SPRFMO

5th Meeting of the Scientific Committee

Shanghai, China, 23 - 28 September 2017

SC5-SQ07_rev1

Distribution, size composition, possible stock structure and the assessment of Jumbo flying squid off Peru

J. Arguelles, J. Csirke, L. Mariategui & R. Castillo (IMARPE)

Distribution, size composition, possible stock structure and the assessment of jumbo flying squid (*Dosidicus gigas*) off Peru

by

Juan Arguelles, Jorge Csirke, Luis Mariategui and Ramiro Castillo
Instituto del Mar del Peru (IMARPE), Callao, Peru

SUMMARY

Recent studies provide some insights into the slight differences in the age or size of sexual maturity and the main distribution areas of jumbo flying squid (*Dosidicus gigas*) which suggests that there are least three strains, groups or population subunits of this species in the Southeast Pacific, and information is provided that shows that all three groups are or have been present off Peru. It is noted that this, added to the extended distribution and wide extension of the fishing grounds, poses serious challenges with regards to the assessment and the management of fisheries both, for Peru in its jurisdictional waters and for the SPRFMO in international waters, within the area of application of the SPRFMO Convention. It is suggested that the SPRFMO Scientific Committee needs to look into the matter of which stock assessment methods can be best used, and which might be the best applicable management options and strategies to eventually be applied within the Convention area. Peru is routinely using hydro-acoustics and more recently also surplus production modelling for the assessment of jumbo flying squid in its jurisdictional waters, and the main constrains, advantages and disadvantages of both methods are discussed in view that the Scientific Committee may wish to consider their possible use for the monitoring and assessment of jumbo flying squid in the Convention area. Particular warnings are made against relying solely on surplus production modelling jumbo flying squid, since it is very unlikely that the assumptions of this type of indirect methods could be properly met, nor their limitations overcome with this species and type of fishery. A series of research activities, much of them already discussed and considered in earlier meetings are revisited stressing the need for their timely implementation by the Committee.

1. INTRODUCTION

Jumbo flying squid (*Dosidicus gigas*) is widely distributed along the Southeast Pacific, where it supports important local fisheries in national jurisdictional waters and also important distant-water fisheries in international waters, off Peru and Chile. As noted in Csirke *et al* (2015), off Peru jumbo flying squid is found in high abundance along the whole coast, at distances ranging from 10 to more than 500 nm from the coastline. Performs diel vertical migrations from 0 to more than 650 m depth, seasonal inshore-offshore ontogenetic migrations, and occasional latitudinal migrations that could reach several hundred miles, mostly associated with the advance of abnormally warm or abnormally cold environmental conditions in some years. Younger and/or smaller jumbo flying squids predominate in oceanic waters, while larger jumbo flying squids are more neritic. They have some reproductive activity all year round but its main reproductive season is from July to February, with peaks between October and January.

Slight differences in the age or size of sexual maturity and main distribution areas suggests that there are least three strains, groups or population subunits of jumbo flying squid (*D. gigas*) inhabiting the Southeast Pacific (Nesis, 1983; Nigmatullin *et al*, 2001), and all three seem to be present off Peru (Arguelles *et al*, 2008; Arguelles and Tafur, 2010; Arkhipkin *et al*, 2014). This, added to the extended distribution and wide extension of the fishing grounds, poses serious challenges with regards to the assessment and the management of fisheries both, for Peru in its jurisdictional waters and for the South Pacific Regional Fisheries Management Organisation (SPRFMO) in international waters, within the area of application of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean (the SPRFMO Convention).

It is expected that this 5th meeting of the Scientific Committee of the SPRFMO will look into these matters in trying determine how to best tackle the challenges associated with the proper monitoring, assessment and eventual management of the jumbo flying squid in the SPRFMO Convention area fisheries. And this paper is intended to assist in these discussions by expanding or updating some of the information on Peruvian squid fisheries and research activities provided in earlier contributions to this Committee, such as those in Csirke *et al* (2015) and Arguelles *et al* (2016).

2. GENERAL DISTRIBUTION

Although jumbo flying squid can be found along the whole Peruvian coast, the main fishing areas of the industrial fleet that operated under Peruvian license off Peru between 1999 and 2011 were found mostly within 150nm, with some catches as far as 450nm, in two general areas, one to the north of Huarmey (10°S) and the other to the south of Callao (10°S) (Figure 1). During this period, the best jumbo flying squid concentrations and the highest CPUE values (higher than 6 tonnes/vessels/hour) were found within 80 miles from the coast in summer, within 100 miles in fall and within 130 miles in winter and spring.

Since no license for industrial fishing vessels to participate in the industrial fishery for jumbo flying squid were granted or renewed beyond December 2011, since 2012 all catches of jumbo flying squid in Peruvian jurisdictional waters come from the local artisanal fishery.

The local artisanal fleet started to increase its catches of jumbo flying squid since 1999. At first, given their limited autonomy, the main fishing grounds of the artisanal fleet were located close to the coast, mostly within 40 nm from the coastline, and closer to their port

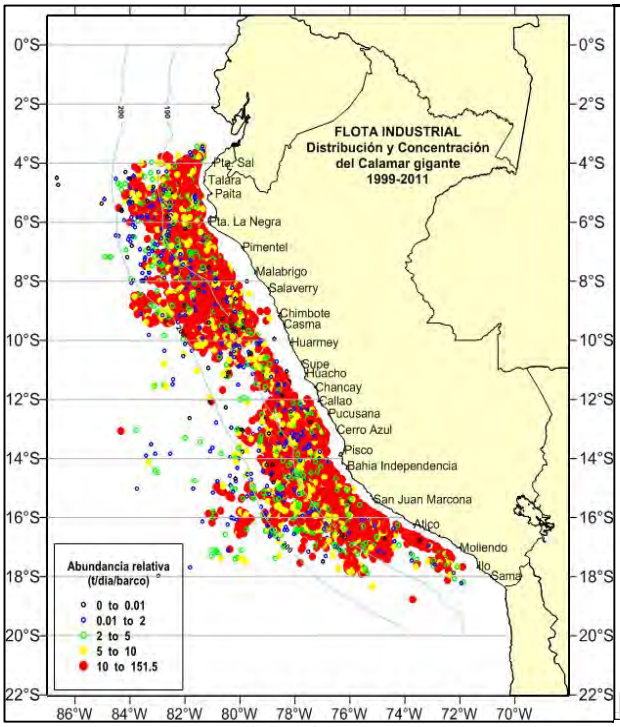

Figure 1.- General distribution and CPUE index (tonnes/vessel/day) of the main fishing sites of jumbo flying squid (*Dosidicus gigas*) by the industrial jigging fleet that operated off Peru between 1999 and 2011

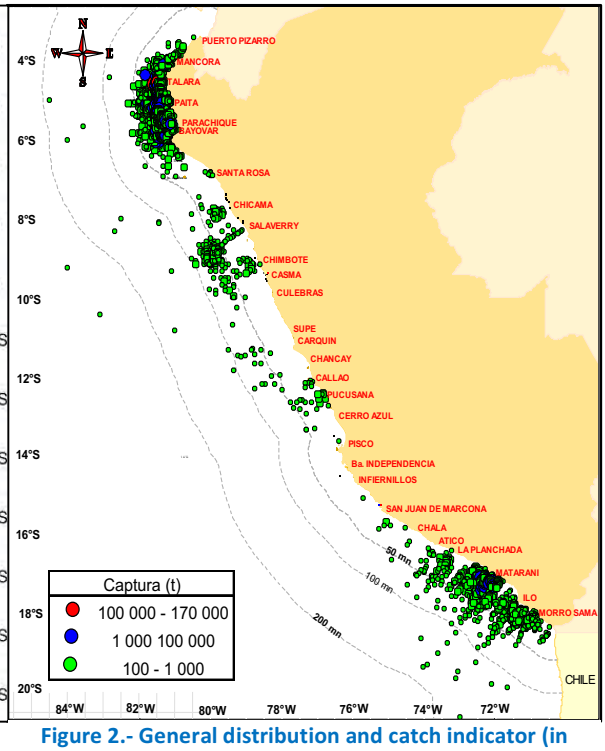

Figure 2.- General distribution and catch indicator (in tonnes) of the main fishing sites of jumbo flying squid (*Dosidicus gigas*) by the Peruvian artisanal jigging fleet, Peru, 1997 to 2014

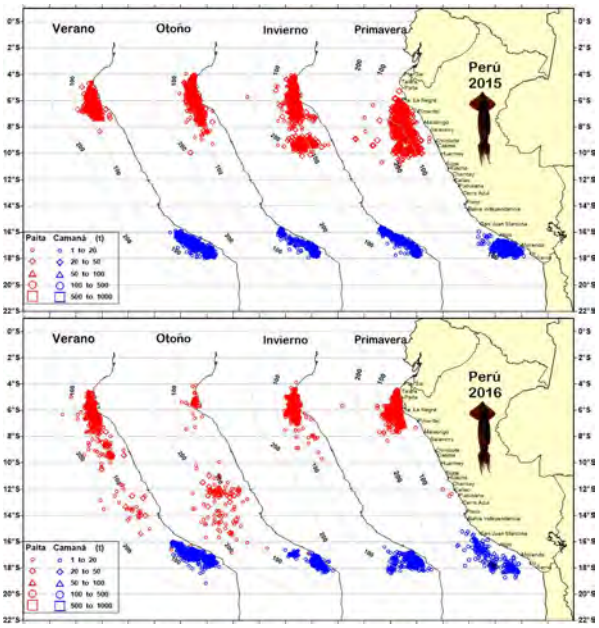

Figure 3.- General distribution and catch indicator (in tonnes) of the main fishing sites of jumbo flying squid (*Dosidicus gigas*) by the Peruvian artisanal jigging fleet, Peru, by season, years 2015 and 2016

or artisanal landing sites in two general areas, one to the north of Bayobar (05°50'S) and the other to the south of Matarani (17°00') (Csirke *et al*, 2015). Between 1999 and 2008 the local artisanal fishery developed rapidly, with more than a six-fold increase in the number of vessels and almost a ten-fold increase in catches, that went from 56,000 t in 1999 to 533,000 t in 2008 (95.4% of Peru total). During the following years, the general distribution area of the main fishing grounds expanded both off-shore as well as along the coast, to include areas to the north of Casma (09°30'S) and to the south of Atico (16°00'S) (Figure 2).

The fishing areas of the Peruvian artisanal fleet fishing for jumbo flying squid has continued to expand in 2015 and 2016, both offshore and along the coast, although at a slower pace than in previous years (Figure 3). It now includes areas to the north of Supe (10°48'S), to the south of San Juan de Marcona (15°20'S), and offshore from Callao (12°00'S).

3. SIZE COMPOSITION AND POSSIBLE STOCK STRUCTURE

The presence of three strains, groups or possible population subunits of jumbo flying squid in the Southeast Pacific proposed by Nigmatullin *et al* (2001), which could be distinguished by their general distribution area and the size (mantle length) at which they reach gonadal maturity, seems now confirmed for the northern Humboldt current system off Peru. As pointed out by Nigmatullin *et al*, this division into three groups or population subunits stems from the observation that there is a group of jumbo flying squids that reach maturity at small sizes (males between 130 and 260 mm - females between 140 and 340 mm) and are found predominantly near the equatorial line; whereas there are those that reach maturity at medium sizes (males between 240 and 420 mm - females

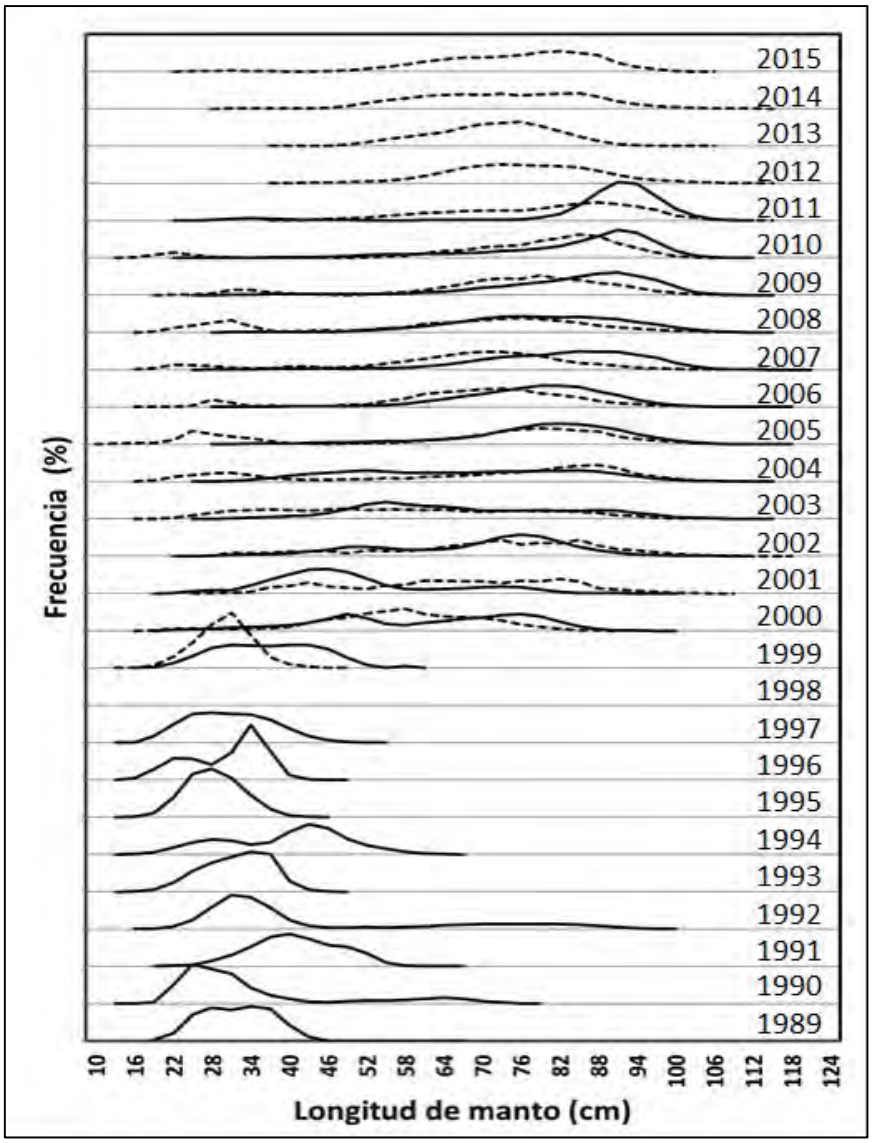

Figure 4.- Length frequency distribution of jumbo slying squid (*Dosidicus gigas*) caught by the Peruvian artisanal fleet (broken lines) and by the industrial jigger fleet (solid lines), by year, years 1989 to 2015

between 280 and 600 mm) and are found throughout most of the species distribution range except for higher latitudes; while there are those that mature at larger sizes (males larger than 400-500 mm - females larger than 550 to 650 mm and eventually 1000 mm and over) and used to be found to the south of 10°S, flowing sometimes to north into Ecuador in cold streams of the Peruvian coastal current. Although, as explained bellow, the expanded northern distribution of this larger size group appears to be more of a constant since 2001.

Arguelles and Taipe (in press) have made an extensive analysis of length frequency and gonadal maturity data of jumbo flying squid off Peru since 1958, including from stomach contents in whales (for 1958-1962) and from scientific surveys and exploratory and commercial fishing with jiggers from 1979 to 2015. Their findings suggest that off Peru there has been a significant shift in the length frequency distribution and the length at gonadal maturity through time. With a predominance of large mature jumbo flying squids with mean mantle size of 73 cm in 1958-1962, smaller and/or earlier maturing squids in the 1970s and 1980s, predominance of mid and small sizes in the 1990s, and predominance of large and/or late maturing squids from 2000 to date. The presence of various size groups and the shift in the dominant size group through time is clearly shown in the mantle length frequency distributions of jumbo flying squid caught by the industrial and the artisanal fleets between 1989 and 2015 in Figure 4, and the sizes of mature females in Figure 5.

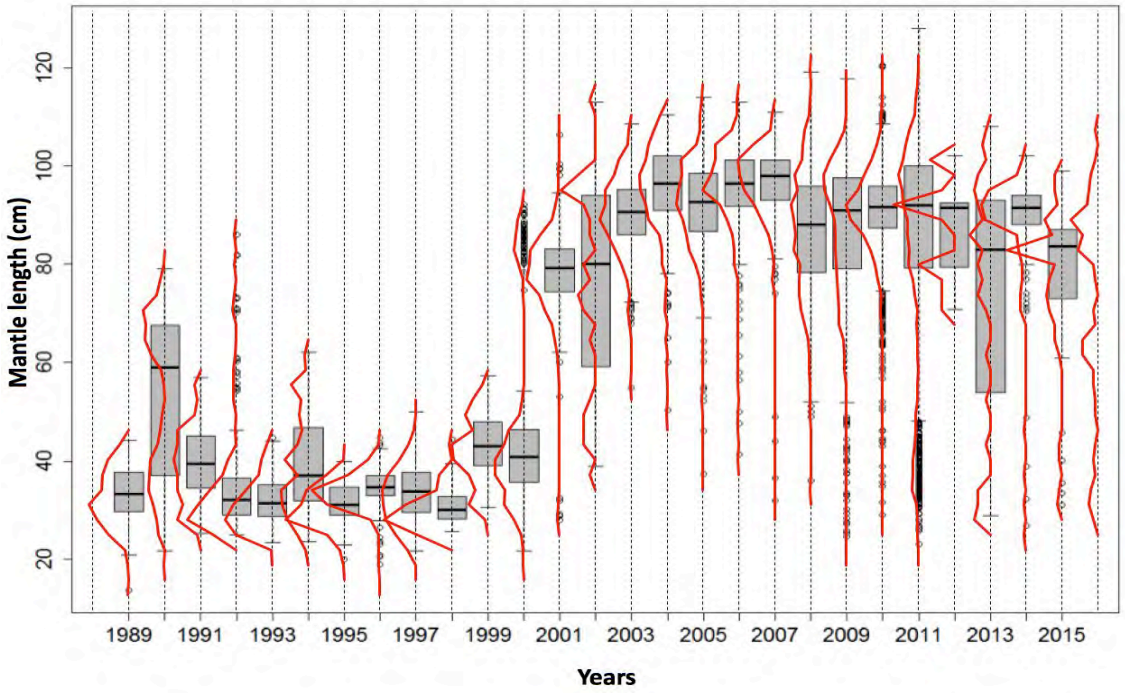

Figure 5.- Annual mantle length frequency distribution of mature females of jumbo flying squid (*Dosidicus gigas*) in Peruvian waters in % (red lines) and variation of their Boxplot values (in black and grey) by year, 1989 to 2016 (adapted from Arguelles and Taipe, in press)

The analyses by Arguelles and Taipe (in press) didn't show significant latitudinal changes in size at maturity, which suggest certain uniformity in the size structure within Peruvian waters, at least across latitudes. However, for recent years there were noticeable differences in length frequency distributions and length and/or age at maturity between the more coastal and the oceanic waters. They found that in the oceanic waters there is a predominance of a range of smaller and possibly younger maturing squids, while in more

coastal waters there is a predominance of larger and possibly older maturing squids. The predominance of smaller maturing jumbo flying squid in oceanic waters beyond the 200 miles from the coast is also confirmed by Liu *et al* (2013) and Li *et al* (2017), who report much smaller sizes at maturity than those found inshore, in Peruvian jurisdictional waters.

The available studies therefore seem to confirm the presence in the coastal and oceanic waters off Peru of the three groups, strains or possible stock subunits of jumbo flying squid described by Nigmatullin *et al* (2001), with some noticeable fluctuations and differences in their dominance over time and space, and also with regards to the fishing grounds and types of fleets exploiting them. The presence of these groups of jumbo flying squids that are maturing at different sizes and possibly also at different ages and time of year, that have different general distribution areas which may tend to overlap, and that are exploited by quite distinct fisheries, a coastal artisanal fishery mainly operating inshore in national jurisdictional waters and a distant-water fishery operating offshore in international waters , poses serious and interesting challenges with regards to which stock assessment methods can be best used, and which might be the best applicable management areas and strategies, particularly with regards to the SPRFMO and the Convention area. This is something on which the Scientific Committee will surely need to spend some significant time and efforts.

4. STOCK ASSESSMENT

The biomass estimations of jumbo flying squid in Peruvian jurisdictional waters have been made primarily by hydro-acoustics (Castillo and Aliaga, 2000; Castillo *et al*., 2009; Segura *et al*, 1996; IMARPE, 2015; Flores *et al*, 2016), and more recently the assessments have also included indirect methods, such as surplus production modelling (IMARPE, 2015a) which benefited from longer CPUE time series becoming available. Both methods have their advantages and disadvantages, and both are now routinely applied for assessing the jumbo flying squid stock in Peruvian waters.

The assessment and biomass estimations of jumbo flying squid off Peru using hydro-acoustics have been made on a regular basis by IMARPE since 1999, as part of its routine pelagic stock assessment surveys, which are primarily directed to assess the biomass of the Peruvian anchoveta (*Engraulis ringens*) but are designed to also provide valuable data for the assessment of other stocks. One usual constrain of this arrangement is that the acoustic surveys directed to anchoveta only need to cover the first 60 to 80 miles from the coast in summer, and the first 120 miles in winter. While it is known that jumbo flying squid has a much wider off-shore distribution. Therefore, while valid for the areas covered, these assessments using acoustic surveys are to be considered as underestimations of the real biomass of jumbo flying squid in Peruvian waters.

Another constrain is represented by the difficulties to properly identify jumbo flying squids in the acoustic records at night, when they are found in a mixed layer with smaller organisms, such as plankton and a variety mesopelagic species. During these pelagic surveys the species composition is determined with the assistance of regular samplings using a standard pelagic trawl net, which usually fails to catch and properly represent the presence of jumbo flying squids, and less so with larger squids. During surveys specifically designed for the assessment of jumbo flying squid one will normally use jiggers to ascertain their presence (and size composition) and would cover a much wider area. But all this translates into lengthier surveys, and one rapidly runs into another major constrain: funding.

In fact, an acoustic survey specifically designed to assess the biomass of jumbo flying squid with an extended offshore coverage was conducted by IMARPE during summer 2015 (IMARPE 2015), but due to time and funding constrains this only focused on the more northern and southern distribution areas of jumbo flying squid corresponding to the main fishing grounds of the local artisanal fleets, with survey profiles extending as far as 270 nm from the coast. Again, this survey provided only a partial estimate of the biomass of jumbo squid available off Peru, but presumably proved to be a better more focused assessment of the existing biomass available to the Peruvian local artisanal fleet, in or closer to their traditional fishing grounds.

One advantage of using hydro-acoustics for the assessment of jumbo flying squid is that one can use the several sound frequencies of the scientific echo-sounder (5 frequencies: 18, 38, 70, 120 and 200 kHz), which allows a better frequency response and eases the identification of the squid acoustic backscattered signals. The other great two advantages of this method are that it provides direct fisheries independent assessments, and that the assessments (of total biomass, general distribution, size compositions, etc.) can be available almost in real-time, soon after the completion of the acoustic survey.

Surplus production models are, in principle, simpler and less costly to apply. And as pointed out in Arguelles *et al* (2016), other than requiring reasonable time series of catch and fishing effort, they don't require much data or biological observations to provide usable estimates of the state and trends of the fishery and the exploited stock. Where results can be expressed as estimates of maximum sustainable yield (MSY), current biomass relative to B_{MSY}, current F relative to F_{MSY} and estimated catch that would correspond to F_{MSY} or to a multiplier of F_{MSY}, which tend to be attractive to and easy to understand by decision makers.

However, it has also been noted that this group of indirect methods rely on some stiff assumptions, such as that the catch is proportional to the stock size and the fishing effort applied, and that there is a strong density dependent effect dominating the population dynamics, implying a strong depensatory stock-recruitment relationship. Assumptions that may hardly be met in the case of the jumbo flying squid stock(s) and fisheries. In addition, these methods have some well-known limitations, such as the strong reliance on having a good contrast in the time series, with observations above and below B_{MSY}, and the inability to incorporate basic but revealing biological information on the characteristics and state of the stock(s), such as on size or age structure, body growth, sexual maturity, spawning, natural mortality, distribution area, etc.

And, last but not least, in the case of severe stock declines due to overfishing or environmental causes (or a combination of both), the surplus production models alone may not be capable of providing reasonable warnings that the assessed stock is declining or has declined. In fact, if any, such a warning will be *post-factum*, only once CPUE values have drop due to the absence of fish, or squids in this case. With the added concern that if the cause of the decline is fishery independent, the decline may go unnoticed for a while, until it is picked up by a fishery dependent decline in catches and CPUE indices. The situation may be more worrisome if we consider the natural lag-time required from the onset of a major long-lasting decline to the time an assessment of the situation can made and the required management decisions can be taken in an intergovernmental context, such as that of the SPRFMO. In a fluent and reasonably well-managed national context, the time-lag from the onset of a major long-lasting decline to the assessment and to the decision making can be reduced to a few weeks, and even a few day days, even if only to

take interim precautionary. But even in the case of a small and agile intergovernmental fisheries management organization, such as the SPRFMO, this process may take several months, and even a year. Which for a depleting stock of a short-lived species may be an undesirable long time.

In the case of Peru, the surplus production models have proven to be useful tools for the assessment and management of the fisheries, even if lately there have been some fitting problems due to the effects of recent El Niño events and the weakening of some of the model's required assumptions. But still, the surplus production model continues to provide valuable information when used in combination with the estimates derived from the application of the more direct hydro-acoustic method. It has also helped that, so far, both assessment methods have provided estimates that are compatible with the high current catches and the apparent state of under-exploitation of the jumbo flying squid in Peruvian waters. It is also noted that IMARPE's regular monitoring of various biological, environmental and fisheries related parameters have also proven of great assistance by providing almost real time information on possible changes in the structure, behavior, distribution and other characteristics of the stock and of the fishery, that are not readily captured by the hydro-acoustic surveys or by the surplus production models.

One other mayor concern with the application of these and any other stock assessment method refers to the stock structure. For jumbo flying squid, this may be a major source of concern given the evidences of the presence of at least three strains, groups or population subunits in the area. Fortunately, as explained above (section 3 and figures 3 and 4), most of the jumbo flying squid present and being caught within Peruvian jurisdictional waters since 2000 belong to the group or stock of large and late maturing jumbo flying squids. Therefore, for the time being, the issue of the three strains, groups or population subunits of jumbo flying squid remains as a major issue being kept in the back burner in the case of Peru, at least for the time being. This may not be the case for the SPRMO Convention area, and this is clearly an issue also deserving the priority attention of this Scientific Committee.

The possible use of the acoustics and surplus productions methods for the monitoring and assessment of jumbo flying squid in the Convention area will certainly be worth considering, possibly in concomitance with other suitable methods, and in so doing the Scientific Committee may wish to take into account the constrains, advantages and disadvantages already identified by IMARPE through their application (of the acoustics and surplus production methods) in Peruvian waters, taking into account amongst others, the differences in distribution, stock structure, types of fleets and monitoring and research facilities between the Peruvian jurisdictional waters and the SPRFMO Convention area.

5. RESEARCH NEEDS

Taking into account the above, and as already pointed out in Csirke *et al* (2015), Arguelles *et al* (2016) and the last two reports of the Scientific Committee, more efforts need to be made within the SPRFMO to:

- Promote, lead and/or undertake a thorough analysis to determine the most suitable stock assessment models and/or methods to be used to assess the stock or stocks of jumbo flying squid within the context of the SPRFMO;

- Promote further research on the population structure and the presence and distribution of strains, groups or population subunits of jumbo flying squid and their migration routes and intermix patterns throughout the Southeast Pacific;
- Ensure the regular monitoring and reporting on jumbo flying squid research and fishing activities in the Convention area;
- Promote, lead and/or undertake a thorough analysis to determine suitable management alternatives to be applied for jumbo flying squid in the Convention area, including the application of precautionary measures and the early introduction of regulatory fishery management measures without waiting for, and eventually prevent, the appearance of signs of population stress;
- Promote and/or undertake research directed to obtain early estimations of recruitment and timely assessment of escapement;
- Promote research on the reproductive process and the effect of environmental factors in determining the timing and the location and extension of spawning areas;
- Promote research on the effects that the depletion by fishing of potential predators of the different life-history stages of jumbo squid may have in favoring the growth and expansion of jumbo squid; and,
- Promote research on the changes in growth rate and the possible effects of changing environmental conditions.

7. BIBLIOGRAPHIC REFERENCES

Arguelles, J., Tafur, R., Taipe, A., Villegas, P., Keyl, F., Dominguez, N., Salazar, M., 2008. Size increment of jumbo flying squid *Dosidicus gigas* mature females in Peruvian waters, 1989–2004. Progress in Oceanography, 79: 308-312

Arguelles, J. & Tafur, R., 2010. New insights on the biology of the jumbo squid *Dosidicus gigas* in the Northern Humboldt Current System: size at maturity, somatic and reproductive investment. Fisheries Research 106: 185-192

Arguelles, J., J. Csirke, C. Yamashiro, L. Mariategui & R. Tafur. 2016. Notes on research needs and the type and level of detail of the data on fishing activities and fishing impacts to be required from all fleets fishing for jumbo flying squid (*Dosidicus gigas*) in the SPRFMO Convention area. Paper presented at the 4th meeting of the Scientific Committee of the SPRFMO. The Hague, Netherlands, 10-15 October 2016. SPRFMO Doc. SC-04-20: 10p (https://www.sprfmo.int/assets/Meetings/Meetings-2013-plus/SC-Meetings/4th-SC-Meeting-2016/SC04-papers/SC-04-20-Research-needs-and-level-of-detail-required-from-fleets-fishing-for-D.-gigas.pdf)

Arguelles, J. & A. Taipe. (in press). Variabilidad espacio temporal de la estructura por tallas de *Dosidicus gigas* en aguas peruanas entre 1958 y 2015. Bol. Inst. Mar Perú (in press): 15p.

Arkhipkin, A., J. Argüelles, Z. Shcherbich & C. Yamashiro. 2014. Ambient temperature influences adult size and life span in jumbo squid (*Dosidicus gigas*). Canadian Journal of Fisheries and Aquatic Sciences, 2015, 72(3): 400-409 (https://doi.org/10.1139/cjfas-2014-0386)

Castillo, R. & A. Aliaga. 2000. Distribución de los recursos pelágicos del 25 al 27 de octubre 1999. Crucero BIC Jose Olaya Balandra. Inf. Inst. Mar Perú. N°156: 37-42

Castillo, R., S. Peraltilla, A. Aliaga, M. Flores, M. Ballon, J. Calderón & M. Gutierrez. 2009. Protocolo técnico para la evaluación acústica de las áreas de distribución y abundancia de recursos pelágicos en el mar peruano. Inf. Inst. Mar Perú. Vol.32: 7-28.

Csirke, J., A. Alegre, J. Argüelles, R. Guevara-Carrasco, L. Mariátegui, M. Segura, R. Tafúr & C. Yamashiro. 2015. Main biological and fishery aspects of the jumbo squid (*Dosidicus gigas*) in the Peruvian Humboldt Current System. Paper presented at the 3rd meeting of the Scientific Committee of the SPRFMO. Port Vila, Vanuatu. 28 September - 3 October 2015. SPRFMO Doc. SC-03-27: 33p (http://www.sprfmo.int/assets/Meetings/Meetings-2013-plus/SC-Meetings/3rd-SC-Meeting-2015/Papers/SC-03-27-Biological-and-fishery-aspects-of-the-jumbo-squid-in-the-Peruvian-Humboldt-current.pdf)

Flores, O., M. Segura & A. Aliaga. 2016. Biomasa y distribución del calamar gigante (*Dosidicus gigas*) en el mar peruano aplicando el método hidroacústico: 1999-verano 2015. Inf Inst Mar Perú. 43(1): 5-10 (http://biblioimarpe.imarpe.gob.pe:8080/handle/123456789/3065)

IMARPE. 2015. Crucero de investigación del calamar gigante, CR. 1501-02, 20 enero al 09 febrero de 2015. BIC José Olaya Balandra - Zona Norte, BIC Humboldt-Zona Sur. Informe Ejecutivo, IMARPE, Callao: 54 pp (http://www.imarpe.pe/imarpe/archivos/informes/CruceroInvestigacionCalamarGigante.pdf)

IMARPE. 2015a. Situación del calamar gigante durante el 2014 y perspectivas de pesca para el 2015. Informe interno IMARPE, Callao, marzo 2015: 10pp (http://www.imarpe.pe/imarpe/archivos/informes/imarpe/inf_calmar_2014_pers2015.pdf)

Li, G., X. Chen, B. Liu & L. Xu. 2017. China's Annual Report to the 2017 SPRFMO Scientific Committee, Part II: the squid jigging fishery. Paper presented at the 5th meeting of the Scientific Committee of the SPRFMO. Shanghai, China, 23-28 September 2017. SPRFMO Doc. SC5-Doc17: 9p (http://www.sprfmo.int/assets/00-SC5-2017/SC5-Doc17-Chinas-Annual-report-part-II-Squid.pdf)

Liu B., X. Chen & Q. Yi. 2013. Comparison of fishery biology of jumbo flying squid, *Dosidicus gigas* outside three Exclusive Economic Zones in the Eastern Pacific Ocean. Chinese Journal of Oceanology and Limnology Vol. 31(3): 523-533

Nesis, K.N., 1983. *Dosidicus gigas*. In Boyle, P.R. (Ed.), Cephalopod Life Cycles. Volume 1. Academic Press, London, 215-231.

Nigmatullin, Ch. M., K.N. Nesis & A.I. Arkhipkin. 2001. A review of the biology of the jumbo squid *Dosidicus gigas* (Cephalopoda: Ommastrephidae). Fisheries Research 54: 9-19

Segura, M., R. , J. Rubio, A. Tello, M. Gutierrez & A. Aliaga. 1996. Crucero de investigaciones sobre el recurso calamar gigante o pota a bordo del BIC SNP-1. CR.9510-11. Inf. Prog. Inst. Mar Perú, 34: 29-65 (http://biblioimarpe.imarpe.gob.pe:8080/handle/123456789/1184)