BATHYMETRIC REQUIREMENTS FOR FISHERIES RESEARCH
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Executive Summary

Knowledge of bottom topography plays a key role in fisheries research studies directed at understanding demersal fish distributions, behaviour, and abundance and in assessing habitat. Methods of observations often include underwater acoustics that can in turn guide various capture operations of target species. However, bottom topography may impose severe limits on acoustic detection and assessment of fishes found in areas of high relief and steep slope. Habitat characteristics of different demersal species from the Chilean coast are used as example and results from two studies conducted on Widow rockfish (*Sebastes entomelas*) along the westcoast of Canada illustrate the importance of having adequate understanding of bottom structures to correctly interpret acoustic observations. Examples are given where acoustic returns from sidelobe detection of bottom lead to echoes that appear as fish schools. The need for careful interpretation of echo returns by fishers and researchers are discussed. New methods to generate a representative 3D model of the bottom surface that can assist in near-boundary fish discrimination are shown. Images provide greater insight to echo source and highlight some of the difficulties associated with classifying acoustic sign. It is here emphasise the importance of good bathymetric knowledge to optimise survey design with regards to minimising sidelobe interference and reducing acoustic shadow zones.

I.- Introduction

The rationale and scientific management of fisheries must depend on a fundamental understandings of fish biology and ecology; that is, what sort of animal fish are, and where and how they live. Fishes are highly adapted to a wide range of habitats from the surface of the sea to deep water, near the shore line and intertidal environment toward the deep shelf and slope. Most of the world fish populations lives over the continental shelf, shelf margins, slope or abyssal plane, over seamounts, pinnacles or cliff edge. Commercial fisheries have been developed in all this kind of environments.

Why are they there?. The reason is simple, they aggregate in areas what ever they could find their food and what ever they could spawn as strategy to avoid losses of the offspring. Coast and continental shelf are productive marine areas especially the eastern boundary of the oceans. Therefore primary production provide the adequate environment to support important fisheries.

The key to this lies in what the fish eat. Many small pelagic fish and shrimps undergo daily vertical migrations, feeding at the surface at night and returning to deeper water during the day. Particularly important in the fisheries is how aggregation pattern have changed historically in relation to stock level, explotation pattern and the environment, and what impact these changes have on commercial fishing and assessment surveys.

Therefore, the knowledge of the fish habitat is essential for the future management of the resources, understanding the habitat as a complex of physical and biotic factors which describe or determine the place where the animal lives (Anderson, 2001; Anderson et al. 2002). In this context, measurement of water depth became one of the fundamental observations made at sea where the acoustics method form our principal means of acquiring bathymetric data since the develops of the echo sounder.

These paper deals with a general overview of the fisheries research, methods of observations, acoustic interpretation, and needs of increase the knowledge to optimise the fisheries assessment.

II.- Fish Stock Assessment Importance

Since 1883, the debate on the causes of fluctuations in stock abundance, that is natural fluctuations vs influence of fisheries, have been recognised as an important knowledge needed to manage the fisheries. At present, things does not seem to be completely different and we still paid attention to fish movements and the availability of fish to fishermen (Fréon & Misund, 1999).

Since 1908 the fishery biologist is dealing with topics as fish age, fish behaviour, age composition, fish tagging, eggs and larvae stock assessment method applied to pelagic stock. In 1954 Beverton initiate the structured model to estimate the mortality rate given catch and effort data.

During the period following the second world war, the direct method of stock assessment began to use analytical approaches, that is using the fishing gears estimating the demersal fish caught by the bottom trawl per unit of time and area, and the hydro-acoustics detection for describing the vertical and horizontal distribution, either demersal or pelagic fishes.

Since 1970, the quantification of biomass by echointegration became the state of the art in the scientific communities. At the beginning, this technique was rather imprecise due to problems of electronic calibration and poor knowledge of the intensity of fish echo energy, now commonly named as target strenght.

During the 80´s considerable technical and methodological improvement took place, developing the possibility of performing absolute measurements of fish abundance and this methodology is now commonly used by scientist for providing fishery-independent estimates of many important stocks around the world.

Nowadays the technique has reached a high degree of sophistication with the use of dual-beam or split beam, like any other, still suffers from some limitations mainly due to fish behaviour, that could be substantially improved with the knowledge of the sea bottom roughness and fish habitat.

III.- Fishing methods and Fleet

There are probably as many different fishing methods as there are species to fish caught by man. Despite the wide variety of methods there are only three main techniques:

- Hooking, individual fish,
- Tangling fish in netting and,
- Actively catching fish in a net such as seine, a trawl or a trap.

The increased power of large fishing ships has made trawling and seining by far the most efficient method. The trawl is primarily an instrument for pulling a sock like net along the seabed. The towing speed must be fast enough to bring the fish exhausted falling into the cod end. The development of more steam-powered ship together with the knowlegde of the seabed roughness greatly have enhanced the efficiency ot the catching method.

Commercially exploited fisheries have been develop in all different environment where fish aggregate, that is: coast, enclosed areas, continental shelf, shelf margin slopes, sea mountain, abyssal rise and canyons. Therefore, adequate knowledge of the sea bottom deep by the fishing boat to operate over fishing ground became essential.

Recent advances in acoustics technologies are offering new opportunities to describe and map marine bottom environment, to describe the sediment structure and ultimately, integration of different observational systems have significantly improve our description and understanding of marine seabed habitat.

IV.- Seabed detection equipment and technology

The echosounder: Fishing vessels are mostly equipped with echosounder. The sound beam is vertically transmitted and the operating frequency may vary from 12 KHz to 200 KHz. Fishermens use the equippment to register simultaneously depth to the bottom and to locate fishes in the water column. Actual echosounders allow to record digital echo and processing different types of echo and data storage.

The sonar: The sonar is commonly used by the purse seine pelagic fisheries boat to detect the fish school in a wide area range around the vessels, while demersal fisheries trawler use it in association or together with others instruments, like multibeam or omnidirectional sonars. There are sonars constructed for detecting targets at a long range that operate at low frequency (20 KHz to 50 KHz) and a beam width of ca. 10 degrees. High frequency sonars operate in frequencies in range 150 KHz to 200 KHz and give more resolution due to the narrower beam width (5 degrees). Both are used for detection and for the extension of targeted schools, respectively. After the detection of fish is complete, sonar instruments are used to estimate school size, to track its depth, speed and swimming direction.

The trawl sonde and gear sensors: This kind of equipment was developed to monitor the vertical opening of the trawl net and the vertical position of the net related to fish concentrations depth and the bottom. The sonde is mounted on the headline of the trawl net and operate sending the information through a cable to the ship or the new version which are cableless sounding. Acoustic sensors to control the functioning and performance of the fishing gear are used to measure trawl depth, doors spread, headline height, temperature, speed and amount of catch in the bag,

Modern trawl sonde have developed variations based on the sector scanning sonar operating on 330 KHz giving detailed image of the trawl opening and how is positioned in relation to fish concentrations and the sea bottom.

Automatic seabed mapping: Commercial fishing vessels have the opportunity to explore and to sample the seabed, combining the information originated from the sea bottom and provided by different devices like: echosounders, sonars, net sounders. In association with a chart plotting, this information may be used to obtain and improve the topography of the bottom. The echosounder depth data and the GPS lat/long data are used to generate topographic seabed maps in real time, combining official vectorised surface maps with self generated bottom charts in a high resolution bottom map (5 m). A software envelop of 3D viewing permit to view the bottom from different angles and views to study the landscape.

New software possibilities allow to detect automatically the bottom hardness and roughness recording historical registers from echosounder profiles. This define and automate the calculation of different indices from seabed backscatter and use them to classify bottom habitat or substrate type of the seabed. The first echo signal processor that was connected to commercial echosounders and that provides hardness information was named RoxAnn (Burns et al. 1989). This system is based on the first and second echosounder bottom return. The RoxAnn echo signal processor has become a useful instrument for trawl fisheries and during scallop dredging. A few Norwegian scallops dredgers have installed an expensive multibeam echosounder (Simrad EM series) to map the contours of the sea bottom (Misund

1997). Recently, QTC VIEW™ has been developed as new classification system based on the shape of only the first returning echo from the bottom. A total of 166 features could be extracted from each echo (Ellingsen et al. 2002).

When a net sounder or trawl instrumentation is in use, the trawl appears in the chart. This gives an indication of the movement of the trawl relative to the vessel and the bottom. This tool is specially useful, when a net is trawled near to the bottom or to avoid obstacles like sea pinnacles and cliff edges.

V.- Distribution of fish resources and fishing ground habitat associated to bathymetry

There are different species of demersal fish that coexist near to the Chilean coast using the productivity of the upwelling ecosystem. However, the distribution of fish is highly related to microhabitat use and the seabed topography, slope and roughness. Examples of distribution goes from the shelf to deeper waters and from the coast to very far away sea mountains.

Chilean Hake – *Merluccius gayi:* The Chilean hake *Merluccius gayi gayi* represent the main demersal fishery performed along the coast of Chile. Since 1992 this species is regulated under a total allowable catch system. During the last 3 years annual quotas are around of 100 thousand tons.

The distribution of Chilean hake is from Arica to Puerto Montt (40ºS). However, the demersal fleet operate between 34º28'S and 39º30'S in depths between 45 to 450 m. In the commercial fishery, there are 13 fishing grounds representing the more important and stable focus of abundance (Figure 1).

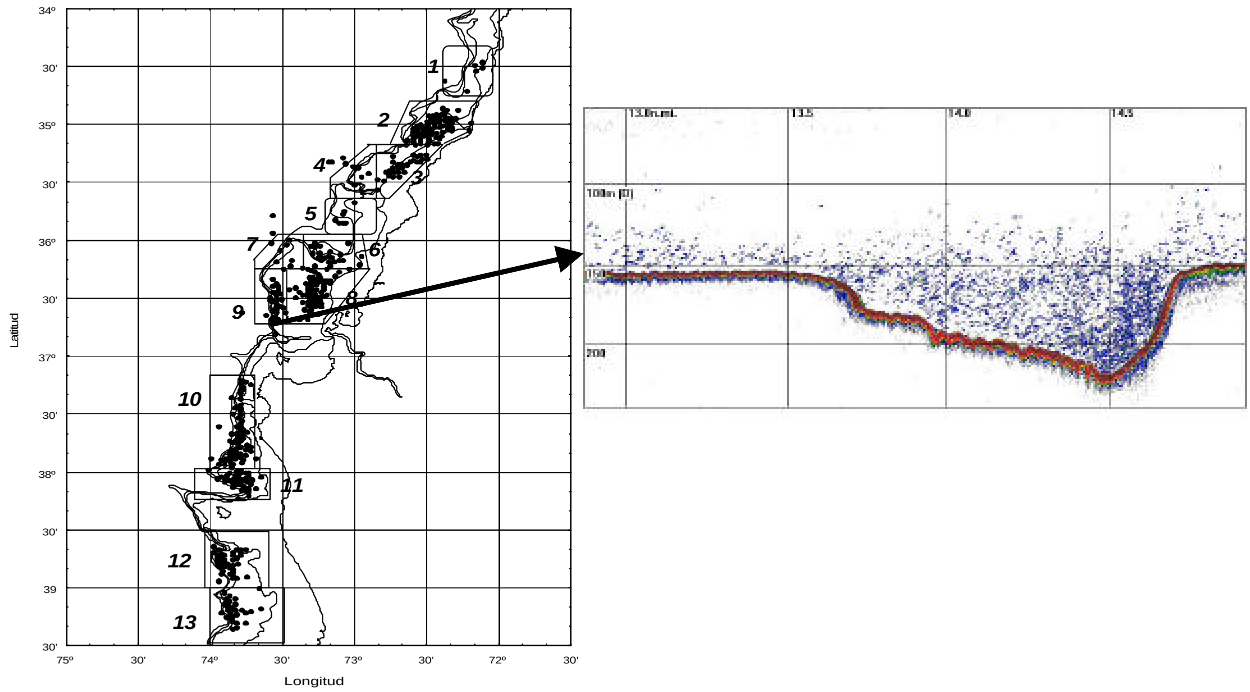

Figure 1. Map of distribution of commercial hauls of Chilean hake during 1997 and location of 13 fishing grounds associated to the main focuses of abundance. Echogram showing hake near to the seabed on the continental shelf.

Haketail (Hoki) – *Macruronus magellanicus:* The Haketail *Macruronus magellanicus* Lönnberg, is mainly distributed from the Gulf of Arauco (37°S) to the austral zone of Chile (57°S). It has been reported near to Valparaíso (Arana, 1970; Aguayo y Gili, 1984). The fish season for *M. magellanicus* by this fleet, begins in September and extends to February-March. In the austral zone of Chile (43°S to 57°S), it is one of the most important and abundant secondary fish resources obtained by bottom trawl fisheries for *Merluccius australis* (Aguayo et al., 1992; Aguayo, 1995). However, catch levels of *M. magellanicus* by the austral bottom trawl fishery are lower compared with the catch got by the industrial purse-seine fleet fishing off the central zone of Chile (37°-39°S). In fact, total catches of *M. magellanicus* reached 375,446 tons in 1996 with 96% done by the purse-seine fleet.

Haketail has been considered an alternative resource for the demersal fleet and can be located in zones near to the margins of distribution of the Chilean hake. Juveniles (< 57 cm total length) are normally pelagic distributed, but adults are distributed in association with the bottom near to the border of the continental shelf between 250 up to 700 m depth (Figure 2).

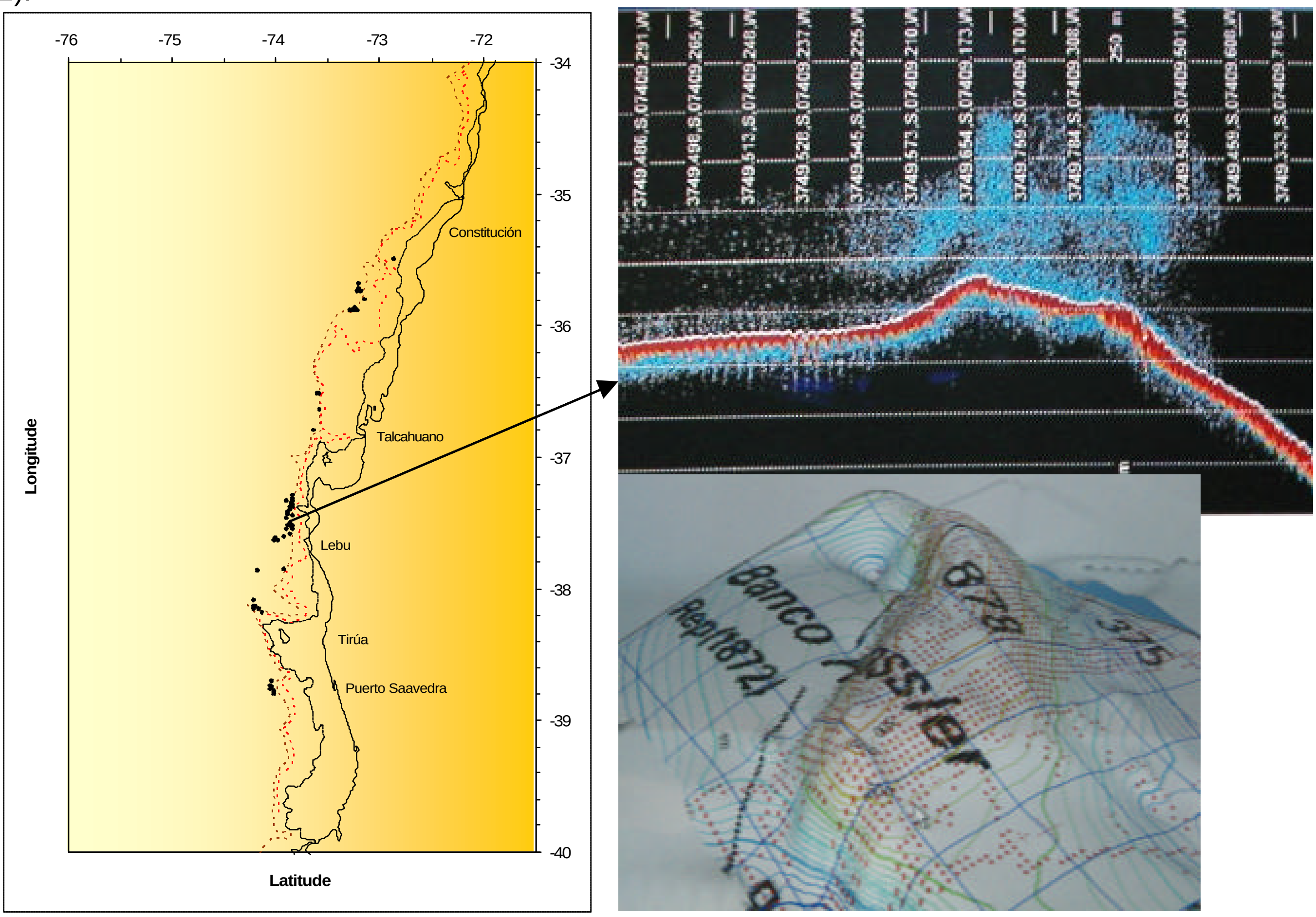

Figure 2. Location of trawls of haketail *M. magellanicus* realized by the demersal fleet of Central Chile (2002). Echogram showing haketail near to the border of the continental shelf (Hassler Bank) and 3D view of the bank plotted by own data of skippers (red crosses).

Cardinal fish (Besugo) – *Epigonus crassicaudus:* The cardinal fish is distributed off the Chilean coast from Taltal (25º05'S) to Puerto Montt (41º45'S), but the fishery operate between Valparaiso (33°30'S) to Isla Mocha (38º15'S) in a depth range from 100 to 500 m, with more dense agregations registered between 280 m and 310 m.

The habit of the cardinal fish is as mesobenthic and some times as pelagial species living above marine elevations in the open sea (Parín *et al.*, 1985). Adult fish are normally located in association with rocky bottoms or near to pinnacles associated to the border of the continental shelf, whereas juveniles are more related with pelagic waters above the continental shelf in a disagregated habit dealing with a pelagic behavior.

There are 12 commercial fishing grounds off Chile, that is extended from the 33º30'S to 38º15'S in bottom depths between 280 to 420 m. Rocky and hard substrates near to islands (38ºS to 38º15’S) and extensions of the margin of the continental shelf (35º45'S to 36º00'S) are more intense visited, searching for more dense schools of cardinal fish.

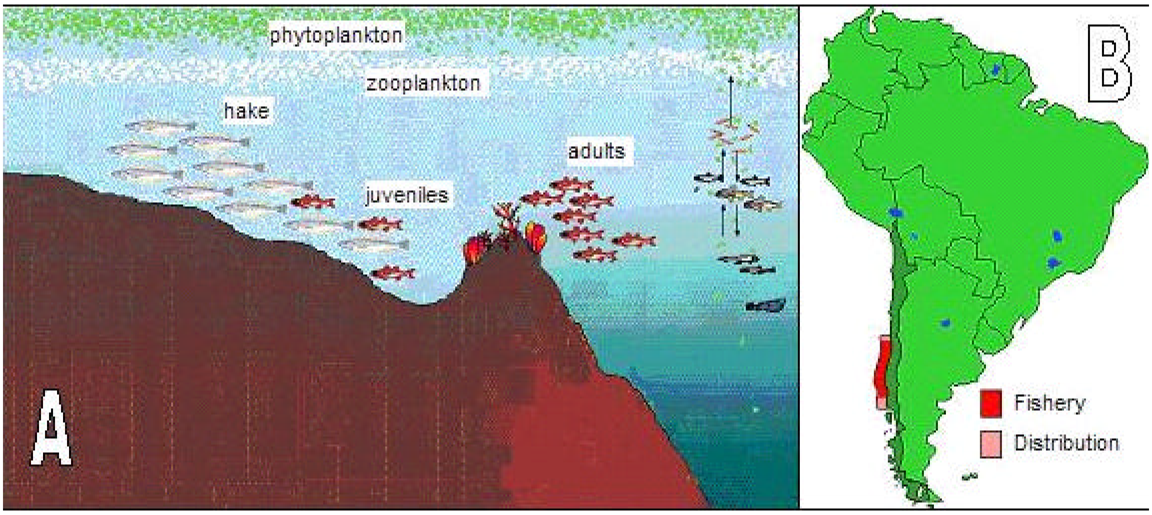

Figure 3. Distribution and schematic location of the Cardinal fish fishery (*E. crassicaudus*).

Orange roughy – *Hoplostethus atlanticus* : The Orange roughy is mainly distributed in Australia, New Zealand, Namibia and Chile (Figure 4). The vertical distribution is between 500 to 1400 m in an habitat is associated with temperatures between 4 and 7 ºC in irregular and very slope types of bottoms between cannions and sea mountains (Figure 5). A maximal size of 56 cm is found in the commercial fishery that represent a maximal weight of 5 kg. The longevity of this species is very high achieving a maximal age more than 100 years old. The age of maturity occurs between 20 and 32 years old representing fish sizes between 28 to 32 cm TL. The period of aggregation of this species occurs between july and august mainly due to spawning habits. Less aggregated shoals can be found between september and january.

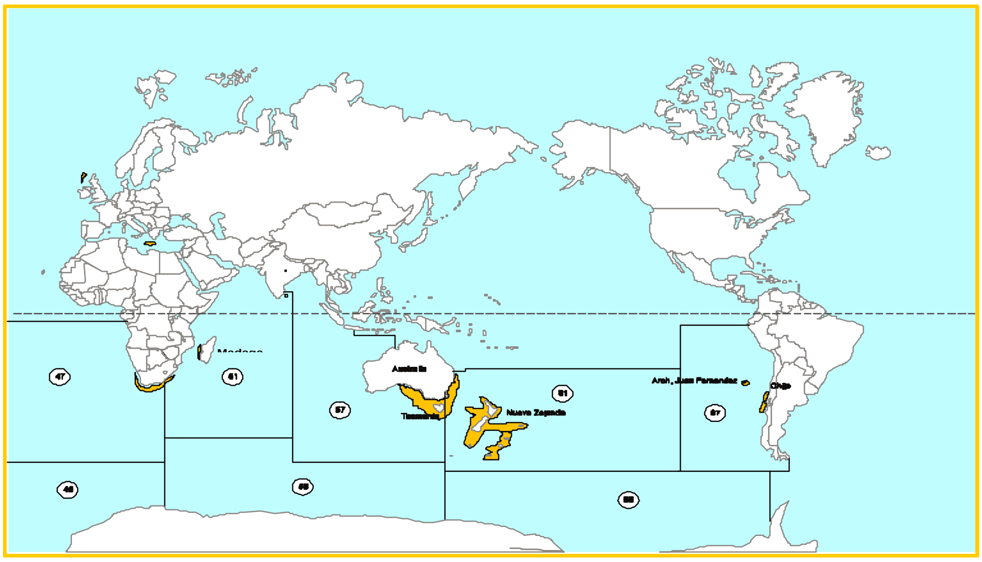

Figure 4. Distribution and schematic location of Orange roughy (*Hoplostethus atlanticus*) .

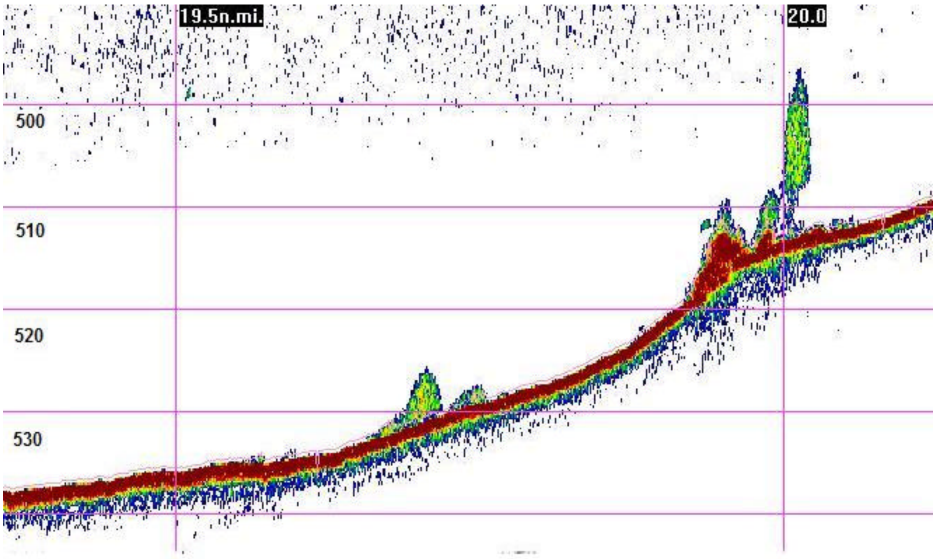

Figure 5. Echogram showing schools of Orange roughy near to pinnacles off Chile (Juan Fernandez Island).

Alfonsino – *Beryx splendens* : This species within Chilean waters is normally found in a range of temperature between 7.5 to 15.5 ºC. The vertical distribution is between 200 to 800 m, but can be found upto 1250 m depth, over irregular and steepy slope types of bottom near to the margin of the continental shelf, some pinnacles and sea mountains (Figure 6). The maximal size of this species in the Chilean fishery goes to 56 cm total length with a maximal weight of 3.5 kg. The Alfonsino achieve a maximal age of 14 years old and is mature between the second and sixth year of life. The normal period of aggregation is during the day and it is determined by the feeding habits and conditions.

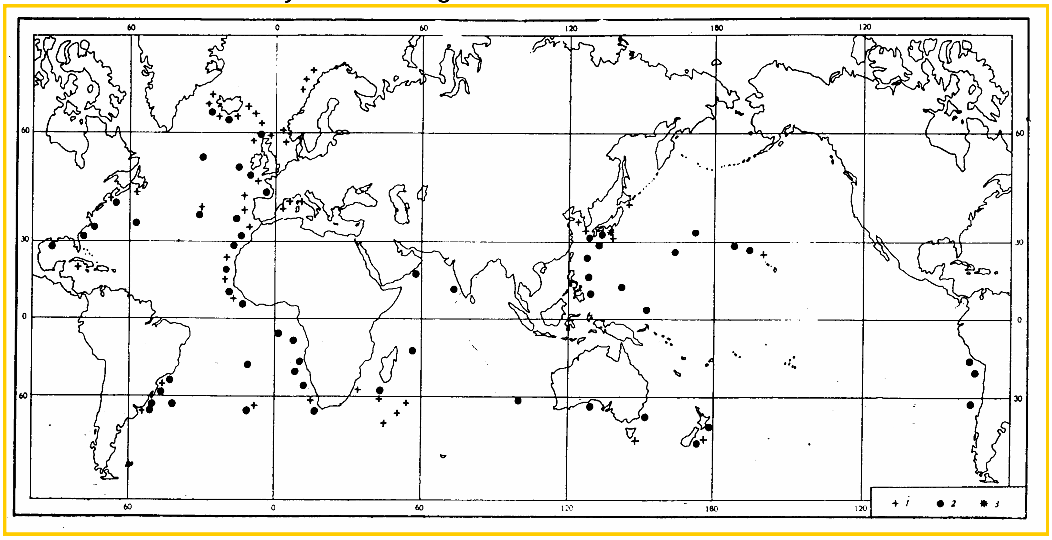

Figure 6. World distribution of Alfonsino Beryx splendens (after Parin et al. 1985)

V.- Applying Bathymetric Knowledge in Fisheries Research: Acoustic Studies of Demersal Fishes and Their Habitats off Vancouver Island.

There are over 35 species of rockfishes (*Sebastes* sp.) that live off the Pacific Coast of British Columbia (Love et al. 2002). With few exceptions, rockfish tend to inhabit areas with various amounts of hard, complex substrata and vertical structure (ie. rock ledges, caves, crevices, boulders, cobble fields, etc). We can generally categorise rockfish communities into five zones based on water depth: 1) intertidal, 2) nearshore (subtidal to about 30m), 3) shallow shelf (30-100m), 4) deep shelf (100-300m) and 5) slope (>200m).

However, within these regions, the biotic complexity can be highly variable depending upon species life history stage, diel or seasonal flux, and environmental factors. Some of the more commercially important rockfishes such as ocean perch (*S. alutus*), widow (*S. entomelas*), and yellowtail (*S. flavidus*) can be found in the deep shelf zone. These species often appear in dense aggregations that show strong affinity to pinnacles and cliff edges during adult and sub-adult stages.

Commercial fishery and research efforts largely employ acoustic methods to observe and assess fish abundance, behavior, and distribution. However, acoustic measurements are highly influenced by fish behaviour, target size, species mix, and soundbeam characteristics as well as bottom proximity, roughness, and scattering properties. In regions where the acoustic scattering properties of the substrate are unknown, near-boundary detection problems suggest that the application of acoustics for biomass estimation of some demersal species is problematic (Stanley et al. 2000) and, in some cases, impractical (Richards et al. 1991, Stanley et al. 1999).

It is necessary emphasises that better near-boundary detection requires knowledge of the 3D boundary shape as well as acoustic parameters such as target size, beam-pattern and beam attitude (Cooke et al. 2002). Examples of methods used to help visualise the acoustic data in a way that lead to a better understanding of bottom structure and of fish behaviour in relation to their habitat are shown.

Two sites at the continental shelf edge off Vancouver Island, British Columbia were identified by commercial fishers as preferred habitat for Widow rockfish (*Sebastes entomelas*). Their acoustic observations at Triangle Island and Pisces Pinnacles fishing grounds (Figure 7) showed 'dense rockfish schools', however these schools were extremely difficult to fish. Trawling efforts typically resulted in lost or damaged gear and fishers were quick to caution that 'what you see is not what you get'. The Pisces Pinnacles area was considered virtually untrawlable, despite its relatively innocent look (B. Mose, **pers. com**.).

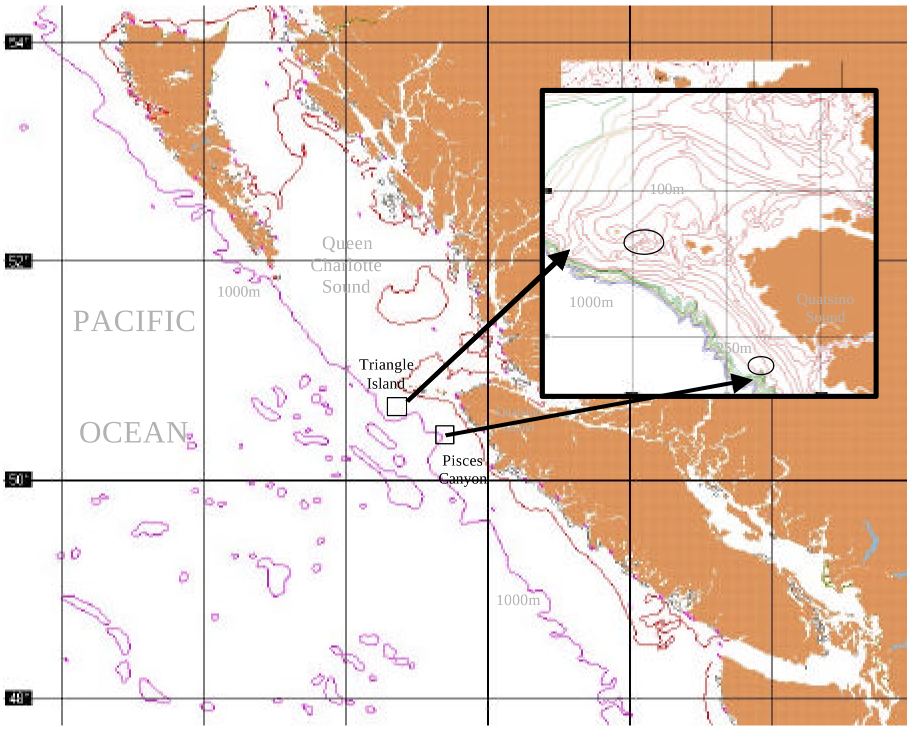

Figure 7. Triangle Island and Pisces Pinnacles study sites off the westcoast of Vancouver Island, British Columbia with an example of the survey patterns used at each location.

Fisheries and Oceans, Canada in partnership with the Canadian Groundfish Trawlers Conservation Society examined the areas acoustically to assess what it was that appeared to be very dense aggregations of rockfish but was in fact 'something more' [than just fish] (Stanley et al. 1999; Stanley et al. 2000).

Applied Methodology: Acoustic data acquisition followed standard survey methodology (Foote et al. 1987; Kieser et al. 1999). In the absence of high resolution bathymetric information, sounder detected bottom depth data were used to create an interpolated surface and 3D elevation maps to visualise the bottom topography from various directions and viewpoints were made (Stanley et al. 2002; Cooke et al. 2002). For the Pisces Pinnacles study site, a new 'true bottom' outline of the topography was created based on maximum signal strength observed along all transects (Figure 8, Bottom mask) to help with identification of signal source. Acoustic backscatter values (Simrad 1993a; Simrad 1993b) were overlaid to show ping location and echo returns in relation to bottom structures. The interpolated maps provide a visual appreciation of the topography that was essential for improving echogram interpretation.

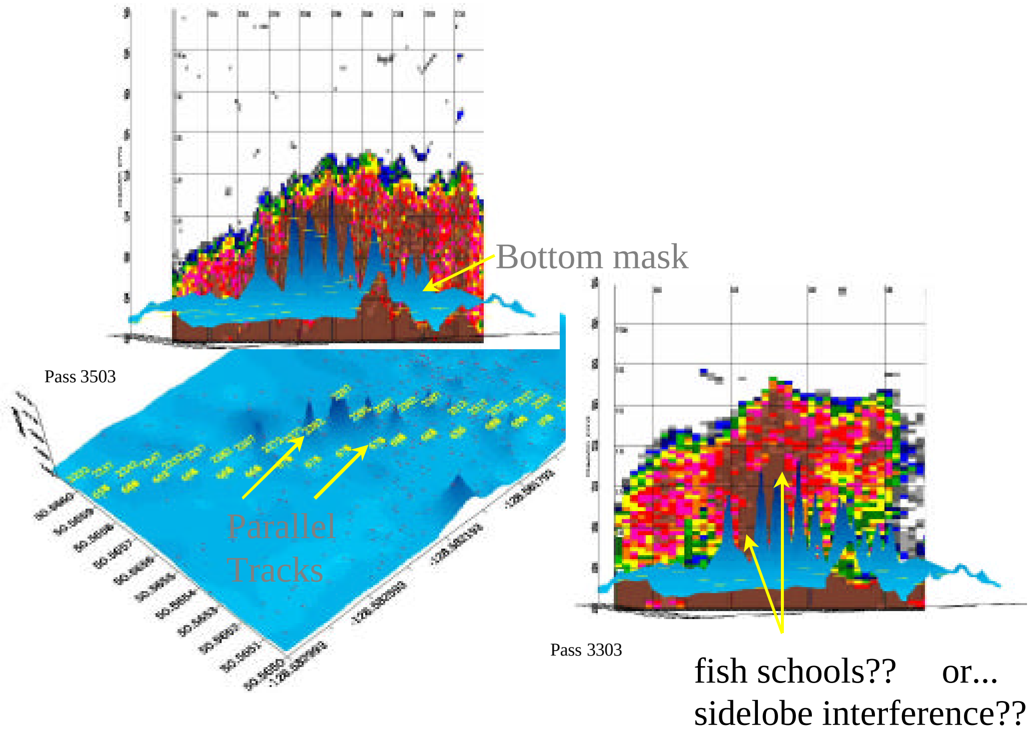

Figure 8. An example of a 3D interpolated elevation map from Pisces Pinnacles with portions of echograms from two passes overlaid on a 'true bottom' image showing ping by ping trackline, bottom detection locations, and Sv values relative to pinnacles. Pass 3503 crossed directly over the middle section of the pinnacles; Pass 3303 ran parallel to 3503 but adjacent to the longitudinal axis of the pinnacles. The yellow lines and markers represent sounder detected bottom tracking for each pass. We created the light blue bottom mask overlay to more clearly define acoustic sign near boundaries and identify possible sidelobe signals

Bottom tracking was intermittent along transects that crossed directly over the steepest terrain (Figure 8, Pass 3503). Little of the high density acoustic sign observed along the cruise tracks where bottom tracking failed could be classified with certainty since there
was little separation from the bottom signal. For passes that the sounder was able to track bottom (Figure 8, Pass 3303), we first viewed much of the off-bottom backscatter as typical

of high density fish aggregations. However, by overlaying the new 'true bottom' outline (Figure 8, bottom mask), we can more clearly identify possible bottom tracking limitations and shadow zones associated with sidelobe echoes of the bottom structure. For the Pisces Pinnacles site, this new insight was key for classification of echo sign that appeared removed from bottom.

Moreover, images provided fishers with a better understanding of difficulties associated with trawling the grounds. Using different perspectives of the same image and by rotating the images around the formations, we were better able to identify transect bearings that were less affected by bottom structure and soundbeam characteristics and more appropriately oriented for detection of fish targets. Zones of uncertainty could be better defined or removed entirely from the integration process.

VI.- Discussion

It is important to know that the knowledge of seabed obstructions is essential for the safety of fishing ships, catching a towed fishing device on an obstruction can lead to the wreck of the ship and the lost of human lives. There are several types of fisheries that can be classified according to the type of instrument that they used, duration of the absence from the port and the equipping of the ship.

The increasing of restricting fishery regulations around the world and accordingly with different fisheries policy impose by fishing nations that increase competition, the evolution of accoustic technique is necessary because it is needed a best targeting at the species to fish, to go, without loosing time, directly to the favorable areas, by selecting its in an easiest way, in advance, to avoid loosing time because of the unforeseen events due to a lack of knowledge of the environment: seabed obstructions that can be snagged by a trawl gear, and finally to have the power of prospecting new potential fishing areas.

To meat this aim the information necessary come from the skipper´s experience and the information he has to his disposal and the way they are presented to him. These information for decision help are computed and displayed by specialized systems as digital plots chart which are more powerful than paper ones.

Competition on more living resources makes the fishery circle more secret and the ship´s manager in industrial fishery have wished more complementary thinking delay because of the confidenytiality of personal plots chart elaborated and used by the trawler´s skippers. In turn, competition between coastal fisherman lead to less dissemination of more detailed charts.

The information analyzed off Vancouver Island help to explain possible reasons for gear loss experienced by fishers and serve as a reminder that even the most experienced of operators can easily misinterpret acoustic sign. The work illustrates that having even a limited knowledge of bottom structures can help in survey design and may provide a strong warning against conducting fishing operations in regions of uncertainty.

Results emphasise the need to map and preview study sites and to incorporate all data sources into the scrutinising process especially when near boundary detection is attempted. In the absence of high resolution bathymetric data, a single pass with a downward looking multibeam sonar, or several closely spaced transects with an echosounder could map a narrow survey corridor and assess acoustic suitability of the area. Once identified, the corridors could be revisited on subsequent surveys.

This approach will be valuable for mounting assessment surveys for near bottom fishes in areas with difficult bottom structure. Imaging of acoustic data in 3D is an effective tool for examining target distributions (Greene et al. 1998) and shoal behaviour (Stanley et al. 2002).

This technique is useful for mapping habitat and visualising echo returns in relation to bottom signal, side lobe echoes, and beam characteristics. Results offer a greater understanding of echo source and improve interpretation of the acoustic returns.

However, additional considerations such as narrower beamwidth, reduced range from transducer to target, and transducer orientation perpendicular to the bottom structure are important factors for improving bottom definition and near bottom detection in areas characterised by steep slopes, pinnacles, or chimney-like formations.

More detailed information on the shape and acoustic properties of boundaries is need to develop scattering models. This information will improve our ability to identify and separate target and bottom echoes and will yield estimates of potential habitat that remains undetected. The question would arise, What data and why?

The use of the acoustics method for the quantification of fish biomass release a great amount of information that could be extracted from the echograms, as the school´s size, shape, structure, position and the sorrounding environment (Reid et al. 2000).

The type of parameter can be classified into five different groups:

1. **Positional**--- temporal, geographical and vertical (i.e., position in the water column).
2. **Morphometric**--- shape, etc.
3. **Energetic**--- total acoustic energy reflected and indices of internal school variation.
4. **Environmental**--- water depth, temperature, hydrographic and physical (seabed structure and topography).
5. **Biological**--- species, age structure, other species, etc.

Each type of parameter is relevant to understanding the school and its relationship to its local environment. Besides the general parameter, morphometry and topography seem to be of relevant importance. Both are expression of how variable the seabed appears.

The information from different sources enables to draw up a summarized list of frequently asked data which can be improved in the future (Reid et al. 2000).

1. **Bathymetry**: Good quality data, reliable and precise with a quality indicator
2. **Artificial obstruction**: wreck, objects, debris, pipelines, cables
3. **Nature of the seabed**: Sand, shell, gravel, rocks, mud
4. **Regulations**: Restricted areas, EEZ limits, limits at sea:natural frontiers.
5. **Deep Currents**, main direction and speed.

All these data would be useful for planning tows safely, avoiding seabed obstructions, prospecting new potential areas and positioning precisely the fishing device on the places where the fish may be founded. Bathymetry, sounding are useful but not sufficient. Skippers need that pinnacles, ridges, cliff edges, pronounced slopes, sedimentologic data or some specific types are brought to the fore.

Fishermen want products that can show directly what they are looking for. That means data compiled and presented in the best way.

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