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Characteristics and Distribution of Coastal Fish Schools around Robinson Crusoe island (Juan Fernandez Archipelago, Chile)

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***Abstract*— The Juan Fernandez archipelago is located along an east-west ridge in the southeastern Pacific Ocean, off the coast of central Chile. It consists of three oceanic islands organized into two subsystems: Alejandro Selkirk (AS), Robinson Crusoe and Santa Clara (RC-SC). The marine ecosystem of this island complex is considered a high priority of national and international conservation, due to the high endemism of species and importance for the local economy. Likewise, biological and fisheries studies of coastal fish resources have been a focus of interest during the last decade. The present work aims at characterizing fish schools assemblages through of a hydroacoustic survey developed during the austral spring of 2015 around the RC-SC. Acoustic observations were collected using SIMRAD EK-60 scientific echo sounders and stereo video cameras mounted on a ROV. Surface (S), medium (M), bottom (F) and columnar (C) schools were identified, with S-type schools being the scarcest. The horizontal distribution of the schools was mostly coastal, comprised by the 20 and 180 m isobaths, organized mostly around rocky reefs. We observed multispecies fish assemblages organize mostly in columnar schools off the rocky reefs (Juan Fernandez morwong, pink maomao, calantias, bigeye, Juan Fernandez trevally, sea sweep, amberjack, rosefish and redbanded perch). The diurnal-nocturnal observations indicated that the schools are highly aggregated during daytime, therefore future acoustic surveys shall be conducted during the day, considering factors as availability, accessibility and logistics. The multispecies nature of the schools requires a careful sampling design of optical system deployment, to avoid biases in quantitative species proportion estimates. Regarding the above, a distribution model is proposed for fishing grounds and distribution of schools, which also contributes to laying the foundations of population assessment programs that require further exploration, supporting the sustainable and responsible exploitation of resources of the RC-SC subsystem.**

Keywords*— Juan Fernández archipelago, fish aggregations, acoustic survey, stereo cameras Juan Fernandez morwong

I. INTRODUCTION

The Juan Fernández archipelago (JFA) is located in the Pacific Ocean, to 667 km west off the eastern coast of South America [1]. It is constituted by three oceanic islands, organized in two subsystems: Alexander Selkirk (AS), Robinson Crusoe and Santa Clara (RC-SC; [2]). Historically the community residing in this island complex has oriented its socio-economic development based on the exploitation of

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benthic marine resources. An emblematic case is the extraction of the endemic Juan Fernández rock lobster (*Jasus frontalis*) consolidated as main activity around the islands of JFA and Islas Desventuradas 'ID' (780 km north off the JFA [3] [4] [5]). The lobster fishery has favorable historical precedents, biological and fishing [3] [6], which has led to the acquisition and recognition of Marine Stewardship Council (MSC) certification in January 2015 for RC-SC, AS and ID subsystems [4] [5]. In a relevant and complementary way, this recognition promotes the planning , implementation and development of programs of study of the species associated with the fishery for the purpose of obtain a greater biological background and maintain the certification, since this and in a smaller dimension the fishery of the golden crab (*Chaceon chilensis*) demand the extraction of high volumes of coastal fish resources, mainly used as baits and secondarily for direct human consumption [3] [6] [7] [8].

Of coastal species, the demersal and endemic Juan Fernández morwong (*Nemadactylus gayi*, Kner 1865) distributed around Juan Fernández and Islas Desventuradas archipelagos [9] represents a central axis in the capture of bait in each of the islands [6] [8] [10] [11], however , the fishing effort is larger and continuous during the year in the RC-SC subsystem [1] [4] [5] [6]. Despite the importance of this and other species, scientific information is non-existent, scarce or insufficient, especially in aspects of distribution. [4] On the other hand, the study of conservation and sustainable use of marine natural resources demands knowledge about fundamental ecological aspects.

Legal bodies, scientific community and local fishermen recognize the fragility of this ecosystem, so that in order to obtain fish resources of interest, fishermen have established internal rules that prohibit the use of trawls in order to avoid deterioration of the seabed and the disproportionate extraction of its endemic fauna [11] [12] [13]. Because of the above, the study of coastal fish resources is subject to the use of non-invasive, non-destructive or selective methodology.

The present work aims to characterize the schools of the RC-SC subsystem, using hydroacoustic and optical methodology [14] [15] with emphasis on the Juan Fernández morwong (*N. gayi*), with the purpose of having a greater ecological background on the vertical, horizontal, diurnal-nocturnal distribution and identification of the species that compose them.

II. Materials and Methods

A. Design of prospecting

Hydroacoustic studies were located in the Juan Fernández archipelago, Chile (33° 77' S, 78° 49' W and 33° 46' S, 80° 46' W), precisely in the RC-SC subsystem (Fig. 1) from 5th November through 9th, 2015 (austral spring). The sampling design included: (i) spatial dimensions from information collected from species associated with the JF lobster fishery (distribution and yield); and (ii) semi-structured interviews to local fishermen [4]. The design was zig-zag type to the coast covering a bathymetric range from ~ 8 m to 250-300 m depth. Three macrozones were prospected, recognized from the name of strategic sectors of fishing and smaller spatial scale: Puerto Inglés (in duplicate), Tres Puntas and El Verdugo-Playa Larga (TABLE I, Fig. 2).

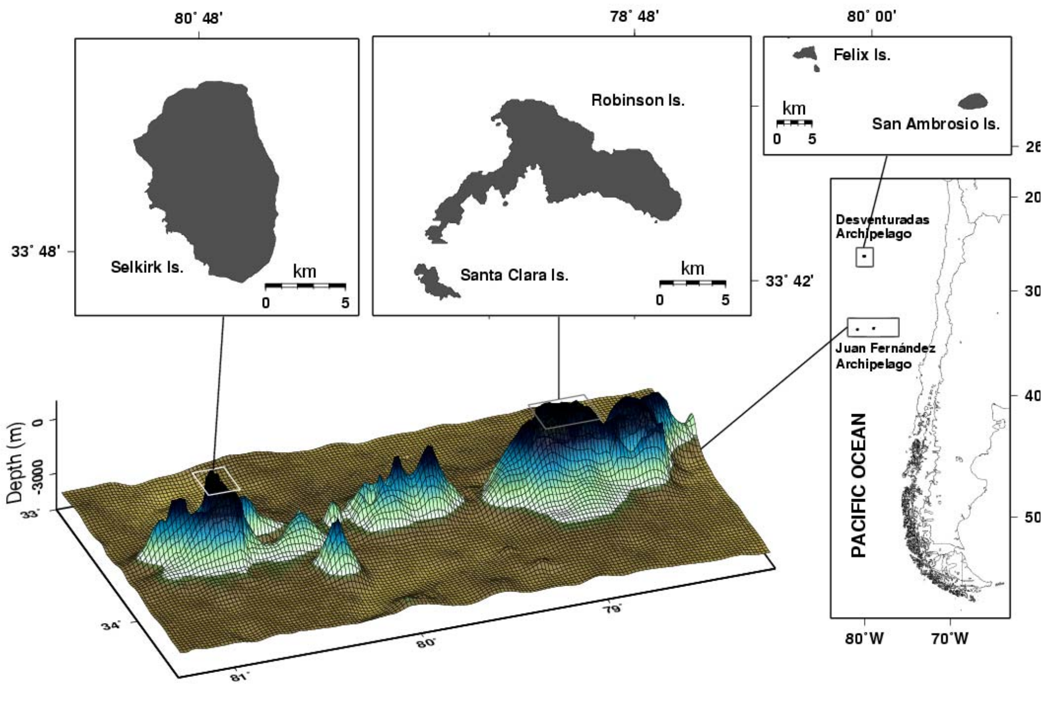

Fig. 1. Geographic location of the Juan Fernández archipelago along an east-west ridge in the southeastern Pacific Ocean, off the coast of central Chile. Subsystems AS and RC-SC.

TABLE I Cruise Schedule.

Day	Activitie
1 (5th nov. 2015)	Equipment tests in Bahía Cumberland
2 (6th nov. 2015)	Puerto Inglés round trip
3 (7th nov. 2015)	Tres Puntas track
4 (8th nov. 2015)	El Verdugo-Playa Larga track
5 (9th nov. 2015)	Puerto Ingles track (revisited)

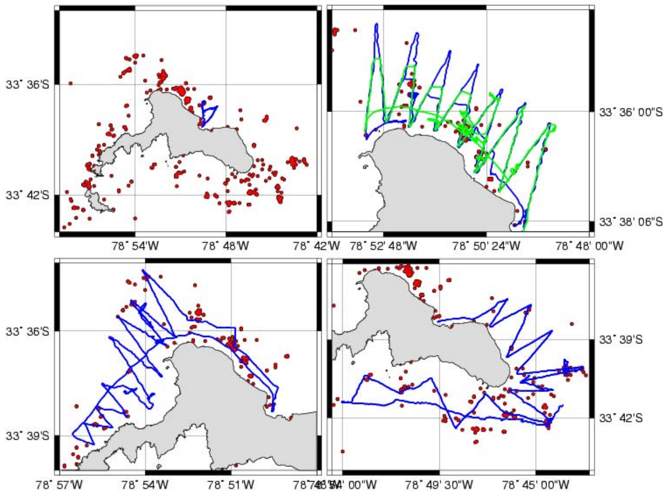

Fig. 2. Hydroacoustic survey track around the RC-SC subsystem. Day 1: equipment tests (upper left panel). Day 2: Puerto Inglés round trip (upper right panel). Day 3: Tres Puntas (lower left panel). Day 4: El Verdugo and Playa Larga (lower right panel). Day 5: Puerto Inglés revisited (upper right panel).

B. *Boad and equipment*

The use of scientific hydroacoustic equipment in coastal and oceanic systems for the study of marine resources requires a safe and reliable work platform. The vessel selected to develop this study was the L/M 'Abbe Muller', deploying a stable hydrodynamic aluminum system laterally attached to the starboard side of the vessel. This system contained two SIMRAD EK60 scientific echo sounders, 38 KHz and 120 KHz. The hydroacoustic records (* *.raw*) originated from the joint performance of both echo sounders, which in turn respond to the observation of schools, were continuously georeferenced along the track. The content was stored for processing using commercial *EchoView 7.1* software. While the optical system featured a remotely operated FOII ROV. Next to the ROV was coupled a system of two cameras of high definition (Go Pro Hero 3+), protected in a sealed system resistant to high depths. The information collected came from the immersions made by the optical system described above, on discrete schools of considerable importance as they were observed by hydroacoustic techniques. The post processing of the obtained videos made it possible the identification of species, according to Mann (1954), Pequeño & Sáez (2000), Dyer & Westneat (2010) and field guides used in the JF lobster fishery [5].

C. *Characterization*

In order to achieve an adequate representation of the site studied and to avoid unnecessary sampling effort, transects were arranged on historic fishing grounds. The vertical distribution of the schools was according to the depth in which they were located in the water column. The schools were typified as surface (S), middle (M), bottom (F) and columnar (C), while the horizontal distribution was made according to the bathymetric depth to which they were observed through hydroacoustic records. Because of inclement weather, the distribution characteristics, both vertical and horizontal, were limited to the macrozone of Puerto Inglés (Novermber 6th and 9th).

Identification hauls allowed to obtain the species composition of the schools. With this information it was decided to dispense with S-type and -M schools, concentrating more analysis effort on the F-type and the M-type schools, both associated with *N. gayi*.

The diurnal-nocturnal distribution was characterized according to the spatial changes experienced during the day and night by the conspicuous school in "El Verdugo" (Fig. 3). This school was prospected with the ROV during the day, identifying large quantities of Juan Fernandez morwong. The spatial-temporal changes were observed during November 8th, prior conducting a guide survey between 16:01 and 16:10 hrs. The site was revisited during the sunset and darkness period.

III. Results

A. *Vertical distribution of schools*

During the cruise, the schools observed in November 6th and 9th were classified into four types: surface (S), medium (M), bottom (F) and columnar (C; Fig. 4). The least observed was the S-type (Fig. 5 and Fig. 6). The schools identified on November 6th were mostly grouped between 90 and 150 m deep, with the most abundant category being C-type, with 10 schools between 120 and 130 m. M-type schools were not present within the first 70 m depth, however at 130 m four of these aggregations were identified. In November 9th, the Puerto Inglés macrozone was again prospected (same as November 6th). More than 4 C-type schools were observed between the strata of 20 to 30 and 50 to 60 m, but most were above 60 m (Fig. 6). The F-type schools were found in greater numbers over 60 m, reaching a maximum of 100 m depth (Fig. 6). In this case, S-type and M-schools were observed, the latter being mostly grouped between the 90 and 130 m depth (Fig. 6).

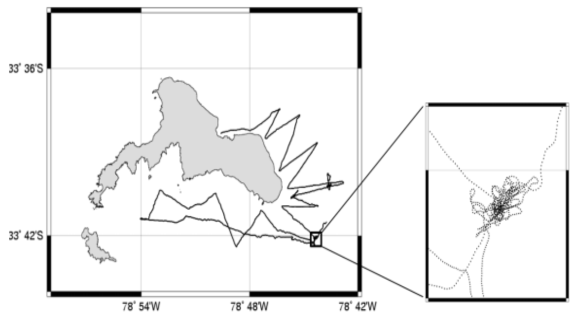

Fig. 3. Sector El Verdugo. Site of intensification of hydroacoustic sampling carried out in order to evaluate the spatial changes in the diurnal-nocturnal scale.

B. Horizontal distribution of schools

The horizontal distribution of schools during November 6th and 9th was mostly coastal, located between 20 and 180 m isobaths (Fig. 5 and Fig. 6). On November 6th, the cumulative proportion of the number of schools indicates that the low (at a lower depth) of the 95 m was grouped 50% of C-type and -F schools, while –M groupings were found under 120 m of depth (Fig. 9). In addition, in areas inferior to 140 m more than 80% of the observed schools were concentrated for the 3 types of aggregations (Fig. 9). For November 9th, it is observed that 50% of M-type and -F schools are grouped under 100 m depth, unlike C-type schools where 50% of observations are under 60 m (Fig. 10). About 80% of the four types of schools were observed at depths less than 130 m (Fig. 10).

C. Identification of species

Videos from 18 ROV dives performed in 5 days of actual work were analyzed. Juan Fernandez morwong individuals were identified near the seabed and associated with F-type schools, while in C-type schools it was observed in the lower zone (Fig. 7). The information of the recordings allowed to see the composition of the registered schools, allowing the identification of 8 other species: pink maomao (*Caprodon longimanus*), calantias (*Callanthias platei*), bigeye (sp.), Juan Fernandez trevally (*Pseudocaranx chilensis*), sea sweep (*Scorpis chilensis*), amberjack (*Seriola lalandi*), rosefish (*Helicolenus lengerichi*) and redbanded perch (*Hypoplectrodes semicinctum*; Fig. 7 and Fig. 8). The maximum depth of immersion of the ROV was at 200 m where no school was found.

D. Diurnal-nocturnal distribution

Space-time changes were evaluated on a school of high importance, fishing and acoustic density [4; 5], recognized as El Verdugo. A series of images were recorded from the echograms each time intercepts the secondary transects (back) and the guide transect (going). The recording occurred as the day passed on a scale of hours. In Fig. 11 the left panel indicates the position and direction of the transect from which each echogram was lifted, while in the right panel the state of the school is observed. During the hours of the day they were C-type aggregations, being able to be extended and very compact (top panel, Fig. 11). These were highly dense and were found in the last fifth of the water column, covering about 30-40 m of vertical extension on the bottom. As got dark the aggregations, they experienced vertical and horizontal dispersion (bottom panel, Fig. 11).

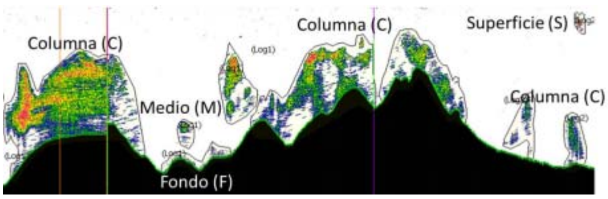

Fig. 4. Typification of observed schools according to vertical distribution.

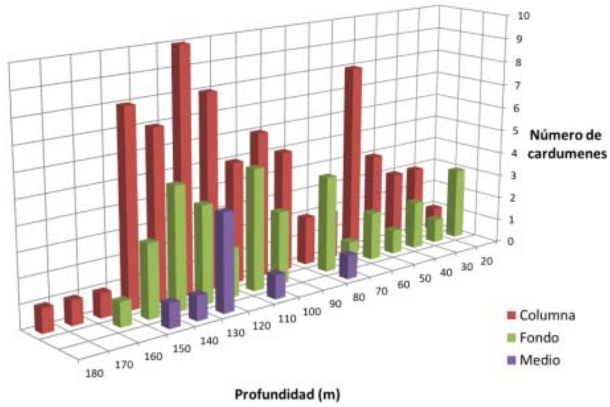

Fig. 5. Number of schools per class and depth stratum, identified on November 6th.

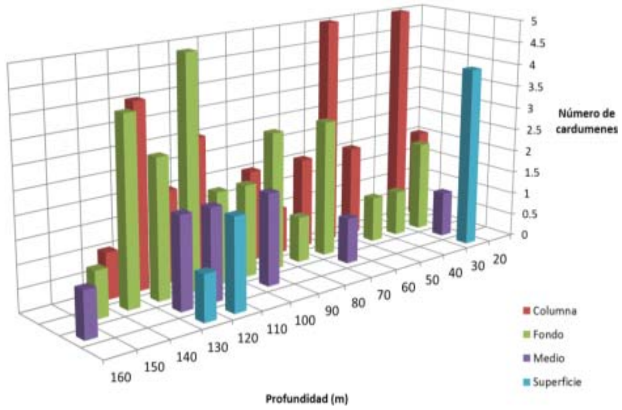

Fig. 6. Number of schools found by class and depth stratum for November 9th.

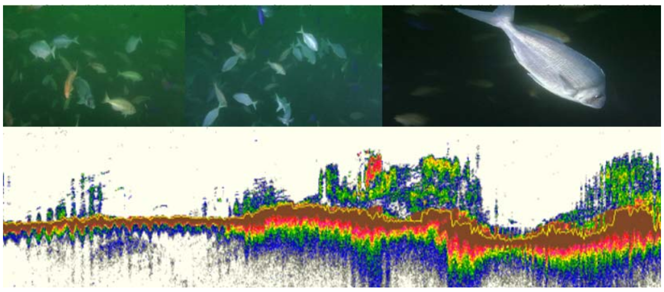

Fig. 7. Multispecies schools type-F and -C attributed to *N. gayi* (Juan Fernandez morwong).

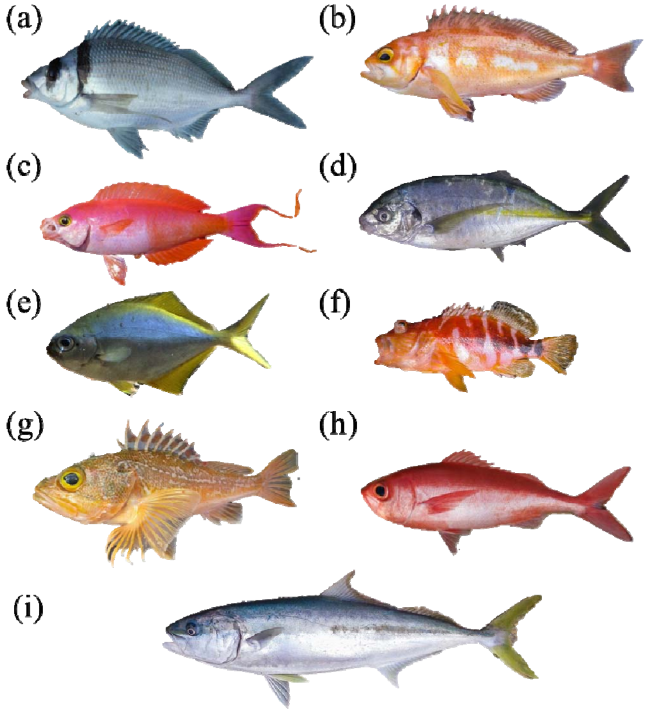

Fig. 8. Species contained within the C-type and -F schools. Juan Fernandez morwong (a), pink maomao (b), calantias (c), Juan Fernandez trevally (d), sea sweep (e), rosefish (f), redbanded perch (g), bigeye (h) and amberjack (i).

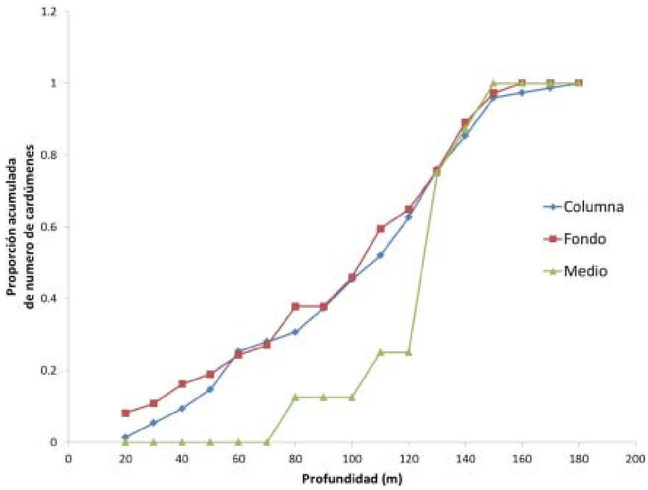

Fig.9. Cumulative proportion of school type per depth stratum during November 6th.

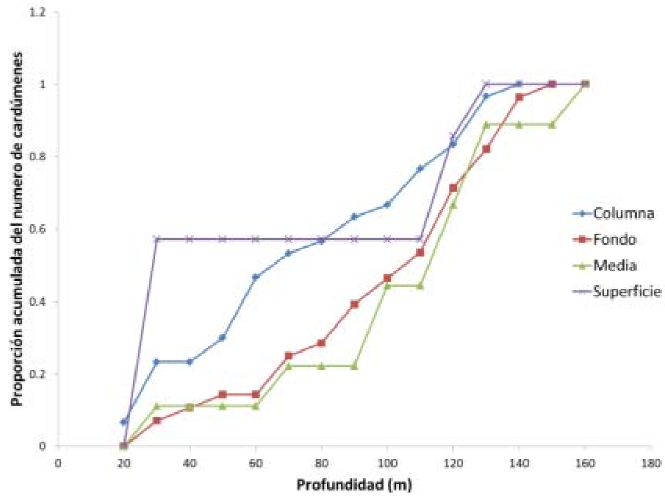

Fig. 10. Cumulative proportion of school type per depth stratum during November 9th

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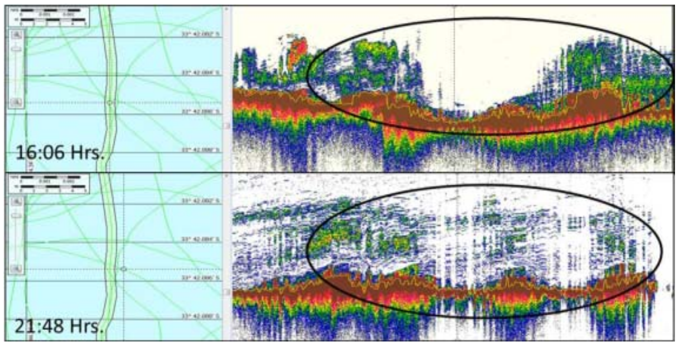

Fig. 11. Spatial change of schools as night falls. Comparison between two coincident echograms of Verdugo sector. Extended and compact school (upper panel). School dispersion vertically and horizontally (lower panel)

IV. Discussion

Although the development of the hydroacoustic theme of this work included the deployment of two multibeam transducers of 38 KHz and 120 KHz, the post processed results derived from the performance of the 38 KHz transducer. This is due to the optimal deployment in the detection of schools and not individual targets [16].

According to the results of vertical distribution, S-type schools, -M, -F and -C were identified. It is emphasized that the species *N. gayi* (Juan Fernandez morwong) was mostly observed on the horizontal plane of the seafloor generating interconnections of small scale columns. This was characterized according to the immersion performed by ROV technology on the El Verdugo sector. Likewise, through immersions in other sites, the composition of the schools where the species of interest was observed was identified. Thus, multispecies schools F-type and to a greater extent C-type were associated with 8 other species (pink maomao (*C. longimanus*), calantias (*C. platei*), bigeye (sp.), Juan Fernandez trevally (*P. chilensis*), sea sweep (*S. chilensis*), amberjack (*S. lalandi*), rosefish (*H. lengerichi*) and redbanded perch (*H. semicinctum* ; [2] [5] [9] [11]). Juan Fernandez morwong aggregations were observed in F-type schools and located in the lower fraction of C-type schools, presenting in both cases a vertical extension of 30-40 m distance from the bottom . The latter is concomitant with the empirical information provided by the same fishers of the RC-SC subsystem [4] [5] and also coincides with the vertical extension of the vertical spinel, fishing gear used in the catch of Juan Fernandez morwong [4] [6] [7] [8] [17].

Regarding the horizontal distribution, the records indicate that the schools would not exceed the 180 m isobath, which is in agreement with the fishing activity or fishing grounds of Juan Fernandez morwong, since this would not surpass the 160-180 m isobaths [4]. At depths greater than 180 m the schools were very scarce and with increasing depth, they decreased in acoustic density and diversity [4].

The study of the spatial changes according to the temporal diurnal-nocturnal scale on the El Verdugo fishery ground indicates that the aggregations are highly concentrated and compact during the day, located in the last fifth of the water column and presenting an approximate vertical extension of 30-40 m from the seabed. In that context, for detailed studies on the resource of interest, it is suggested to deploy optical, acoustic, as well as biological samples, during the day considering availability, accessibility and logistics. It is essential to have clear visibility of the environment, since during the lobster fishing season (October 1th – May 15th; D.S. (MINAGRI) Nº 223 of 1963 and D.S. (MINECON) Nº 311 of 2004; [3] [18]) because a great number of traps are deployed around the islands, which could cause entanglement in the boat and optical systems.

The performance of surveys, combining acoustic and optical systems [14] [15] [19] [20] [21], will require identification sampling that allow an efficient vertical and horizontal deployment to avoid overestimation caused by double registration . This implies obtaining reliable estimates of the percentage composition and biological information of the size structures (stereometry) of the species contained in the prospected schools [14] [15] [22] [2] [3] [24] [25] [29]. This latter, together with estimates of target strength [26] [27] will make it possible to weight the "NASC " acoustic backscatter coefficient for each identified species . Thus , greater quantitative records regarding the fish populations housed in the RC-SC subsystem will be available.

According to information documented in this research, a distribution model is proposed regarding fishing grounds (Fig. 12; [4]) and distribution of the schools. To do so, consider (i) ship days, (ii) sampling design, and (iii) methodology. The seasonal component indicates that the appropriate period should be outside the lobster fishing season, which concerns the May-September period. The diurnal-nocturnal component indicates that hydroacoustic, optical and biological studies should be performed during the day, while the horizontal distribution suggests prospecting polygons that do not exceed 200 m depth, where transects are mostly superimposed on historical fishing grounds, for which a 5 zone track is proposed. This division considers to a certain extent climatic aspects, sea conditions and logistics (Fig. 12; [4]). The TABLE II summarizes the distances to be covered in each of the five acoustic tracks, considering a total acoustic survey distance of 160 mn. The longest tracks are 42 mn, these could be covered in 6 hours of navigation considering a prospecting speed of 5 knots, not including the time required to make the identification sampling.

It is suggested to make the research hauls with a camera drag system [14] [15] [24] [28] [29].

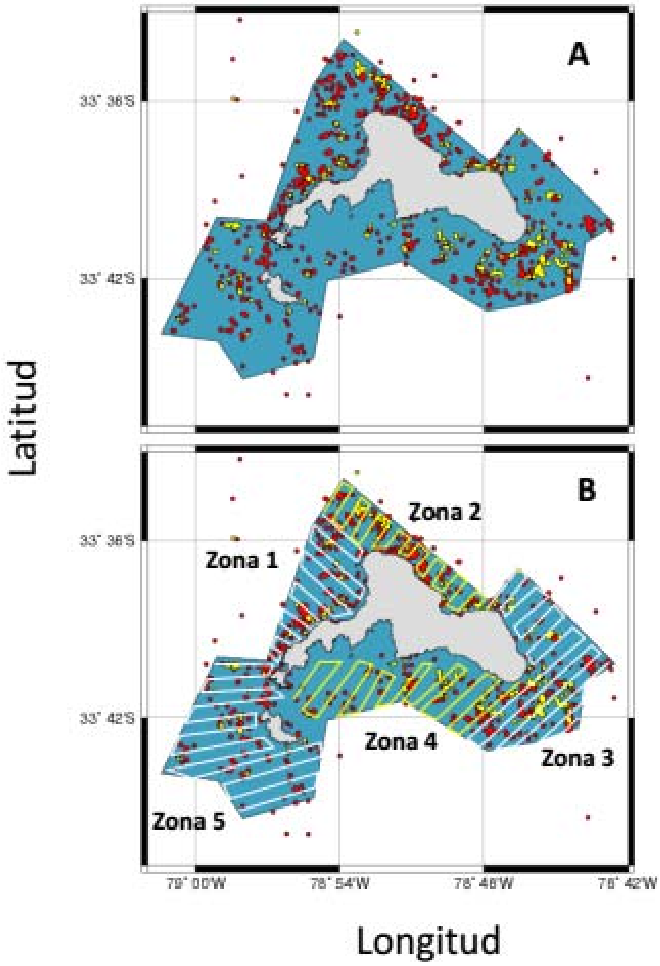

Fig. 12. Spatial distribution of Juan Fernandez morwong fishery in the RC-SC subsystem and polygon that demarcates the proposed prospecting area (A). Scheme with five acoustic tracks for the prospecting area, zones 1-5 (B).

TABLE II Total distances (in nautical miles) of the acoustic tracks in each studio zone

Zone	Distance (mn)
1	22.9
2	21.2
3	41.5
4	32.3
5	42.1

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