it inhabits shallow continental and shelf waters (20-35m depth). After the autumn fall of temperature in shelf waters, fish migrate to a depth of 150-200m and over.

Spawning takes place in summer (December-beginning of February) and towards March, the spawning fish are not usually found (not more than 1%), though in February-March, the major number of mature fish (more than 90%) are at stages VI-II and II of gonad development.

The commercial part of the population of the species consists of fish 14-33cm in length, on average 20.3cm (males) and 23.6cm (females), and 121.0g and 204.5g of weight respectively. Females of the species predominate not only in size and weight but also in numbers (6:1). Trematomus centronotus feeds actively after spawning. The average index of stomach fullness is 2.56 units in summer-autumn. Polychaeta, gastropods, pteropods and, to a lesser extent, krill and fish, are prominent in fish food ration.

Trematomus bernaechii

Trematomus bernaechii is a third species by abundance in benthic ichthyofauna of the Ross Sea (about 2%). In summer-autumn fish occur at the same depth of the continental shelf and island waters as Trematomus centronotus and T. newnesi. Towards the beginning of winter, fish migrate along the shelf to a depth of over 100m (130-150m).

Spawning takes place in the summer-autumn season from January to mid-March. In March, about 10% of fish of the mature part of the population are at the spawning stage. Females predominate in number in concentrations (4:1).

Fish of 15-36cm in length (on average 25.8cm) are found in the commercial part of the population. Males are larger than females (27.7 and 23.7cm, respectively) ; male weight on average is 384g, females - 214g.

Towards the end of spawning, fish feed intensively. The index of stomach fullness at that time is 2.69. Benthic organisms (polychaeta, gastropods) and, to a smaller extent, fish, krill, fish eggs and copepods, are prevalent in the food ration.

Trematomus eulepidotus

Fish are widespread throughout the shelf of the Ross Sea. There are always a few fish as by-catch in catches. The commercial part of the population consists of fish 14-16cm in length and 70-100g in weight. Spawning is in spring-summer (November-January). Spawning is completely finished by February. After spawning, fish feed very actively on krill (index of stomach fullness is 1.80 units).

Coryphaenoides whitsoni

Fish inhabit the upper part of the continental slope (400-500m depth). At present, only a small area is known in the central part of the Ross Sea where Coryphaena whitsoni forms spawning concentrations at the end of February.

The beginning of spawning is at the end of summer (February) : at this time about one-third of the mature part of the population spawns. Females clearly predominate on spawning grounds (9:1).

Fish of 25-90cm length are in catches of bottom trawl (on average 57.7cm). Females are larger than males (62.4 and 55.2cm, 1430 and 967g respectively). Even during spawning, fish feed very actively. Index of stomach fullness is over 2.30. Euphausiids, fish and small jelly fish are the principal food.

Chionodraco hamatus

Chionodraco hamatus is a typical representative of the Antarctic ichthyofauna. In the Ross Sea it is distributed throughout the area in near-bottom layers (300-600m). Juveniles are found in surface layers. Island parts of the shelf are spawning grounds of Chionodraco hamatus. Spawning is from January to February. Towards the end of summer, spawning males are not usually observed; the number of spawning females (at stages IV-V and V) is not over 0.5%. Fish of 22-46cm in length were observed in catches of bottom trawls. Females are larger than males (38.4 and 36.4cm, 475 and 375g, respectively). Intensity of feeding in summer is low; index of stomach fullness if 0.56 (on average), while fatness is rather high during that time (2.76 units).

According to feeding behaviour, Chionodraco hamatus is an active predator. Fish (about 90%) and krill are principal parts of its food ration. Antarctic sidestripe is most frequent in stomachs.

4. Conclusion

Fisheries scientific and search research carried out by USSR in Antarctic waters in the last 20 years is based on systematic, large-scale, complex investigations. This has allowed them to determine the general regularities of bioproductivity formation in open waters of the Southern Ocean, in shelf island waters, on banks and in high-latitude zones of coastal seas.

Distribution and life cycles of Euphausia superba Dana and of Antarctic fish - living resources of the Antarctic, were studied in great detail. Geomorphological and oceanological features of Antarctic waters from the South Polar Front to the Antarctic continental shelf were comprehensively discovered. It permitted determination of the principal factors on which bioresources distribution was dependent, as well as the biological peculiarities of organisms in several areas ; to assess the possibility of their commercial utilisation keeping in mind seasonal and year-to-year variations.

Summary analyses of all these results has shown that according to hydrobionts composition and their distribution, peculiarities of ecology and structure of biological communities, the Antarctic area to the south of the Antarctic Convergence is subdivided into two natural zones. Following the climatology classification, the more northern zone, located within the area of influence of the Antarctic Circumpolar Current (ACC), may be called a zone of open Antarctic waters. The southern zone, located at higher latitudes - a zone of pack ice, respectively.

The zones have different climatic and ice conditions, distribution of physical and chemical water parameters, distribution of biogenous elements, horizontal and vertical water circulation, characteristic features and regularities of bioproduction processes. The zone of open Antarctic waters is entirely within the area of ACC influence and it is free of ice all the year round. Almost all species in the zone have circumpolar areal of habitat and are distributed broadly around Antarctica. In zooplankton composition, copepods are prevalent in numbers and biomass. Macroplankton, in particular, euphausiids (except the S. Georgia area and some others where krill aggregations are observed regularly) is developed to a lesser extent. For this reason, a complex of marine organisms - consumers (mainly mesopelagic fish, deep-water squid and sperm whales) are dominant here. Only in areas around islands and underwater banks, fish resources are represented by benthic and benthopelagic fish of the Nototheniidae family.

Environmental conditions are substantially different in the pack-ice zone. For more than half the year, the water area of the zone to the south of about $60^{\circ}S$ is covered with ice. However, during the warmest season

(January-April) the pelagic complex of hydrobionts is prevalent in the zone. The complex consists of macroplankton (mainly E. superba and other invertebrates), benthopelagic nototheniid fish, seals and baleen whales.

The ichthyofauna of these regions is presented by cold-water coastal species of nototheniid fish among which happen to be quite a few abundant prospective species. First of all, these are Antarctic sidestripe, several species of g. Trematomus and g. Chionodraco.

On the background of zonal subdivision, the Atlantic Ocean Sector (AS) is distinct. In condradistinction to another two sectors, AS is characterised by complicated bottom relief, a large number of islands and elevations and also by considerable extension of the Antarctic Peninsula to the north. The general pattern of distribution of marine organisms and level of the formation of their bioproductivity is dependent on the features of AS. In the southern part of the Scotia Sea in the area, of the Secondary Frontal Zone, the particular abundance of euphausiid macroplankton is observed, mainly of E.superba. It provides, in particular, shelf waters of islands with a high level of bioproductivity. Mass aggregations of euphausiids in shelf waters of the Scotia Sea islands and in adjacent waters increase food availability for shelf fish considerably, mainly for fish which move up into pelagic waters and feed very actively on macroplankton. For this reason, island shelf areas are characterised by very high fish productivity.

It is not by accident that mean values of biomass and fish productivity at S. Shetland, the S. Orkney Is. and Antarctic Peninsula are considerably higher than on the continental shelf : 8.4-10.2 and 2.1-2.5 t/km^2 ; and respectively 4.6-5.1 and 1.3-1.5 t/km^2. In other sectors, which are studied to a lesser extent, areas of increased productivity (including fish), in general, are close to the continental coast. However, in some areas of the low-latitude zone, are found places with increased productivity (due to krill and mesopelagic fish concentrations), e.g. to the north of S. Georgia, at Bouvet Is., Crozet Is., Prince Edward Is. and others.

Thus, these are results of long-term fisheries research (mainly carried out by USSR), patterns of marine organisms distribution, ecological and biological patterns which determine the possibility of their commercial utilisation.

It is necessary to continue directed complex research into bioresources and environment in order to study further the quantitative parameters of Southern Ocean ecosystems and populations of Antarctic marine living resources.

In this connection, it is necessary :

- to carry out search and scientific research expeditions in the open waters of the Southern Ocean and in coastal seas ;
- to study factors which determine seasonal and year-to-year variations in krill and fish concentrations ;
- to study space structure of krill and fish populations, separate sub-populations and other aggregations ;

In relation to Antarctic fish -

- to carry out complex expeditions in order to study features of local distribution, dynamics of length-age structure of populations, reproduction and migration patterns of littoral and mesopelagic fish ;
- to carry out trawl surveys in order to assess stocks of each species and fish productivity of separate regions in general ;
- to study trophic fish relationships ;
- to separate individual ichthyocenosis and to study their functions in ecosystems ;

In relation to Antarctic krill resources -

- to study further the dynamics of Southern Ocean waters and to assess the level of isolation of separate circulation systems in order to determine the stock units for management ;

- to study factors which determine distribution of krill throughout the areal, to assess and to describe relations between oceanological conditions and krill distribution ;

- to study features of krill behaviour and biology which determine formation and disintegration of krill aggregations ;

- to study function regularities of pelagic communities in ACC waters and in high-latitudes of coastal seas ;

- to develop methods of krill biomass and stock assessment in order to evaluate their year-to-year variations ;

- to study structure and functioning of large Antarctic ecosystems : the zone of open Antarctic waters and the zone of pack-ice.

Table 1

Information on Cruises in Atlantic Sector, 1962-1983

Coded signs of the principal fields of research :

1 - oceanographic research (hydrology, hydrochemistry, plankton) ;

2 - studies of krill biology and distribution ;

3 - studies of Antarctic fish biology and distribution ;

4 - studies of fishing methods, processing technology and mechanization.

Name of Ship	Dates	Study Area	Principal Fields of Research
1	2	3	4
"Muksun"	Jan 1962	Scotia Sea	2
"Muksun"	1963	Scotia Sea	1-2
"Ak. Knipovich"	Jan-Mar 1965	Scotia Sea	1-3
"Langust"	Dec 1966-Apr 1967	Scotia Sea	1-3
"Ak. Knipovich"	Jan-Mar 1967	Scotia Sea	1-3
"Langust"	Oct 1967-Mar 1968	Scotia Sea	3
"Ak. Knipovich"	Feb-Apr 1968	Scotia Sea	1-3
"Ak. Knipovich"	Jan-Mar 1969	Scotia Sea	1-3
"Ak. Knipovich"	Feb-Apr 1970	Scotia Sea	1-3
"Langust"	Dec 1969-Mar 1970	Scotia Sea	3(2)
"Argus"	Jul-Oct 1970	S. Georgia	1-3
"Ak. Knipovich"	Sept-Dec 1970	Scotia Sea, Bouvet Is	1-3
"Atlant"	Oct 1970-Feb 1971	Scotia Sea	3
"Salehard"	Oct 1971-Feb 1972	Scotia Sea	2-3
"Langust"	Jan-Apr 1972	Scotia Sea	1-3
"Evrika"	Feb-Apr 1972	S. Georgia	3
"Salehard"	Aug-Oct 1972	S. Georgia	3
"Gizhiga"	Oct 1972	S. Georgia	2-3
"Salehard"	May 1973	S. Georgia	1-3
"Salehard"	Nov 1973-May 1974	Eastern part of Scotia Sea	1-3

1	2	3	4
"Ak. Knipovich"	Dec 1974-Feb 1975	Scotia Sea	1-3
"Atlant"	Oct-Dec 1974	S. Georgia	3
"Kvant"	Dec 1974-Mar 1975	S. Georgia	3
"A. Johani"	Jan-Apr 1976	S. Georgia	3
"Ak. Knipovich"	Jan-Apr 1976	Bellingshausen Sea, Scotia Sea, Antarctic Peninsula	1-3
"Gizhiga"	Feb-Jul 1977	S. Georgia, eastern part of Atlantic sector	1-2
"Anchar"	Feb-Jul 1977	S. Georgia	2-3
"Gizhiga"	Jul 1977-Jan 1978	Scotia Sea	1-2,4
"Ak. Knipovich	Jan-Apr 1978	Bellingshausen Sea Scotia Sea, Antarctic Peninsula	1-3
"Volzhanin"	Jan-Jul 1978	Scotia Sea	1-3
"Gizhiga	Mar-Jul 1978	Scotia Sea	1-3
"Atlant"	Nov 1978-Jan 1979	Scotia Sea	1-3
"Ak. Knipovich"	Dec 1978-Feb 1979	Scotia Sea	1-3
"Gizhiga"	Dec 1978-Mar 1979	Scotia Sea	1-3
"A.Johani"	Jan-Apr 1979	S. Orkney	2,3
"Volzhanin"	Jun-Oct 1979	Scotia Sea	2-3
"Pioner Latvii"	Oct-Dec 1979	S. Shetland	1-3
"Salehard"	Dec 1979-Mar 1980	Ob and Lena Banks, Gunnerus Bank (Riiser-Larsen Sea)	1-3
"A. Johani"	Feb-May 1980	Scotia Sea	2-3
"Salehard"	Aug-Oct 1980	Scotia Sea	2
"Pioner Latvii"	Nov 1980-Feb 1981	S. Georgia	2.3
"Ak. Knipovich"	Mar-May 1981	Scotia Sea, Lazarev Sea	1-3
"Odyssei"	Nov 1980-Apr 1981	Scotia Sea	1-2
"Evrika"	Jan-Apr 1981	Lazarev Sea, Scotia Sea	1-3
"Zvezda"	Feb-Mar 1981	Bellingshausen Sea, Antarctic Peninsula	2
"Anchar"	Feb-Mar 1981	Scotia Sea	2,3
"Argus"	Apr-Jul 1981	Scotia Sea	1-2,4
"Salehard"	Sep-Oct 1981	Scotia Sea	2-3

1	2	3	4
"Volzhanin"	Aug 1981-Jan 1982	Scotia Sea	2-3
"Pioner Latvi"	Jan-Mar 1982	Antarctic Peninsula	2-3
"Argus"	May-Jul 1982	Antarctic Peninsula	1-2
"Salehard"	May-Jul 1982	Bouvet Is and adjacent waters	1-2
"Ak. Knipovich"	Mar-May 1982	Amundsen Sea, Scotia Sea	1-2
"Volzhanin	Apr-May 1982	Scotia Sea	2
"Salehard"	Dec 1982	S. Georgia	3
"Pioner Latvii"	Apr-Jul 1983	S. Georgia	2,3
"Volnyj Veter"	Jan-Apr 1983	Lazarev Sea	1-3
"Argus"	Mar-Jul 1983	Scotia Sea	1-2,4

Table 2

Water Temperature in the Region of S. Georgia
(in ^{o}C)

Layer (m) \ Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0-20	2.4	3.0	3.0	2.6	1.6	0.5	0.2	-0.04	-0.1	0.5	0.9	1.8
150-200	1.0	1.0	1.1	1.3	1.4	1.3	1.2	0.8	0.7	0.6	0.8	0.8

Table 3

Phytoplankton Production and Summary Biomass
of Zooplankton and Euphausiid
in Several Regions of Antarctic AS

Region	Area	Primary Production			Biomass of Zooplankton	
					Summary	Euphausiids
	$x10^4 km^2$	$g^C/m^2/day$	$g^C/m^2/year$	tons of C $x10^6$ per year	million tons	million tons
Western Region						
Open waters	33.40	0.30	80.0	26.69	2.7-3.2	0.81-0.96
S. Orkney Is.	0.44	0.91	130.0	0.59	0.06-0.07	0.02
S. Sheltand Is.	1.98	0.91	130.0	2.58	0.26-0.31	0.08-0.09
Total for Western Region	35.82	0.35	83.3	29.86	2.99-3.58	0.09-1.07
Underwater mountain Discovery	5.17	0.2-0.8	152.8	7.89	0.79-0.95	-
Bouvet Is.	17.36	0.2-0.9	99.5	17.27	1.73-2.08	0.52-0.62
Underwater elevation	44.45	0.2-0.9	85.0	31.12	3.11-3.73	0.93-1.12

Table 4

Information on Cruises in Indian Ocean Sector
1967-1983

Coded signs of the principal fields of research :

1 - oceanographic research (hydrology, hydrochemistry, plankton) ;

2 - studies of krill biology and distribution ;

3 - studies of Antarctic fish biology and distribution ;

4 - studies of fishing methods, processing technology and mechanisation.

Name of Ship	Dates	Study Area	Principal Fields of Research
1	2	3	4
"Aelita"	1967-1988	Crozet Is., Kerguelen Is.	3
"Aelita"	Nov 1968-Mar 1969	Crozet Is., Kerguelen Is.	3
"Skif"	Dec 1969-Apr 1970	Crozet Is., Kerguelen Is.	3
"Aelita"	Feb-Apr 1970	Crozet Is., Heard Is.	3
"Skif"	Nov 1970-Apr 1971	Kerguelen Is., Crozet Is. Ob and Lena Banks	3
"Kara-Dag"	Jun-Oct 1971	Kerguelen Is., Crozet Is.	3
"Skif"	Aug-Oct 1971	Kerguelen Is., Ob and Lena Banks	3
"Kara-Dag"	Sep 1971-May 1972	Kerguelen Is., Ob and Lena Banks, Commonwealth Sea	1-3
"Fiolent"	Jun-Jul 1972	Kerguelen Is., Crozet Is. Ob and Lena Banks	1,3
"Skif"	Jan-May 1972	Kerguelen Is.	1,3
"Fiolent"	Oct 1972-Jan 1973	Kerguelen Is., Crozet Is. Ob and Lena Banks	3
"Kara-Dag"	Nov 1972-Feb 1973	Kerguelen Is.	1,3
"Chatyr-Dag"	Dec 1972-Apr 1973	Antarctica coast, Crozet Is. Ob and Lena Banks	1-3

1	2	3	4
"Kara-Dag"	Jun-Aug 1973	Kerguelen Is.	1,3
"Chatyr-Dag"	Jun-Aug 1973	Kerguelen Is., Crozet Is. Ob and Lena Banks	2,3
"Skif"	Sep-Nov 1973	Crozet Is., Ob and Lena Banks	1,3
"Chatyr-Dag"	Mar-Apr 1974	Antarctica coast Ob and Lena Banks	1-3
"Skif"	Mar-Apr 1974	Kerguelen Is., Ob and Lena Banks	1,3
"Chatyr-Dag"	Oct-Nov 1974	Ob and Lena Banks	1,3
"Skif"	Oct 1974-Jan 1975	Kerguelen Is., Ob and Lena Banks, Antarctica Coast	1,3
"Skif"	Jun-Jul 1975	Kerguelen Is., Ob and Lena Banks	1,3
"Skif"	Mar-Jul 1976	Kerguelen Is.	1,3
"Skif"	Oct-Dec 1976	Kerguelen Is.	1,3
"Chatyr-Dag"	Oct-Dec 1976	Kerguelen Is. Ob and Lena Banks	1,3
"Skif"	Mar-May 1977	Kerguelen Is., Antarctica Coast	1-3
"Chatyr-Dag"	Jan-Mar 1977	Antarctic	1,2
"Kara-Dag"	Feb-May 1977	Antarctic, Ob and Lena Banks, Kerguelen Is.	1-3
"Komsomolets"	May-Aug 1977	Kerguelen Is.	3
"Kara-Dag"	Oct-Dec 1977	Kerguelen Is., Ob and Lena Banks	3
"Chatyr-Dag"	Dec 1977-Mar 1978	Antarctic	1-3
"Fiolent"	Dec 1977-Mar 1978	Kerguelen Is., Antarctic	1-3
"Zvezda Kryma"	Jan-Mar 1978	Kerguelen Is., Antarctic	2
"Kara-Dag"	Mar-Jul 1978	Kerguelen Is., Ob and Lena Banks	3
"Chatyr-Dag"	May-Oct 1978	Ob and Lena Banks	3
"Mys Octrovskogo"	Nov 1978-Mar 1979	Ob and Lena Banks Antarctic	1-3
"Chatyr-Dag"	Dec 1978-Mar 1979	Antarctic Ob and Lena Banks	1-3

1	2	3	4
"Fiolent"	Apr 1979	Ob and Lena Banks	3
"Mys Ostrovskogo"	Nov 1979-Apr 1980	Kerguelen Is., Ob and Lena Banks, Antarctic	1-3
"Skif"	Dec 1979-Apr 1980	Ob and Lena Banks Antarctic	1-3
"Kara-Dag"	Dec 1979-Mar 1980	Antarctic	1-3
"Mys Ostrovskogo"	Jun-Sept 1980	Kerguelen Is.	1,3
"Kara-Dag"	May-Aug 1980	Antarctic, Ob and Lena Banks	1-3
"Skif"	Aug-Oct 1980	Ob and Lena Banks	3
"Chatyr-Dag"	Oct-Nov 1980	Kerguelen Is.	3
"Skif"	Jan-May 1981	Antarctic, Ob and Lena Banks	3
"Kara-Dag"	Nov 1980-Apr 1981	Antarctic, Ob and Lena Banks	1-3
"Mys Ostrovskogo"	May-Oct 1981	Kerguelen Is. Ob and Lena Banks	3
"Zvezda Azova"	Jul 1981	Kerguelen Is.	3
"Chatyr-Dag"	Oct 1981-Feb 1982	Kerguelen Is., Antarctic	1-3
"Mys Ostrovskogo"	Dec 1981-Mar 1982	Kerguelen Is.	3
"Skif"	May-Jul 1982	Ob and Lena Banks	3
"Skif"	Oct 1982-Feb 1983	Kerguelen Is. Antarctic	1-3
"Novoukrainka"	Jan-Mar 1983	Antarctic	1-3
"Poltava"	Jan-Apr 1983	Antarctic, Ob and Lena Banks	2,3
"Zvezda Kryma"	Mar-May 1983	Antarctic, Ob and Lena Banks	2,3
"Chatyr-Dag"	Jul-Aug 1983	Antarctic, Ob and Lena Banks	1-3
"Fiolent"	Nov 1983-Mar 1984	Antarctic, Ob and Lena Banks	1-3

Table 5

Meteorological Conditions
Commonwealth Sea

	Air temperature (^{o}C)	Recurrence of precipitations (%)	Cloudiness (1/10th) units	Recurrence of fog (%)	Atmospheric pressure (m/bar)	Mean wind speed (m/s)
December	+1-2	15-40	7-9	5-15	986-988	5-6
January	+2-2	20-40	7-9	5-10	986-988	5-7
February	+1-4	20-45	7-9	5-10	984-990	5-7
March	0-8	30-50	7-9	5-10	988-986	7-8

Table 6

Year-to-Year Variation of Water Temperature
in Commonwealth Sea

Temperature	Year										
	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
$\bar{t}o$	0.66	-	1.45	-	1.78	1.61	0.89	1.44	0.85	0.10	0.49
$\bar{t}min$	-1.43	-	-1.31	-	-1.23	-1.18	-0.96	-1.44	-1.31	-1.39	-1.57
$\bar{t}max$	1.78	-	1.76	-	1.75	1.73	1.73	1.73	1.78	1.70	1.73

Table 7

Information on Cruises in Pacific Ocean Sector

Coded signs of the principal fields of research :

1 - oceanographic research (hydrology, hydrochemistry, plankton) ;

2 - studies of krill biology and distribution ;

3 - studies of Antarctic fish biology and distribution.

The following ships were involved : "Professor Derugin", "Mys Jnony", "Mys Tyhij", "Mys Dalnij", "Mys Babushkina", "Heracl", "Poseidon" and others.

Dates	Study Area	Fields of Research
1	2	3
Dec 1967-Feb 1968	D'Urville, Somov, Amundsen Seas	1,2
Nov-Dec 1968	D'Urville, Somov, Amundsen and Bellingshausen Seas	1,2
Dec 1969-Mar 1970	Mawson, D'Urville, Somov, Amundsen and Bellingshausen Seas	1,2
Jan-Mar 1972	D'Urville, Somov Seas, northern part of Ross Sea	1,2
Dec 1972-Mar 1973	D'Urville, Somov, Amundsen and Bellingshausen Seas	1,2 1,2
Jan-Apr 1974	Somov Sea, Balleny Is. and to the east up to 180°	1,2
Feb-Apr 1975	Somov Sea	1,2
Jan-Mar 1976	Somov Sea, eastern part of D'Urville Sea	1,2
Jan-Apr 1977	Somov Sea	1,2
Jan-Apr 1977	Mawson, D'Urville and Somov Seas	1,2
Dec 1978-Apr 1979	Mawson, D'Urville, Somov and Ross Seas	1,3
Jan-Apr 1981	Mawson, D'Urville, Somov and Ross Seas	1,3
Jan-Apr 1982	Mawson, D'Urville, Somov and Ross Seas	1,3
Jan-Apr 1983	Mawson, D'Urville, Somov and Ross Seas	1,3