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A century of oceanographic and fisheries exploration on the continental shelf off Argentina

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ABSTRACT: A detailed analysis is presented of the main contributions, both local and international, to the fields of oceanography and fishery sciences resulting from exploratory cruises carried out on the continental shelf off Argentina over the last 100 years. The end of the 19th century is chosen as a starting point for this analysis as it marks the beginning of active marine research by Argentinian scientists and an accumulation of information on Antarctic and Subantarctic organisms in foreign journals. Mention is also made of previous contributions derived from the classic expeditions and global circumnavigational voyages during the 18th and 19th centuries. Although the aims of those were not always strictly oceanographic, they rendered significant information to this field of knowledge. In the early years, references arose mainly from the particular geographic situation of the Argentinian shelf, a necessary passage in the navigation routes to the Pacific Ocean, and later on the way to Antarctica. Sources of information are divided into four categories: (a) foreign scientific projects in the area; (b) investigation by Argentinian scientists and research vessels; (c) joint projects between Argentinian and foreign institutions; and (d) contributions from sources other than oceanographic cruises (commercial navigation, maritime weather reports, satellite images, etc.). The analysis includes an updated and classified bibliographical list of the main contributions to the fields of oceanography and fishery sciences derived from those sources, published either in international or local journals or appearing as technical and internal reports. The motivations, objectives and main achievements of foreign surveys and programmes in the area and their impact on local scientific progress are discussed. The early 'sixties mark a turning point in the evolution of international research in the area. The creation of biological stations along the Argentinian coast, and the support given to the pooling of human resources set the basis for the development of bilateral programmes. Similar progress in Brazil and Uruguay led to the outgrowth of regional activities. Joint scientific efforts described in this analysis include the programmes carried out by the research vessels of Germany ("Walther Herwig", "Meteor"), Japan ("Kaiyo Maru", "Orient Maru", "Shinkai Maru"), Poland ("Professor Siedlecki"), Russia ("Evrika", "Dimitry Stefanov") and the USA ("Vema", "Atlantis II"), the achievements of which are a landmark in the evolution of marine science in the area.

INTRODUCTION

The exploration of the Southern Ocean in search of new fisheries resources started during the last two decades of the 17th century. The Patagonian shelf lay, particularly prior to the opening of the Panama Canal (1913–1914), on the course of the commercial fleet leading to ports on the Pacific Coast, or transporting saltpetre and guano from Chile and Peru. Several oceanographic vessels explored the continental shelf off Argentina.

This paper summarizes the vast and varied oceanographic and fishery information generated by the classic circumnavigational voyages, and polar expeditions, by international cooperation programmes and by seagoing activities organized by Argentinian laboratories and scientists. A review is presented of the most significant voyages, cruises

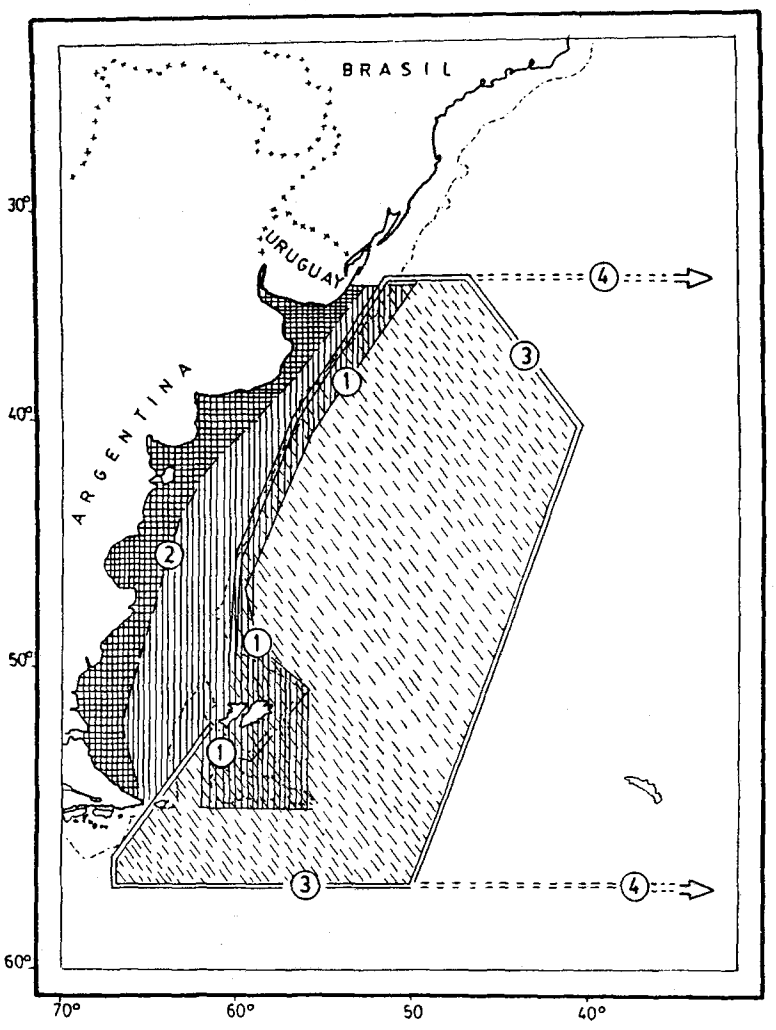

Fig. 1. Area covered by the exploratory cruises analysed. The references in the map indicate: (1) The continental shelf off Argentina (vertical grid); (2) The Argentinian coastal region (horizontal grid) (3) The continental slope and oceanic basin off Argentina (slanting grid); and (4) South Atlantic coast-to-coast explorations (open grid)

and scientific programmes operating in the southwest Atlantic from 34° to 60 °S, comprising the continental shelf, adjacent waters and oceanic basins (see map, Fig. 1). Their contributions to the field of marine science, particularly from the last decade of the 19th century, which marks the beginning of oceanographic research in Argentina, are analysed. Results deriving from these scientific enterprises are in many cases difficult to trace: they have been published in several languages, and very frequently are included in what is considered "grey literature". Angelescu & Sánchez (1994) have treated the contributions of Argentinian scientists – mostly in Spanish, and sometimes appearing as internal technical reports from 1895 onwards – in detail, particularly those that include data sets.

We shall herein make special reference to published reviews on different oceanographic topics that may be considered useful in order to introduce the reader to local literature.

HISTORICAL BACKGROUND

Exploratory voyages on the Argentinian shelf prior to 1890 include the great circumnavigatory voyages of French, British, Italian, German and Spanish vessels, and the first expeditions to the Antarctic. Maps marking the routes of the major expeditions passing through the Argentinian shelf were presented by Ehrlich & Sánchez (1990). Very detailed reviews of these voyages and their contributions to the field of oceanography are given by Norman (1937), López (1963) and Ringuelet (1984), and in several papers presented at the 4th International Congress of the History of Oceanography (Lenz & Deacon, 1990).

Geographic explorations before the "Challenger" voyage, were not oceanographic in intent, but had considerable oceanographic significance. Physicians and naturalists on board made the first collections of marine organisms in the area. As a result of these collections, several publications on the fauna of the region appeared in Europe before the end of the 19th century (see Carcelles [1947] for a complete review).

No analysis of research activities carried out by scientists of different foreign countries on the oceanography of the Argentinian shelf during these early years would be complete, without special mention of the contributions that Otto Krümmel made to the field of physical oceanography – at the time he was geographer in the Kiel Laboratory – and J. Klähn. These authors used, as additional sources of information, the reports contained in the log books of sailing-vessels and steamers. Krümmel (1882) gave the first description of the pattern of surface currents between Cape Horn and the Rio de la Plata. He described three regions, a coastal one with temperate waters, the slope with cold waters of sub-antarctic origin (Malvinas/Falkland current), and the warmer waters of the Brazil current, east of the slope. With additional data from the Hamburg Maritime Observatory, and the information reported in the Wind Charts for the South Atlantic Ocean, and Coastal Region of South America, published by the British Admiralty (1901–1902), Klähn (1911) was able to describe monthly differences in the distribution of surface water temperature, and in the pattern of currents, and analyze the causes that generated them. The significance and validity of these pioneer contributions was to be recognized by oceanographers working in the area in the decades to come.

INTERNATIONAL RESEARCH ON THE ARGENTINIAN SHELF FROM 1890

During the last decade of the 19th century, the expeditions conducted by Professor Plate of the University of Berlin, and Dr. Michaelsen aboard the "Sara" of the Natural History Museum of Hamburg, obtained faunistic collections from the Magellan region. Also during the last decades of the century – following the recommendations of the International Congresses of Geography of London (1895) and Berlin (1898) – the presence on the Argentinian shelf of international expeditions leading to Antarctica markedly increased. Gerlache de Gomery's expedition aboard the "Belgica" (1897–99), the Swedish South Pole Expedition, conducted by O. Nordenskjöld on board the "Antarctic" (1901–1903), the Scottish National Antarctic Expedition (1902–1904) aboard the "Scotia", and two French Antarctic Expeditions (1903–1905 and 1908–1910), both conducted by

Dr. Jean Charcot, collected specimens from Patagonia, the Magellan region, Fireland, the Malvinas Islands and Burdwood Bank, in the southernmost extreme of the Argentinian shelf, which led to the elaboration of the first hypothesis on the origin of polar fauna and on the zoogeographical division of the area between the austral extreme of the Argentinian shelf and the Antarctica.

The dominant hydrographic feature of the southwest Atlantic is the subtropical confluence, which marks the encounter of the Brazil current flowing polewards along the continental margin of South America, and the Malvinas current flowing northeastwards along the Argentinian continental slope. The confluence region was first described by Brennecke (1921) from the oceanographic sampling carried out in the German Antarctic Expedition on board the "Deutschland" (1911–1912). During the same voyage, Lohmann (1911, 1920) made observations on the plankton of the area, and also analysed the distribution of both currents, using planktonic organisms, mostly diatoms, as biological indicators.

Further results on the latitudinal range of planktonic organisms characteristic of each current were published by Hentschel (1933, 1936) from material collected during the German Atlantic Expedition aboard the RV "Meteor" (1925–1927). Although the main objective of this programme was oceanographic – the celebrated G. Wüst was the physical oceanographer on the "Meteor" expedition – the programme in fact was multidisciplinary, comprising studies on meteorology, marine chemistry and geology. In order to study the water masses stratification and circulation in the Atlantic an innovation was introduced in the sampling scheme, in comparison with those of the circumnavigation and polar voyages. The study area was covered by a series of transects across the Atlantic from the east coast of South America to the west coast of Africa, and regularly-spaced stations were distributed on each transect. The results of this expedition were compiled in a thirty-volume report. The "Meteor" expedition may be considered as the start of a new period in oceanography: the period of systematic surveys. Details of the cruise and the characteristics of the vessel may be found in the first volume, edited by Spiess (1932). In the first decades of this century, whaling had become an important activity in the Falkland Dependencies. In order to preserve this resource and expand the fisheries around the islands, a comprehensive programme to study the Southwest Atlantic Ocean was proposed by the Discovery Committee of Great Britain. The programme included the oceanographic explorations of R. V. "Discovery" and "Discovery II" (1931–1935), and the first trawling surveys in the Patagonian region aboard the R. V. "Scoresby" (1927–1932). Outstanding results were: the general account of the hydrology of the South Atlantic Ocean, including an extensive study of the confluence region (Deacon, 1933, 1937), the description of water masses and circulation patterns on the Patagonian shelf, plankton production and drift, a comprehensive ichthyological catalogue (Norman, 1937), and the first contributions to fishery biology and resource assessment in the region (Hart, 1946). After the conclusion of the "Discovery" Committee Programme, the activities of foreign research vessels on the Argentinian shelf, without the participation of local scientists, were reduced to a few isolated cruises in the course of more than fifty years. Parallel to the decline of foreign explorations, was an increase of national activities and bilateral cooperation projects. These will be dealt with in the following chapter.

Mention should be made here of the presence of two European research vessels

surveying our study areas. The "Calypso" (1961–1962) explored the coastal region off Argentina, and produced information on the hydrography and on the taxonomy of finfish of the area (Roux, 1973); the German R. V. "Ernst Haeckel" (1966) carried out studies on physical oceanography on the continental shelf and slope off southern Brazil, Uruguay and Argentina. Published information includes data basis and profiles of sea water temperature, salinity, dissolved oxygen, nutrients, and chlorophyll; also in situ observations of surface currents (Nehring & Brosin, 1968).

In recent years, after the Malvinas War, the assessment of the fisheries resources of southern Patagonia by British scientists has, however, been reinitiated by the Marine Resource Assessment Group of the Imperial College, and several papers have appeared in the international literature, mostly on the cephalopod and fish species of the area (Beddington et al., 1985).

OCEANOGRAPHIC CRUISES AND FISHERY EXPLORATION IN ARGENTINA

Oceanographic research in Argentina began during the second half of the 19th century and has continued until now, undergoing an evolution that may be classified in four epochs.

The beginning of Oceanography in Argentina (1874–1938)

The first activities of systematic exploration of the continental shelf, gulfs and coasts of Argentina, consisted of hydrographic and topographic surveys, eventually with the addition of flori-faunistic collections.

The first voyage was carried out by the brig ARA "Rosales" in 1874 (ARA is the abbreviation of the Navy of the Argentinian Republic). Within the sphere of the Navy, Argentina established the Central Hydrographic Office in 1879. In the following years, several expeditions were made by naval vessels sailing from the River Plate to the southern coast of Fireland. The primary aim was to provide information for hydrographic charts and for navigation, and also to promote settlements in the austral territories. The results of these voyages were diffused, in part, in publications of the Argentinian Navy (Hydrographical Annals, Journal of Navy Publications, and Bulletin of the Navy Centre). The scientific staff on board came mostly from the Natural Science Museums, the Universities of Buenos Aires and La Plata, and the Office of Fish and Game of the Ministry of Agriculture (see Carcelles, 1947, and Popovici & Riggi, 1948, for a detailed review). They obtained collections of seaweeds, molluscs, crustaceans and fish, which resulted in the first publications – mostly on taxonomic identifications, geographical and ecological distributions. The first autochthonal contribution to the field of marine ichthyology – a list of scientific names of fishes – was given in 1876 and 1888 by H. Weyenberg and Dr. E. L. Holmberg, respectively; some years later, Dr. Carlos Berg (1895) produced the first catalogue of fishes distributed along the coasts of Argentina and Uruguay. In 1900, Dr. Fernando Lahille, the first French marine biologist to work in Argentina, carried out systematic explorations of the Argentinian Continental Shelf, and began his series of contributions on the Argentinian marine fauna. Early in the century, Lahille (1900) carried out a series of fishing trawls in San Maítas Gulf during an exploration voyage aboard the ARA "Azopardo", and had the intention to found the first Marine Biology

Station in Mar del Plata, in 1898 (for more details and complete list of Lahille publications, see Birabén, 1941).

With the voyages of the ARA "Patria" in 1914 and 1915, Martín Doello-Jurado, the first Argentinian marine biologist, started a more consistent programme of collections of sea organisms including plankton. Periodic hydrographical surveys were based on previously established programmes. Their frequency increased, and their spatial coverage was extended. Doello-Jurado enthusiastically advocated a regular programme of marine field activity and the study of marine science at University level; he created the Malacology and Marine Invertebrates Section in the Argentinian Museum of Natural Science (MACN) of Buenos Aires, organized an active group of collectors of marine specimens, and, in 1928, founded the first permanent Argentinian Marine Biology Station in Puerto Quequén. He was the first to notice the presence of sub-antarctic specimens in lower latitudes, i.e. off Buenos Aires Province and Uruguay, and correctly ascribed this to the influence of the Malvinas current (Doello-Jurado, 1918, 1938).

This pioneer epoch comes to an end with the incorporation in 1928 of two oceanographic vessels constructed in Great Britain: the ARAs "San Luis" and "San Juan", later to become "Bahía Blanca" and "Madryn", respectively.

The epoch of interinstitutional cooperation (1938–1959)

Characteristic of this period (covering a time-span of twenty-one years), is the organization of multi-disciplinary cruises based on inter-institutional collaboration to carry out oceanographic, biological and fisheries research over the whole extension of the Argentinian Continental Shelf and the slope. During 1938–1948, cruises were carried out exclusively on vessels of the Argentinian Navy. On the basis of an agreement of cooperation between the Naval Hydrographic Service (SHN) and the Natural Science Museum of Buenos Aires, a series of six cruises were carried out, during this first stage. Biological sampling was now a component of cruise-planning. The Argentinian shelf, the largest in the southern hemisphere, was the object of broad surveys, and collections of plankton, benthic invertebrates and fishes were obtained.

Based on the combination of hydrographic and biological information, it was possible to relate the origin and characteristic of water masses to the regional and ecological distribution of marine organisms, to divide the area into zoogeographic regions, and to interpret the seasonal migration of commercially important fish species (Parodiz, 1942; Pozzi, 1944; Balech, 1949). During this first stage there was a significant increase of scientists working in the field of marine biology, and consequently a rise in the number of scientific contributions and a growth in the collections of biological material of the Natural Science Museums of Buenos Aires and La Plata. The first information on the fish resources of the continental shelf, the component species, their geographic distribution, and the oceanographic characteristics of fishing grounds was produced.

In 1949, a working team was formed in the Ichthyology Section of the Buenos Aires Natural Science Museum (MACN), with the purpose of investigation in the fields of Fishery Biology and Ichthyo-parasitology. This team was formed by European specialists Drs. Z. Popovici, L. Szidat, and V. Angelescu, and a group of Argentinian scientists: Professors F. Gneri, A. Nani and E. Sicardi. They organized the biostatistical sampling (in the laboratory), of fish species from the Rio de la Plata area. From 1952 onwards, fishery

vessels of the commercial fleet were integrated into research projects in order to carry out the sampling of fish and invertebrate species of economic importance. Characteristic of this second stage (1952–1959) were the combined scientific programmes – between the Naval Hydrographic Service, with oceanographic vessels, the above-mentioned team of the MACN and the Fisheries Research Department of the Ministry of Agriculture (DIPMAG), – with scientific and technical staff trained in the biostatistical sampling of fishes and decapod crustaceans. Fishery investigation was carried out mainly on board various fishing vessels, and in the laboratories of the MACN of Buenos Aires and the DIPMAG. Four programmes, under the name of "Operations", were performed during this time.

The Hake Programme ("Operación Merluza", developed between May 1954 and November 1956), was the most far-reaching, covering wide latitudinal (34°–42°S) and bathymetric (40–200 m) ranges, which corresponded to the fishing grounds of the off-shore fleet. Among the biological results of the environmental studies, mention should be made of the contributions concerning the taxonomy and ecological distribution of species of phytoplankton published by Balech (1959) and Frenguelli & Orlando (1959). From biostatistical sampling of randomly-chosen samples of fish species from the commercial catches, it was possible to obtain the first results on the population structure of the northern stock of the common hake *(Merluccius hubbsi)*, its distribution in relation to water masses and currents, and the migratory cycle of the adults (Angelescu et al., 1958).

The second programme ("Operación Nivel Medio", geographically limited to the area of 38° S), consisted of fifteen monthly voyages on oceanographic vessels of SHN, between July 1957 and December 1958. The objective of these cruises was to carry out studies on the fishery biology and environmental conditions prevailing during the life cycle of the shrimp *Pleoticus muelleri*. Samples for the biostatistical study were mainly obtained from aboard a prototype vessel of the shrimp fishing fleet (Angelescu & Boschi, 1959).

The last two combined programmes (the operations "Centolla and Cuenca") were carried out in the summer of 1959/1960, in the inner Patagonian shelf (44°–55°S) and the area northwest of the Malvinas Islands. The oceanographic studies – mainly on basic physical parameters – only included the area of San Jorge Gulf (45°19'–46°50'S). Samples of catches were analyzed on board the fishing vessel, these samples mainly comprised the common hake, the longtailed hake *(Macruronus magellanicus)*, and the king crab *(Lithodes santolla)*; results of these cruises were published by Angelescu (1960).

The combined sampling strategy for oceanographic and fishery data, developed from 1952–1959, was to be essentially maintained as the basic pattern in the cruise-planning for fishery research on the Argentinian shelf, for years to come.

The third epoch: advances in marine science as a result of international cooperation (1957–1980)

Ehrlich & Sánchez (1990) listed a series of events that took place in Argentina during the '50s and '60s, that permitted the materialization of joint research activities between Argentinian and foreign scientists. Among them are the creations of the Department of Oceanography in the SHN, the National Council for Scientific and Technical Research

(CONICET), the Institute of Marine Biology of Mar del Plata (IBM), the Centre of Marine Biology (CIBIMA), with its central venue in Buenos Aires and marine stations in Rawson, Puerto Deseado and Ushuaia, and the Argentinian Institute of Oceanography (IADO) in Bahía Blanca, a centre for the development of all branches of oceanography.

Scientific collaboration with the USA: progress in the fields of geophysics and physical oceanography

The first results deriving from international cooperation were obtained in the fields of geophysics and physical oceanography. Joint scientific efforts between the USA and Argentina began in 1957, and have since then materialized in several projects in those branches of marine science. Four bilateral programmes between the Argentinian Naval Hydrographic Service and the Lamont Geological Observatory (Columbia University, New York) and Texas A & M University, were carried out from 1957–1980.

As a part of the scientific activities programmed for the International Geophysical Year (1957–58) a series of seven cruises was planned between 1957 and 1962 on board four oceanographic vessels of the Naval Hydrographic Service and the RVs "Vema" and "Theta" of the Lamont Geological Observatory (Valdez & Aguirre, 1976). The primary aims of these cruises were to study the physical and chemical properties of different water masses, the circulation of deep waters, the geological structure of the sea bottom, the propagation of sound in the ocean, and to obtain samples of abyssal fauna. Among the important results from the continuous seismic refraction and reflection measurements taken during this programme, were the geophysical description of the submerged Argentinian coastal plain and the characteristics of the sediment deposition on the Argentinian basin (Ewing et al., 1964). Cooperation between the Department of Oceanography and Meteorology of Texas A & M University and the Argentinian Hydrographic Office and Hydrobiological Station of MACN (Puerto Quequén) resulted in a joint project named "Productividad". The main interest in these investigations was to measure primary production and standing crop of the phytoplankton, and to determine regional and seasonal variations in productivity along the Argentinian Continental Shelf, in the Drake Passage and the Weddell Sea. A secondary objective was to study the species composition of the phytoplankton and zooplankton populations at the stations where productivity measurements were made. Results of this programme are given by El-Sayed (1964, 1965).

From October 1976 to May 1978, personnel from the Lamont-Doherty Geological Observatory participated in four cruises aboard the ARA "Islas Orcadas" (formerly USNS "Eltanin") with the cooperation of the Argentinian Navy Hydrographic Service. The physical oceanographic component of these cruises was designed to investigate the circulation and distribution of water masses in the Atlantic sector of the Southern Ocean (Huber et al., 1981). By combining satellite observations of the Brazil and Malvinas currents, from 1975–1978 with the hydrographic measurements on board the "Islas Orcadas", Legeckis & Gordon (1982) were able to describe the sea surface temperature patterns associated with the two major currents and show that after the encounter, warm and cold eddies are ejected from the main flow. It has been estimated that the available potential energy of these eddies is of the same order of magnitude as the Gulf Stream rings (Garzoli & Garrafo, 1989).

The project, known as "International Southern Ocean Studies", was designed to evaluate and test various Antarctic Intermediate Water formation and circulation mechanisms. As part of this project, hydrographic information was collected in the austral winter of 1980 on board the R. V. "Atlantis II". The cruise covered an extended area of the continental slope, adjacent waters and southern seas. Cruise sampling scheme and data set are given by Piola et al. (1981).

The FAO Project of Fishery Development

A major part of the cruises carried out on the Argentinian Continental Shelf between 1966–1975 were part of a cooperation project between the FAO of the United Nations and the Argentinian Government, with several local institutions as counterparts (the Naval Hydrographic Service and Institute of Marine Biology, the National Directory of Fishery, and the National Institute of Industrial Technology) and with the official venue in Mar del Plata. A total of 33 international and national experts were assigned to the project, which flourished from 1966–71; after a gap of two years, complementary assistance was granted in 1974.

From the beginning, a central issue of the project was to develop a systematic programme of oceanographic and fishery cruises covering the different hydrographic scenarios on the Argentinian Continental Shelf. Three research vessels were assigned to the project, with permanent dedication, the oceanographic ARA "Capitán Cánepa" of the Naval Hydrographic Service, and the fisheries research vessels "Cruz del Sur" provided by FAO, and "Eolo" by the Argentinian Government. For additional sampling of fish and decapod crustacean species of the coastal region and inner shelf, vessels of the commercial fleet of the Mar del Plata port were hired.

The ARA "Capitán Cánepa" carried out fourteen cruises of the series "Pesquerías" (the Spanish word for Fisheries), between 1966–1970, in the fishing grounds of the most important economic species. Besides data on the horizontal and vertical distribution of physical parameters and nutrients, results were obtained on the distribution and abundance of phyto-, zoo-, and ichthyoplankton. Bathymetric registers were made, and bottom sediments were collected. Furthermore, environmental conditions and plankton samples were studied seasonally in one transect off Mar del Plata (Ramirez et al., 1973).

The activity of R. V. "Cruz del Sur" comprised 23 cruises of exploratory and experimental fishing, and 7 oceanographic surveys during the period 1966–1975. Results of oceanographic, biological and fishery investigations were published in the series of Technical Reports and Information Documents of the Project, and also in several numbers of the Bulletin and Contributions of the "Instituto de Biología Marina" of Mar del Plata and in "Physis", the Journal of the Natural Sciences Association of Argentina.

As regards fisheries resources, the information obtained during this period refers mainly to biomass assessments of the stocks of common hake (Rojo & Silvosa, 1969, 1970; Odemar & Silvosa, 1971) and anchovy (Aasen, 1967; Brandhorst & Castello, 1971b; Brandhorst et al., 1971), to aspects of the fishery biology of several fish species (Rojo & Silvosa, 1969; Brandhorst et al., 1974) and decapod crustaceans and mollusc bivalves present in the commercial catches (Boschi & Scelzo, 1969; Fenucci et al., 1974; Scelzo et al., 1974); also to studies of the hydrological characteristics of their habitats (Brandhorst & Castello, 1971a). Ichthyoplankton surveys rendered information on the identification and

delimitation of the spawning grounds and seasons of several fish species, on the description of the oceanographic characteristics prevailing in them (Ciechomski, 1969), and gave the first assessment of the spawning biomass of the anchovy (Ciechomski & Capezzani, 1973). Based on the distribution of physical parameters, Aasen & Castello (1968) were able to detect new fishing grounds for pelagic species such as the bonito *(Sarda sarda)*.

The joint scientific efforts of FAO experts and Argentinian institutions acting as counterparts, and the periodicity and continuity of the sampling programme, provided results that meant a relevant step forward in the knowledge of the fisheries ecosystems of the Argentinian Sea, their potential, and related environmental conditions.

Fisheries exploration programmes in cooperation with foreign countries on the basis of bilateral agreements (1966–1980)

From 1966, a series of cruises were carried out in foreign research and fishing vessels, in the continental shelf off Argentina, including the southernmost extreme (Burdwood Bank), and the slope. Bilateral agreements and research programmes were signed between national authorities and the governments of Germany, Japan, and Poland. On the Argentinian side, the principal counterparts were the Institute of Marine Biology of Mar del Plata and, from 1977 onwards, its successor the National Institute of Fisheries Research and Development (INIDEP). These institutions collaborated, having the necessary logistics and scientific staff.

The main objective of these cruises was to increase the knowledge on the time-space location of demersal (common hake, and accompanying species) and pelagic fish (anchovy, mackerel, Fuegan sprat), squid and decapod crustacean stocks, and the estimation of their abundance. In many of these cruises, fishing data were supplemented by hydroaccoustic registers and a complete environmental sampling including basic physical parameters, meteorological measurements, and the distribution and abundance of phytoplankton, zooplankton, ichthyoplankton and benthos.

Bilateral exploration programmes during these periods included three visits of the German R. V. "Walther Herwig" (1966, 1970–71, 1978; Schmidt, 1971; Ciechomski et al., 1979), an experimental fishing project aboard the German R. V. "Marburg" (1979; Dahm, 1980), a series of cruises on three Japanese R.V.s "Kaiyo Maru" (1969–70; Hanamura, 1971; Bellisio & López, 1973), "Orient Maru" (1976–77; Cousseau, 1978) and "Shinkai Maru" (1978–79; JAMARC, 1977; Cousseau et al., 1979), and a late spring survey of the Patagonian shelf on the Polish R. V. Professor Siedlecki (1973; Burczynski & Wrzesinski, 1974; Cotrina et al., 1976). From the chronological and operational standpoints, the contributions that derived from the programmes were a complement, and later a continuation, of the FAO Project of Fishery Development.

A principal objective of these programmes was the survey and assessment of fishery resources of the Patagonian, Fuegan and Malvinas regions. Demersal resources were generally evaluated through the swept area method (Ehrich, 1980; Otero et al., 1983), and occasionally through hydroaccoustics with echointegrator (Burczynski & Wrzesinski, 1974). Hydroacoustic and ichthyoplankton methods were also used for the spring assessment of the anchovy stocks aboard "Shinkai Maru" (Matsumiya & Hayase, 1982; Ciechomski et al., 1983).

The operational capacity of the research vessels involved, the extended time/space

coverage of the individual cruises, and the continuity achieved, particularly during the combined programmes of the "Walther Herwig", "Shinkai Maru" series (autumn 1978–autumn 1979), permitted the investigation of fishery resources of such areas as the continental slope and Burdwood Bank, of which only occasional references were available. The spawning and nursery grounds of Southern Patagonian species were described for the first time (Ciechomski et al., 1975). The abundances of fish eggs and larvae were related to environmental variables, including the densities of accompanying zooplankton (Ciechomski & Sánchez, 1983). The structure, distribution and abundance of the stocks, the fish communities and the prevailing hydrographic conditions of the shelf and slope regions were described in detail Hatanaka, 1986; Inada, 1983; Ishino et al., 1983; Menni & Gosztonyi, 1982; Menni & López, 1984; Otero et al., 1982; Podestá, 1990). Target species were the common hake, the longtailed hake, the southern blue whiting *(Micromesistius australis)*, the southern cod *(Salilota australis)*, the kingklip *(Genypterus blacodes)*, and the squids *Illex argentinus* and *Loligo gahi*; at the same time, a taxonomical catalogue of the fish species, decapod crustaceans and cephalopods trawled of Patagonian shelf was produced by Nakamura (1986). Most of the contributions by the Argentinian scientists form part of the volume edited by Angelescu (1981), and are in relation to the "Walther Herwig/Shinkai Maru" programmes. Many others were published in the two periodical publications of INIDEP (Contribuciones and Revista de Investigación y Desarrollo Pesquero).[1]

International cooperation covered all the fisheries exploration activities on the Argentinian Continental Shelf during the third epoch, and a good part of the oceanographic cruises. Local hydrographic research included important achievements, such as the repetition, in 1957, of the southernmost intercontinental transect of the R.V. "Meteor" programme. The confluence region was actively investigated by Argentinian scientists through a series of projects (Valdez & Aguire, 1976), with the main objective of locating and describing the region and the processes involved, through basic hydrographic data and planktonic indicators (Lusquiños, 1966; Boltovskoy, 1970). Mention should also be made of the series of 40 oceanographic cruises carried out by the R.V. "El Austral" of CONICET (the former "Atlantis", built in 1930 for the Woods Hole Laboratory) during 1970-78, with a coverage of over 35,000 miles, mostly on the inner shelf and coastal area of Buenos Aires Province and North Patagonian shelf (IADO, 1981). The intense hydrographic activity during this period is reflected in the amount of publications on the oceanographic characteristics of the area. In addition to those already cited, reference should be made to the contributions of Thomsen (1962) and Lusquiños & Valdez (1971) on the description of the water masses of the Southwest Atlantic. More recently though, based on data collected during this third epoch, Bianchi et al. (1982) presented a statistical analysis of the temperature and salinity characteristics of the austral extreme of the Argentinian Continental Shelf. Likewise, Martos & Piccolo (1988) reported on the seasonal hydrographic characteristics of the shelf in the area 38° - 42°S, from data collected between 1957 and 1980.

Regional cooperation developed during this period regarding the field of oceanography. From 1962 to 1966, four cruises aboard the ARA Cánepa were carried out as part of

[1] A complete list of all papers published is available on request from the Institute Library (the author's address)

the project "Tridente", a joint scientific effort of Argentina, Brazil and Uruguay for the intensive study of the different water masses of the south american coast from Cape Frio (Brazil) to Cape Horn. Also in 1962, the Regional Advisory Fisheries Commission for the Southwest Atlantic (FAO/CARPAS) was created, with the participation of Argentina, Brazil and Uruguay. The official venue was the Regional Fishery Office of FAO for Latin America in Rio de Janeiro. Until its conclusion, CARPAS held periodical meetings of scientists of the three countries, and produced a series of publications catalogued as "Theme", "Occasional" and "Technical" Documents. In 1974, the Combined (Argentina/Uruguay) Technical Commission of the Maritime Front (CTM) was appointed as a result of the creation of a common fishing area between the two countries. During the following decade, and due to the initiative of its Scientific Secretary, the late Héctor Otero, the CTM actively promoted the regional scientific integration through the materialization of joint exploratory cruises, international training courses, annual scientific meetings, and the publication of the CTM journal (formerly "Publicaciones de la Comisión Técnica Mixta del Frente Marítimo", now called "Frente Marítimo") which includes contributions from the two countries, from Brazilian scientists of the Rio Grande University, and even from Russian scientists working on the Southwest Atlantic.

The fourth epoch: the incorporation of fishery research vessels to INIDEP and the development of new cooperation programmes (1980–1992)

The National Institute for Fisheries Research and Development (INIDEP) was created in 1977 on the premises of the former Institute of Marine Biology in Mar del Plata. The tasks of INIDEP consist carrying out research and development programmes in relation to all fisheries resources, including freshwater species; also on marine algae and mammals. During this period, two modern fishery research vessels were incorporated by INIDEP, the R. V. "Dr. E.L. Holmberg", constructed in Japan in 1980 (GRT 858, length overall 62 m) and the R. V. "Cap. Oca Balda" built in Germany in 1983 (GRT 1100, length overall 65 m). Coastal research has been carried out since 1980 with a new "Capitán Cánepa" built in Argentina in 1964 (GRT 230, length overall 39 m) as a fishery vessel, and later adapted to perform some oceanographical operations.

With the incorporation of these three vessels, INIDEP concentrated most of the local activity on the Argentinian shelf and accumulated a large amount of information on the resources under commercial exploitation comprising some 56 species (45 fish spp., 3 cephalopod spp., 3 mollusc bivalve spp. and 5 decapod crustacean spp.), including their biomass estimates and potential yield. A review on this subject has recently been published by Boschi (1993). Investigations on the early life history stages of fish have increased markedly during the last decade; regional revisions of this type of study, including comprehensive bibliographies, were presented by Ciechomski (1991) and Sánchez (1991).

A main objective of the oceanographic cruises carried out by INIDEP during this period was the description of frontal systems, which in our area include the riverine plume of the Rio de la Plata, an extended and highly productive shelf break front and the tidal frontal system off Peninsula Valdés (Carreto et al., 1986). The principal fisheries ecosystems and fish assemblages on the Argentinian Continental Shelf were described focusing on different aspects of fisheries ecology with a multispecies approach

(Angelescu, 1982; Angelescu & Prenski, 1987). INIDEP authorities favoured the realization of research programmes to satisfy the requests of the fishing industry, which yielded some interesting results in the field of experimental fishing with the incorporation of new fishing gears and techniques.

Three major bibliographic initiatives, appearing during this period, deserve a special mention. The Zooplankton Atlas of the Southwest Atlantic (Boltovskoy, 1981), which appeared as a special publication of INIDEP, includes the work of several specialists on the taxonomy, distribution and ecology of the different groups, including the larval stages of decapod crustaceans and fishes, with excellent illustrations, exhaustive bibliography and a detailed review of the oceanographic conditions of the Southwest Atlantic. Likewise, the contribution of Menni et al. (1984, fish spp.) and Boschi et al. (1992, crustacean spp.) are a fundamental reference for ichthyologists and fishery biologists working in this area. These publications include the taxonomic classification, with keys and systematic revisions, collection references and adequate illustrations of the marine fish and crustacean species of Argentina and Uruguay.

A significant step forward in our comprehension of the hydrology of the region derives from the synoptic and global observations of the sea surface by means of environmental satellites. Recently, Podestá et al. (1991) described the annual cycle of surface temperatures in the area. The combination of historical data series with satellite-derived information, has broadened our knowledge of the water masses' characteristics of the Southwest Atlantic, and reinforced the value of information obtained in former times (Balech, 1986; Fedulov et al., 1990; Severov, 1990). Also during this period, the use of historical data sets permitted the elaboration of several theoretical models on the mean seasonal transport on the Argentinian Continental Shelf (Lusquiños & Schrott, 1983; Forbes & Garrafo, 1988).

Relevant information for the understanding of oceanographic, and fisheries, processes came from the use of maritime weather reports. The information contained in the US National Climatic Center's files of surface marine observations enabled Bakun and Parrish (1991) to estimate sea surface temperature, wind stress, surface Ekman transport distributions and wind mixing indices, and extend their framework of comparative climatology of reproductive habitats of neritic pelagic fishes to include the Southwest Atlantic.

Although less frequent during the third epoch, bilateral programmes have rendered valuable results particularly in the fields of oceanography, survey and appraisal of cephalopod resources and recruitment studies. Two joint programmes with the ex-Soviet Union allowed exploration in areas where very little information was available. In 1988, the R.V. "Evrika" surveyed the Argentinian shelf, slope and adjacent waters, to a bottom depth of 4500 m. The main objectives of this cruise were to investigate the distribution and abundance of the early developmental stages of the cephalopods, mainly *Illex argentinus*, and the distribution and feeding ecology of the common hake (Nigmatulin, 1989; Brunetti & Rossi, 1990; Brunetti & Ivanovic, 1992). More recently (March/April 1992) the R.V. "Dimitri Stefanov" surveyed the coastal region of the Argentinian Province of Santa Cruz, Magellan Strait and Fireland, in order to locate and assess the coastal population of the Fuegan sprat (*Sprattus fuegensis*) an up to then enigmatic species (Sánchez et al., 1993).

A joint project with Japan and Uruguay, including a cruise on the R.V. "Kaiyo Maru"

in the winter of 1989, supplied a large amount of information on the distribution and abundance of early and juvenile stages of squid species, mainly *Illex argentinus* and *Loligo sanpaulensis*, and references to the occurrence of other cephalopod species in the continental shelf, slope and adjacent waters off Argentina and Uruguay (Brunetti et al., 1990; Kawahara, 1991). With the accumulation of information from previous epochs, and particularly after the incorporation of the new research vessels, the time was ripe for local and bilateral programmes to enlarge the framework of classical systematic surveys to include process oriented investigations.

In 1980, the first toxic red tide outbreak was detected in the area of Peninsula Valdés (Carreto et al., 1981). A series of cruises were carried out in order to investigate the processes that originate, maintain and propagate the bloom of the dinoflagellate *Alexandrium excavatum*. The existence of the tidal frontal system in the area was in fact discovered during the initial stages of this programme (Carreto et al., 1993). Following the first episode, the toxic area expanded to cover nearly all the Argentinian coastal ecosystem. Since then, paralytic shellfish poisoning is regularly monitored in Argentina.

Process-oriented investigations were also carried out in the field of larval fish ecology. The drift and mortality of a patch of anchovy eggs and larvae were studied by Sánchez et al. (1991) in a Lagrangian experiment aboard R.V. "Dr. E. L. Holmberg" in the spring of 1983.

During the last decade, an intensive programme was carried out in the Southwest Atlantic to study the processes involved in the complicated dynamics of the confluence region (Olson et al., 1988). From 1984 to 1990, seven oceanographic cruises were carried out as part of the project "Confluence", with the participation of Argentina, France (Laboratoire d'Oceanographie Dynamique et Climatologie, University of Paris) and the USA (Lamont-Doherty Geological Observatory), aboard two Argentinian R.V.s ("Puerto Deseado" and "Cap. Oca Balda") and the French "Le Suroit". Primary objectives of this project were: to monitor the variability of dynamic topography in the area of the confluence, and to study the time-space fluctuations of the associated thermo-haline fronts; to obtain detailed seasonal water mass descriptions of the region, detect changes in water mass composition and evaluate the modifications due to small-scale mixing across the frontal region, and to determine the strength of the CO_2 sink in the region during winter conditions (Guerrero et al., 1987; Charo et al., 1991). Indirect wind observations (Garzoli & Clements, 1986) and the time-space variability of the confluence dynamics (Garzoli & Bianchi, 1987) have been studied by a setting of inverted echo sounders. Descriptions have been presented on the transport, frontal motion and the potential energy of the eddies ejected from the main flow (Garzoli & Garrafo, 1989).

In the spring of 1989, a high-spatial resolution experiment designed to elucidate processes relevant to fish recruitment variability was carried out on board the German R.V. "Meteor", with the participation of physical and biological oceanographers from five countries (Argentina, Brazil, Germany, Sweden and Uruguay). The project was carried out under the umbrella of the "Ocean Science in relation to Living Resources" programme of IOC/UNESCO. The objective of this cruise was to investigate the integrated impact of hydrographic and biological parameters of different physical environments on larval fish survival (IOC/UNESCO, 1990; Nellen, 1990).

As a consequence of all this collaboration – national and international – in 1974 Argentina created a centre of oceanographic data (CEADO) organized by the Naval Hydrographic Service (SHN) and CONICET.

CONCLUSION

Figure 2 is an attempt to summarize all the above information about scientific research on the Argentinian Sea and adjacent waters. We have classified cruises of the different chronological periods analyzed, on the basis of several criteria. Classification corresponding to the area surveyed (1-4 in the front basis of the figure) is the same as for Figure 1. Depending on its main objective, each cruise was classified as: (A) hydrographic; (B) includes the collection of plankton/benthos samples, environmental monitoring, etc. oceanographic; (C) experimental-exploratory fishing; (D) fisheries oceanography. According to the country that organized the cruise, these have been classified as: (I) foreign; (II) foreign with Argentinian participants, (III) cruises resulting from bilateral agreements; and (IV) Argentinian cruises.

The general trends are self-explanatory. In all the periods analysed, most of the cruises took place on the continental shelf and coastal regions. In the early days, coastal research prevailed. From 1960 onwards, there has been a general increase in the number of cruises and a predominance of cruises covering the entire shelf. As regards their objective, it is clear that in the beginning, research programmes were mostly hydrographic (over time biologists were incorporated into these programmes), so that thereafter oceanographic cruises predominate. During the last decade, the majority of cruises were promoted by INIDEP, and, consequently, were mostly stocks assessment and fisheries oceanography cruises. The impact of international cooperation during the third epoch, together with the increasing incidence of local activities over time, becomes evident.

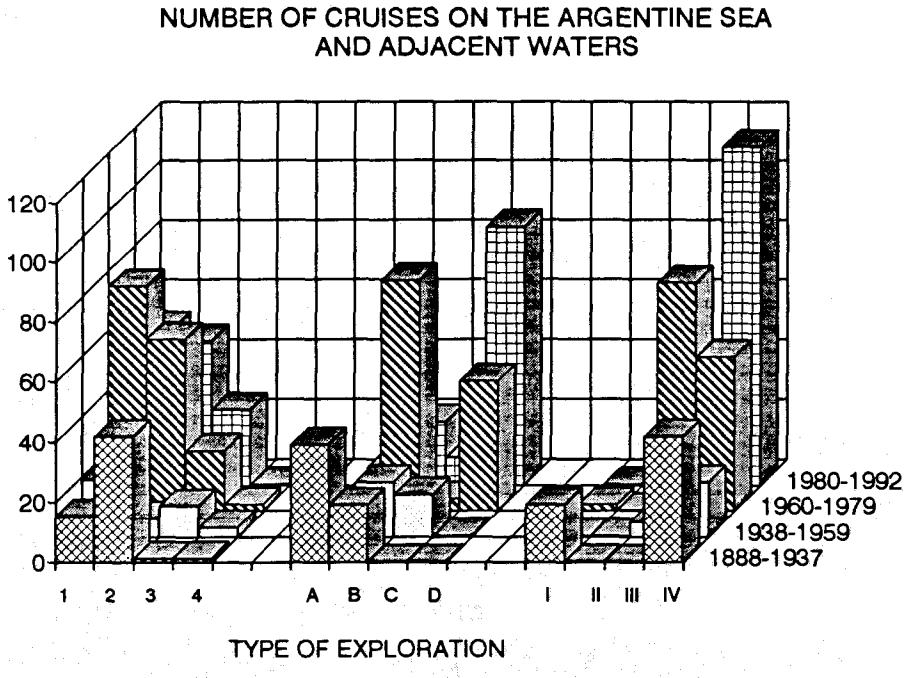

Fig. 2. Number of cruises on the Argentinian shelf and adjacent waters, classified chronologically and according to the type of exploration. See text for explanation of references

Trends observed in the evolution of oceanographic and fisheries research in other parts of the world were also observed in our study region. The subsidiary role of marine biology to hydrographic programmes during the 19th century, the gradual incorporation of naturalists, and, with the course of time, marine biologists and biological oceanographers to those programmes, the transitions from botany and zoology to ecology, from fish to fishery biology and later fisheries ecology, the need to develop regional joint programmes, and the tendency to move from systematic to process oriented survey: all of these have been reported elsewhere on many occasions.

We did not attempt to include in this paper an exhaustive list of bibliographical citations derived from those scientific initiatives. A more detailed review, with full bibliographical references and tabulated fisheries programmes operating in the region from 1874 onwards, has recently been presented by Angelescu & Sánchez (1994) in a Spanish version of this Paper. Some readers may feel that some authors or important papers have not been referred to. Our criterion, albeit subjective, has been to cite those papers that will help the interested reader to work their way through the extensive literature on this region. It has been our intention, in writing this contribution, to present for the consideration of our colleagues attending the scientific Symposium on the occasion of the centennial of the Biologische Anstalt Helgoland, the results of the scientific efforts of all the oceanographers and fishery biologists working on this distant region of the World Ocean, many times under unfavourable conditions. To all of them goes the tribute of our recognition.

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