SPRFMO
South Pacific Regional Fisheries Management Organisation

SPRFMO SC 2ND HABITAT MONITORING WORKSHOP REPORT

6 October 2019
Havana, Cuba

3.

SPRFMO SCW9 Report 2019

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The 2nd Habitat Monitoring Workshop Report was prepared under the overall direction of the Habitat Monitoring Working Group Chairpersons, Mariano Gutierrez and Aquiles Sepulveda.

Martin Pastoors is acknowledged for his significant reporting contributions.

Contents

SPRFMO SCW9-Report

Report of the Second SPRFMO Habitat Monitoring Workshop

Havana, Cuba, 6 October 2019

Adopted 11 October 2019 11:30 am

1. Welcome and Introduction

1. The Co-Chairs (Mariano Gutierrez and Aquiles Sepulveda) welcomed delegations to the 2nd meeting of the SPRFMO Habitat Monitoring Working Group (HMWG). The Chair opened proceedings at 9:00 am on October 6th 2019, and participants introduced themselves. A list of participants is provided in Annex 1.

1.1. Workshop Arrangements

2. The Chair outlined procedural matters including the workshop schedule, administrative arrangements, and appointment of a rapporteur. Martin Pastoors (EU) volunteered to perform rapporteuring duties.

1.2. Agenda Adoption

3. The Agenda (Annex 2) was adopted without amendments.

1.3. Nomination of Rapporteurs

4. The workshop agreed that Co-Chairs and rapporteur would draft the report of the workshop to be adopted in the SC7 plenary session held on October 10th, including the recommendations to the Commission.

2. Habitat Definition

5. The definition of habitat as considered by the SPRFMO's Scientific Committee (SC6-Doc07[1]) is:

"The habitat is the place where a particular population of a species or group of species lives. It represents the spatial area that meets the suitable conditions for the species to live and reproduce, perpetuating its presence".

6. Habitat is described by features that define it ecologically, distinguishing it from other habitats in which the same species could not find favourable conditions. In the particular case of the pelagic habitat:

"it has a fluctuating surface and volume in time and space. This variability has a critical effect on the populations that inhabit a geographic area".

7. The habitat is mostly led by the trophic interactions within the ecosystem. The species that contribute the most to this level as far as the pelagic environment is concerned are the macrozooplankton (e.g. krill), and mesopelagic fish, among which lantern fish (*Vinciguerria lucetia*) is the most important species across the South Pacific (SP). Apart from the expected ecology relationships between fish and the environment, their plasticity and tolerance to changing conditions have to be evaluated for every species and according to different life stages and regions in the SP.

8. There is an important amount of different data sources and techniques and methods to collect, process and analyse data, but cooperative links must be established for specific projects addressing the different habitat definitions needed to support fisheries management from the perspective of quantitative ecology.

[1] Report of the Habitat Monitoring Task Group

9. The conditions for developing research on "habitat monitoring" already exist at least for Jack mackerel (e.g. the techniques of data collection, the sources of information, the existence of oceanographic and climatic models, the knowledge of the biology of Jack mackerel, until the habitat modelling). The next challenge will be to define and extract the pertinent indicators for achieving the main goals of the HMWG (to support stock management and habitat monitoring).

3. Report of the First HMWG Workshop

3.1. Summary of conclusions and recommendations from the presentations made on characterizing and modelling the Jack mackerel habitat

10. Paper SC7-HM01 "Observations on the preferred habitat of Jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*) in Peruvian national waters during 2018 and early 2019" was presented.

11. This paper showed that there were clear differences in oceanographic conditions and spatial distribution of Jack mackerel and chub mackerel observed in Peruvian waters during 2018-2019. During this period a large overlap in the distribution of both species was observed. No conclusions were reached on the significance and causal mechanism of these interactions, suggesting that more detailed data and in-depth studies are needed, including through retrospective analyses.

12. Nevertheless, the new available methods and models for the analysis of georeferenced information and data on fish distribution, concentration, abundance, etc., and the related environmental conditions are potentially very useful tools, although some methodological and technical improvements are required to fully and effectively benefit from their practical use.

13. The HMWG noted that the distribution of jack mackerel and their habitat is changing rapidly over time and within years. New models need to be developed that can handle these rapid changes and thereby improve or replace the existing models (GLM, GAM, HSM);

14. The HMWG noted that incorporation of the available information on top predators is expected to further improve our understanding of the jack mackerel habitat.

15. The HMWG noted that the historical dimension of the changes in habitats needs to be taken into account by collating historical information on environmental and biological variables.

16. The HMWG noted that attention should be given to all life-history stages in order to provide a broader ontogenetic approach through observations and analysis at the appropriate time and space resolution.

17. The HMWG noted that when those aspects can be approached it will be time to review the stock structure hypotheses, including the metapopulation one.

18. Paper SC7-HM02 "Habitat Monitoring of Chilean Jack mackerel based on acoustics from fishing vessels in Chile" was presented.

19. This paper showed that during 2018 the highest densities in the Central-south Chile were observed in the austral summer months with a maximum Nautical Acoustic Scattering Coefficient (NASC) near to 2,000 m^2/nm^2.

20. The highest acoustic densities were registered in 2019 during February to April with levels exceeding a NASC of 9,000 m^2/nm^2.

21. Total abundance of Jack mackerel was estimated at 2,664 million individuals representing a biomass of 1,081,072 t of Jack mackerel in the central-south zone of Chile, with a coefficient of variation of 4.96%. Results obtained were used to update the series of historical estimates of relative abundance that are registered for this fleet since 2004.

22. The HMWG noted that acoustic recordings from fishing vessels in Chile is available since 2004 as an index of abundance.

23. The HMWG agreed that the time series of acoustic index of abundance should be explored as a new information source for the assessment of Jack mackerel.

24. Paper SC7-HM03 "Spatio-temporal distribution pattern of Chilean jack mackerel (*Trachurus murphyi*) fishing grounds and environmental variability off southern-central Chile" was presented.

25. This paper showed that the spatio-temporal distribution of Chilean jack mackerel catches revealed marked differences in the seasonal pattern of catches and in the offshore extension of the purse-seine fleet. According to the above, three periods were identified: i) 1995-2001 characterised by catches throughout the year, an offshore extension during July and August that did not exceed 900 km and an average annual catch of 2.1 million tonnes; ii) 2002-2011, with catches throughout the year, mostly in the first half and a large offshore extension of the fleet from March to August reaching up to 1800 kilometres offshore and an average annual catch of around 900 thousand tonnes, and finally; iii) 2012-2019 characterised by concentrated catches in the first half, absence of fishing activity between September and November, with an offshore extension that did not exceed 600 km and average catches around 290 thousand tonnes.

26. Environmental variability, based on satellite information revealed a highly dynamic habitat influenced by El Niño/La Niña events, and characterised by strong spatial gradients mainly associated with a coastal zone of highly productive upwelling, seasonal migration of the Pacific anticyclone and the presence of a coastal transition zone with strong mesoscale activity. Interannually, a period of negative anomalies in the sea level height and primary production and positive sea surface temperature between 1995 and 2002, followed by a period of neutral activity between 2003 and 2013, and a period of positive anomalies of the sea level height, low kinetic activity and higher productivity between 2014 and 2019.

27. The HMWG noted that there was a low correspondence between habitat variations and changes in jack mackerel fishing areas, suggesting a high plasticity of the species against environmental changes.

28. The HMWG agreed that it is important to describe different habitat conditions depending on the behaviour of Jack Mackerel: spawning, nursery and feeding habitat.

29. The HMWG agreed to incorporate more information about predators and biological factors (reproductive: fecundity and atresia levels, parasites, energy content).

30. The HMWG **agreed** to incorporate more information on historical spatial temporal patterns of the fishery.

3.2. Applicability of data collected from fishing vessels targeting pelagic species

31. The HMWG was shown a presentation of progress on the Oceanbox integrated fisheries data solution.

32. A major challenge in dealing with acoustic data from commercial vessels is coping with the logistics of fishing operations and the scale of the information that could be collected. The OceanBox consists of a combination of hardware components and associated software that allows for continuous processing of sensor data. Automated procedures convert Simrad acoustic data into NASC values by time-intervals (minute) and by depth layers (10 m). A detecting bottom algorithm is under development. The summarised information, together with other sensor information is sent to the secured cloud environment taking into account irregular satellite bandwidth. The system is currently being tested on five pelagic trawlers (including one operating in the South Pacific). Once proven successful, this system can be scaled up with relatively modest efforts to cover a substantial number of vessels in the pelagic fleet. In remote areas like the South Pacific this method could greatly enhance the data basis behind the estimates of stock abundance and habitat composition by effectively utilising the scientific-quality instruments on board of commercial vessels.

33. The HMWG **noted** that calibration of the offshore vessels is still a challenge because of rough sea conditions and high time pressure on the fishing operations.

34. The HMWG **agreed** that the existing literature and experience on echosounder calibration against known seafloors needs to be compiled and explored for application in the South Pacific.

35. The HMWG **agreed** that the recording and use of sonar data, in addition to the traditional echosounder data, should be explored.

36. The HMWG **noted** that there is a need to make comparisons between the automatic school detection algorithms and manual scrutiny of the echograms in order to validate the algorithm.

37. The HMWG **noted** that the calculated abundance indices could be compared against estimates from scientific surveys in the same periods and areas.

38. The HMWG was shown a presentation on estimating and predicting the fleet distribution.

39. This ongoing project is intended to generate statistical models (e.g. INLA) to be run annually on among others VMS data and a set of co-variates such as dissolved oxygen, temperature etc. The goal is to set up a statistical model to predict the fleet distribution although the design of the model has to be based on past VMS data (2001 onwards) to allow the model to be used routinely.

40. The algorithms will rely on explanatory variables that are routinely and easily available for the whole SPRFMO area and time period. Prey distribution and oxycline depth are key factors in the distribution of Jack mackerel and can be derived from satellite data plus variables such as chlorophyll, distance to the coast and distance to the shelf break. It is also being considered whether El Niño events, the subtropical front and others could explicitly be taken into account.

3.2.1. *Calibration of echosounders aboard fishing vessels*

41. It was agreed that calibration of digital echosounders (Demer et al. 2015[2]) being deployed by a number of fishing vessels is no longer a matter of discussion. The only concern regarding the use of fishing vessels as scientific platforms is the level of noise a vessel can produce when steaming though it can be measured by applying the existing protocols.

42. There are three methods recommended to calibrate echosounders: by using a sphere according to the frequency (Demer et al. 2015[2], SPRFMO 2015[3]); to calibrate an echosounder against the sea bottom in specific locations where previously another calibrated echosounder has taken accurate measurements of its target strength (Manik et al. 2006[4]); and to intercalibrate echosounders aboard different vessels, being the pre-requisite to have previously calibrated one of them (Foote et al. 1987[5]).

3.3. *Review of papers focused in Jack mackerel and published in the past 20 years*

43. A review of the scientific literature on Jack mackerel during the past 20 years could not be carried out during the course of the workshop.

44. However, the HMWG **agreed** that there are several highly relevant scientific papers on the habitat of the South Pacific which should be used for a review of the current knowledge on the habitat. Annex 3 contains a summary of some these papers on the topic of ecosystem status overview at seasonal to decadal scale.

4. Habitat Monitoring Working Group Activities

4.1. *Summary of Inter-Sessional Activities*

45. SPRFMO HMWG members held a workshop during a special session of the ICES - Fisheries Acoustics Science and Technology Working Group (FAST) Meeting held in Galway, Ireland, on April 30th. A workshop report was submitted to the SPRFMO Secretariat and a summary of the entire session is available in the FAST Meeting Report (SCW7).

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[2] Demer, D., L. Berger, M. Bernasconi, E. Bethke, K. Boswell, D. Chu, R. Domokos, A. Dunford, S. Fassler, S. Gauthier, L. Hufnagle, M. Jech, N. Bouffant, A. Lebourges-Dhaussy, X. Lurton, G. Macaulay, Y. Perrot, T. Ryan, S. Parker Stetter, S. Stienessen, T. Weber, N. Williamson. (2015). Calibration of acoustic instruments. *ICES Cooperative Research Report 235*, 136 pp.

[3] SPRFMO (2015). Report of the SPRFMO Task Group on "Fishing Vessels as scientific platforms", 2014-2015. Third meeting of the Scientific Committee, Port Vila, Vanuatu, 2015. 44 p.

[4] H. Manik, M. Furusawa, K. Amakasu (2006). Measurement of sea bottom surface backscattering strength by quantitative echo sounder. *Fisheries Science 72*. 503-512. 10.1111/j.1444-2906.2006.01178.x.

[5] K. Foote, H.P. Knudsen, G. Vestnes(1987). Calibration of acoustic instruments for fish density estimation: a practical guide. *ICES Cooperative Research Report 144*, 61 p.

46. SPRFMO HMWG members participated in the ICES Mesometh (Mesopelagic fish) Workshop during April 27 to 28th in Foras na Mara, Ireland. The report of the workshop includes a summary of the mesopelagic fish research currently being conducted in different countries (Peru, Chile, Australia, New Zealand, EU among others).

47. SPRFMO HMWG members from Chile and Peru participated at the 7th habitat conditions Workshop of Chilean jack mackerel of the Peru-Humboldt System held at Lima, Peru on 1st to 5th July. A paper was submitted (SC07-HM01) to SPRFMO based on the analysis done during the workshop.

4.2. State of the Art of Habitat Monitoring

48. State of the art of habitat monitoring has been divided into 6 components (Annex 4).

1. Oceanographic modelling;
2. Echosounder: quantitative measurement of prey;
3. Applications of acoustic methods to characterise ecosystems;
4. Sonar and fish avoidance;
5. Top predator observations;
6. Parasites, fat content and diet composition.

4.3. Proposed Workplan

49. The proposed workplan (WP) for the HMWG has been drafted after a discussion on the scope and HMWG ToR and contains the following components to be developed during the period 2020-2024:

1. The Jack Mackerel Habitat concept;
2. Retrospective analysis;
3. Training, sharing and capacity building;
4. Development and application of tools;
5. Utilisation of different platforms;
6. Organisation of a symposium on habitat monitoring.

4.3.1. *Jack Mackerel Habitat Concept (ontogeny approach)*

50. The HMWG agreed to establish groups of specialists to develop an interdisciplinary ontogeny approach to the definition of Jack mackerel and other species' habitat, considering that that should be done in the mid-term for:

1. Every species of interest, not necessarily species under management;
2. Every life stage;
3. Every region.

51. The three criteria when possible might be linked to the identification of spawning and recruitment. When consistent the findings should conduce to the definition of a stock structure for every species or the review of the existing ones for the benefit of fishery management under an ecosystem approach.

4.3.2. *Retrospective analysis (data bases)*

52. There is a large amount of data and analysis existing in different institutions linked to SPRFMO that could be shared for the benefit of the scientific community. That data is related to species of interest, and might be organised into databases, the main sources being:

1. Catches
2. Latitudinal-longitudinal distribution, abundance
3. Acoustic properties (TS) of species of interest
4. Environmental information (depth of oxycline, O_2 saturation (%), zpk)
5. VMS
6. Trends of abundance before the fishery (paleoichtyology)
7. Scientific and grey literature

53. The HMWG noted that the retrospective analyses will require access or integration of databases held by different members of the HMWG and other working groups of the SC.

4.3.3. *Training, sharing and capacity building:*

54. The HMWG noted that there is a need for training and capacity building on data management, different technologies, methods and analysis techniques. This need is not only related to the national scientific institutions but to the universities, NGOs and the skippers, fishermen and crew of the fishing fleets operating in the Convention Area. The specific topics of training and capacity building are still to be identified, although during the workshop the need of improving abilities for sonar data analysis was highlighted, which implies both skippers and scientists, the purpose being to increase the acoustic fish stock assessment capacities.

55. The HMWG agreed to develop an inventory of technologies available aboard fishing vessels in order to identify the potential to collect data using the technologies currently being deployed. A protocol has existed since 2009 ("Guidelines for Acoustic Data Collection aboard Fishing Vessels operating in the SPRFMO area") which should be updated and submitted to the SC for approval (SP08-SWG-JM11)[6].

56. The HMWG agreed to develop an inventory of research programmes currently developed by the industry and the scientific institutions regarding data collection from different sources (e.g. SST sensors, sightings data, acoustics data etc). This is focused on identifying opportunities for cooperation, exchange of information and progress toward the drafting of needed protocols to make all the data comparable across the SPRFMO area.

4.3.4. *Development and application of tools:*

57. The HMWG noted that one of the aims of the HMWG is to promote cooperative links within the SPRFMO community. The main tools to be developed by the HMWG will be the following:

1. Protocols (for data collection, storage, analysis etc);
2. Indexes useful for fisheries management;
3. GAM, GLM, INLA, ROMS etc.;
4. Geostatistics;
5. Big data and machine learning (e.g. for acoustic classification of targets)

4.3.5. *Utilisation of different platforms:*

58. The HMWG noted that the following platforms could be used to collect data for habitat monitoring:

1. Scientific surveys;
2. Fishing vessels (based on an inventory of technologies and research programmes);
3. Satellite oceanography;
4. Gliders, buoys, AUV.

4.3.6. *Organisation of a symposium on habitat monitoring*

59. The HMWG recommended that a Symposium on Habitat Monitoring be organised prior to the 2022 meeting of the Commission. The likely date for such a symposium would be the first half of 2021 and the location would be in South America.

60. The HMWG recommended that a Steering Committee be established for organising the Symposium on Habitat Monitoring.

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[6] Post-meeting note; the Secretariat also note that SPRFMO also has a generic acoustic survey design for spawning orange roughy aggregations within the SPRFMO area (SC6-DW05).

5. Report adoption

61. The report was adopted on 11th October 2019 at 11:30 am.

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Annex 1. List of Participants

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SPRFMO SCW9-Report

Annex 2. Workshop Agenda

1) Welcome and summary of intersessional HMWG activities
2) Presentations on the submitted working papers to the SC7 regarding characterising and modelling the Jack mackerel habitat
3) Review/discussion evaluating the applicability of data collected from fishing vessels targeting pelagic species
4) Review/discussion on further developments of standardised oceanographic data products and modelling
5) Discussion on the Future Habitat Monitoring Workplan
6) Explore possibilities to organise a symposium on the topic of pelagic habitat in the 2020s
7) Drafting of a summary report and power point for the HMWG session
8) Closing of the workshop

Annex 3. Ecosystem Status Overview at Seasonal to Decadal Scale

(*Review/discussion on further developments of standardised oceanographic data products and modelling*)

A review was made of published literature on the status of the Humboldt Current System (HCS). Recent studies have been based on the analysis of oceanographic data (e.g. biogeochemistry, paleoceanography, acoustics) and fishing data (landings, CPUE). Three of the documents are summarised in order to provide an approach to an ecosystem status overview at seasonal to decadal scales.

Climate change impacts, vulnerabilities and adaptations

FAO (2018). Chapter15: South-West Atlantic and South East Pacific marine fisheries. A. Bertrand (IRD), R. Vögler Santos (PDU) and O. Defeo (UNDECIMAR).

Key messages from this review paper are:

- In the Humboldt Current System (HCS), globally the most productive marine ecosystem in terms of fish caught, climate is considered to be the most important driving factor.
- Industrial fisheries developed during a period of exceptional productivity in relation to that of the last thousands of years. This also means that "normal or mean" productivity of the system is lower than at present and that it could "shift-back".
- An increase in upwelling-favourable winds off Chile and a decrease off Peru is projected, together with an overall decrease in plankton abundance.
- Climate change **could** shift the HCS out of its current favourable state in terms of fish productivity.
- El Niño events may become more frequent and major regime shifts may happen. These projections have a high level of uncertainty, but potential consequences are considerable.
- Institutionalising participatory governance systems, promoting dedicated scientific studies and **improving monitoring** would increase the adaptive capacity of small-scale fisheries to cope with climate change.

Fish debris in sediments from the last 25 kyr in the Humboldt Current reveal the role of productivity and oxygen on small pelagic fishes

R. Salvatteci, D. Gutierrez, D. Field, A. Sifeddine, L. Ortlieb, S. Caquineau, T. Baumgartner, V. Ferreira, A. Bertrand (2019). *Progress in Oceanography 176 10.1016/j.pocean.2019.05.006.*

Anchovy have been the predominant small pelagic fish throughout the record, at least over centennial to millennial timescales. Its abundance reached a maximum during the Current Warm Period, an era characterised by high productivity and intense OMZ conditions. Thus, industrial fisheries developed during a period of exceptional productivity in relation to that of the last 25 kyr. The records reveal that dramatic decreases in pelagic fish abundances have occurred in response to past large-scale climate changes than those observed in the instrumental period, which suggests that future climate change may result in substantial changes in ecosystem structure.

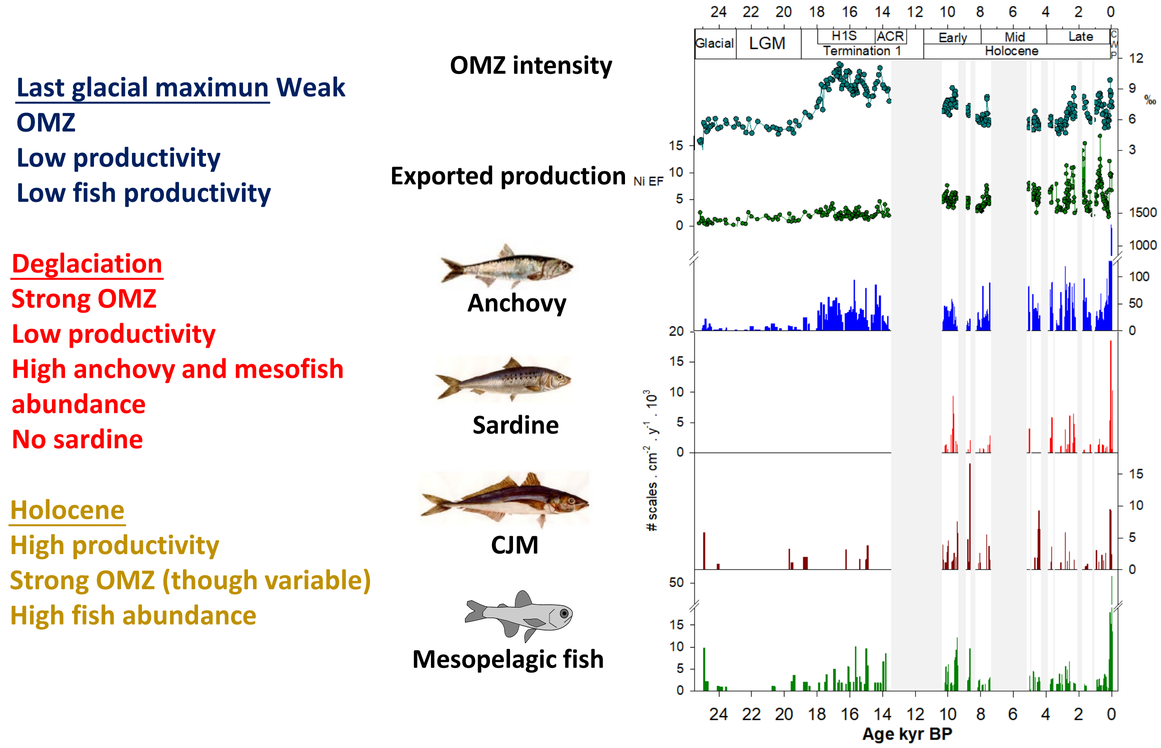

Figure 1. 25 thousand years in the Humboldt Current System. The exported production, OMZ intensity and relative abundance of anchovy, sardine, Jack mackerel and mesopelagic fish is higher for the last century, the only exception being the dominance of Jack mackerel during the early Holocene (9 thousand years before present).

Upper ocean hydrology of the Northern Humboldt Current System at seasonal, interannual and interdecadal scales.

C. Grados, A. Chaigneau, V. Echevin, N. Dominguez. (2018). *Progress in Oceanography 165*:123-144

The large and long-term database also allowed us, through a composite analysis, to investigate the impact of the eastern Pacific El Niño and La Niña events on the NHCS hydrology. On average, during these periods, large temperature (±3–4°C) and salinity (±0.1–0.2) anomalies are observed, impacting the water column of the coastal ocean off Peru down to 100–200 m depth. At 100 km from the coast, these anomalies are associated with a maximum deepening (shoaling, respectively) of the thermocline of 60 m (25 m) during composite El Niño (La Niña) events. At interdecadal scale, a similar approach reveals sea-surface temperature variations of ±0.5°C, associated with a deepening (shoaling) of the thermocline of 5–10 m during warm (cold) periods.

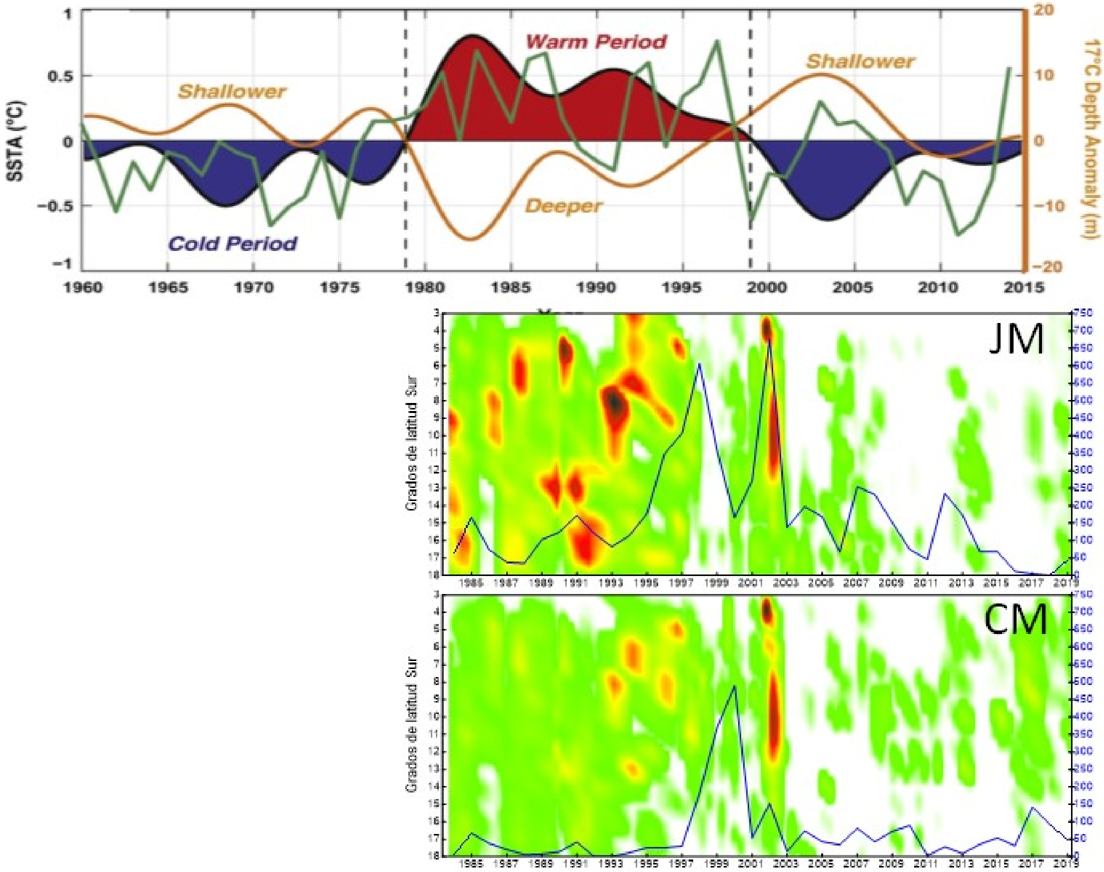

Figure 2. Time series of sea-surface temperature anomalies (SSTA) in the NHCS. This time series has been low-pass filtered with a cutoff period of 8 years to identify interdecadal cold (in blue) and warm (in red) periods. The time series of the annual PDO index is also superimposed (green solid line). Hovmöller diagrams of the latitudinal biomass of jack mackerel (JM: mid panel) and chub mackerel (CM: low panel) have been fitted to the time series to show the matching of warm periods to higher abundance of Jack mackerel and Chub mackerel. Source: Grados et al.[7] (2018, top panel), data from IMARPE, graph made by M. Gutierrez (mid and lower panel).

Distribution changes and interactions of Jack Mackerel off Peru as observed using acoustics.

(M. Gutiérrez , A. Bertrand , M. Ballón, P. Espinoza, A. Alegre, F. Gerlotto. (2008). Chilean Jack Mackerel Workshop. SPRFMO Jack Mackerel Workshop 2008. CHJMWS paper 16).[8]

Jack mackerel (*Trachurus murphyi*) has been acoustically assessed since 1983 by the Instituto del Mar del Perú (IMARPE). Monitoring of Jack mackerel supported the management of the fishery off Peru which was initiated by foreign fleets during the 1970s. By the mid 1990s an offshore Peruvian purse seine fleet started to operate although their activities were soon affected by changes in distribution and a reduction of Jack mackerel abundance after the strong El Niño event of 1997-98. Since this event, cold coastal waters extend far from the coast, the oxycline is shallow, anchovy dominate the system, and the abundance and distribution of squat lobster (*Pleuroncodes monodon*) and jumbo squid (*Dosidicus gigas*) increased. However, the abundance and availability of Jack mackerel, sardine and mackerel (*Scomber japonicus*) reduced dramatically. Using a GAM approach changes of Jack mackerel distribution and related (abiotic) parameters were found during the period in which IMARPE conducted acoustics surveys, and negative correlations were described among the abundance of mentioned species. Using acoustic data from commercial fishing also found interactions between Jack mackerel and its prey, mainly euphausiids. These results might support the hypothesis according to which the

[7] Upper ocean hydrology of the Northern Humboldt Current System at seasonal, interannual and interdecadal scales. (2018). C. Grados, A. Chaigneau, V. Echevin, N. Dominguez. *Progress in Oceanography 165*:123-144

[8] https://www.sprfmo.int/assets/Meetings/Meetings-before-2013/Scientific-Working-Group/Jack-Mackerel-Workshop-2008/16-Peru-Distrubution-changes-and-interactions-on-CJM.pdf

main drivers of Jack mackerel distribution along the South American coast are the prey distribution and the location of the Oxygen Minimum Zone. Finally, we emphasise the use of acoustic techniques to collect simultaneous in situ data from fishing vessels about a variety of species, preys and predators, to support the necessary ecosystem approach adapted to the fishery of Jack mackerel.

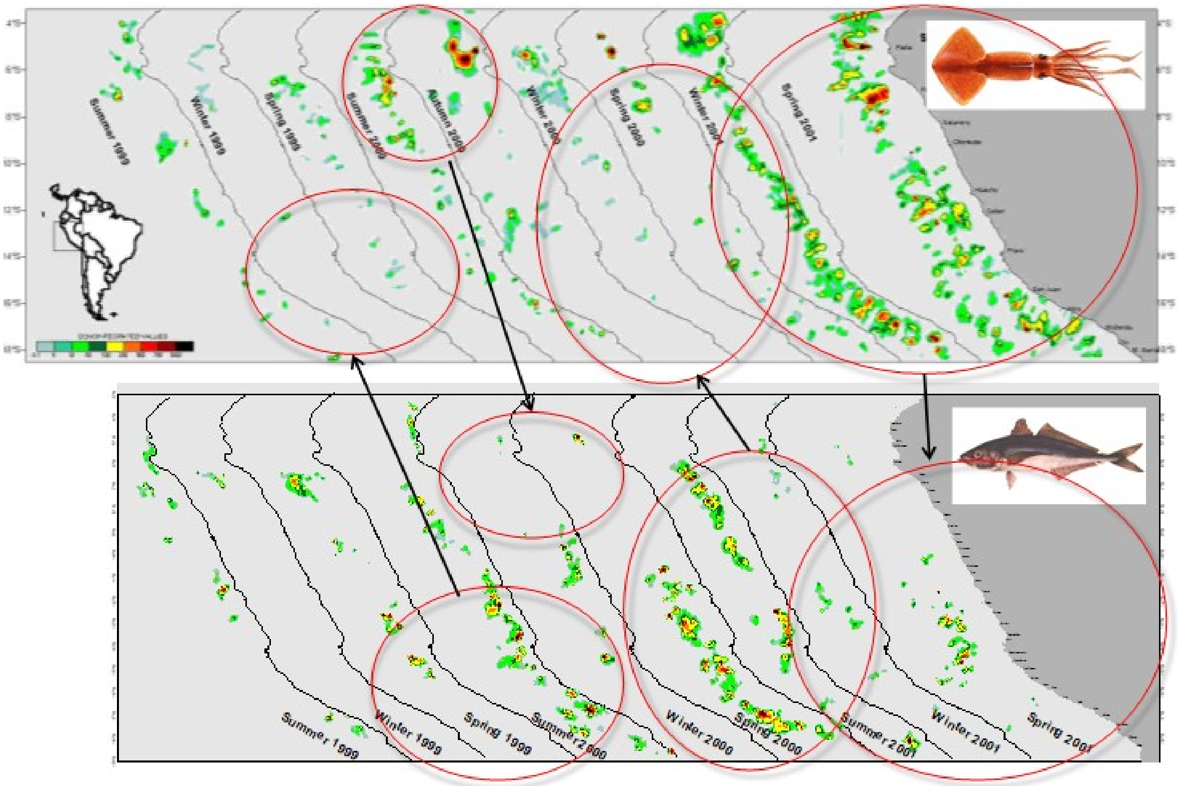

Figure 3. Time series of acoustic abundance for jumbo squid *Dosidicus gigas* (top panel) and Jack mackerel *Trachurus murphyi* (low panel). The distribution of acoustic density for both species is shown with clustered colours, where black and red colours indicate high biomass, orange to yellow indicate medium biomass, and green colours show low biomass. Red circles and ellipses connected with black arrows highlight areas where there is negative correspondence between the distribution and the abundance of both species.

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Annex 4. State of the Art of Habitat Monitoring (HM)

Oceanographic modelling

Models can be used for the following purposes: explanation; experimentation; prediction and optimisation. The possible model types are: static, dynamic or distributed; one or more dimensions; holistic or reductionist; empirical or theoretical; deterministic (mathematical) or probabilistic (statistical); numeric or analytic; analogue or digital; bioenergetics; realistic (multi species statistical models); biogeochemical models (ROMS, PISCES etc); short-chain model (Lotka-Volterra, SMOM etc); models based on individuals (INVITRO, ichtyop etc); ecosystem models (EwE, Atlantis, Osmose, Seapodym etc).

Between the most commonly used models by the scientific marine community the following can be highlighted:

Regional Ocean Modelling System (ROMS)

ROMS are ocean models widely used by scientists for a diversity of uses. ROMS were originally developed and supported by researchers of the University of California, Los Angeles with contributors worldwide. ROMS are used to model how a given region of the ocean responds to physical forcings such as heating or wind, but also to inputs like sediment, freshwater, nutrients etc. A couple of examples of use of ROMS are next cited to illustrate how they are being used for habitat monitoring purposes.

Biogeochemistry models

(O. Andrews, E. Buitenhuis, C. Le Quéré, P. Suntharalingam (2017). Biogeochemical modelling of dissolved oxygen in a changing ocean. *Philosophical Transactions of the Royal Society A 375*: 20160328)

Secular decreases in dissolved oxygen concentration have been observed within the tropical oxygen minimum zones (OMZs) and at mid- to high latitudes over the last approximately 50 years. Earth system model projections indicate that a reduction in the oxygen inventory of the global ocean, termed ocean deoxygenation, is a likely consequence of on-going anthropogenic warming. Current models are, however, unable to consistently reproduce the observed trends and variability of recent decades, particularly within the established tropical OMZs. A series of targeted hindcast model simulations can be produced using a state-of-the-art global ocean biogeochemistry model in order to explore and review biases in model distributions of oceanic oxygen. It is shown that that the largest magnitude of uncertainty is entrained into ocean oxygen response patterns due to model parametrisation of pCO_2-sensitive C:N ratios in carbon fixation and imposed atmospheric forcing data. Inclusion of a pCO_2-sensitive C:N ratio drives historical oxygen depletion within the ocean interior due to increased organic carbon export and subsequent remineralisation. Atmospheric forcing is shown to influence simulated interannual variability in ocean oxygen, particularly due to differences in imposed variability of wind stress and heat fluxes.

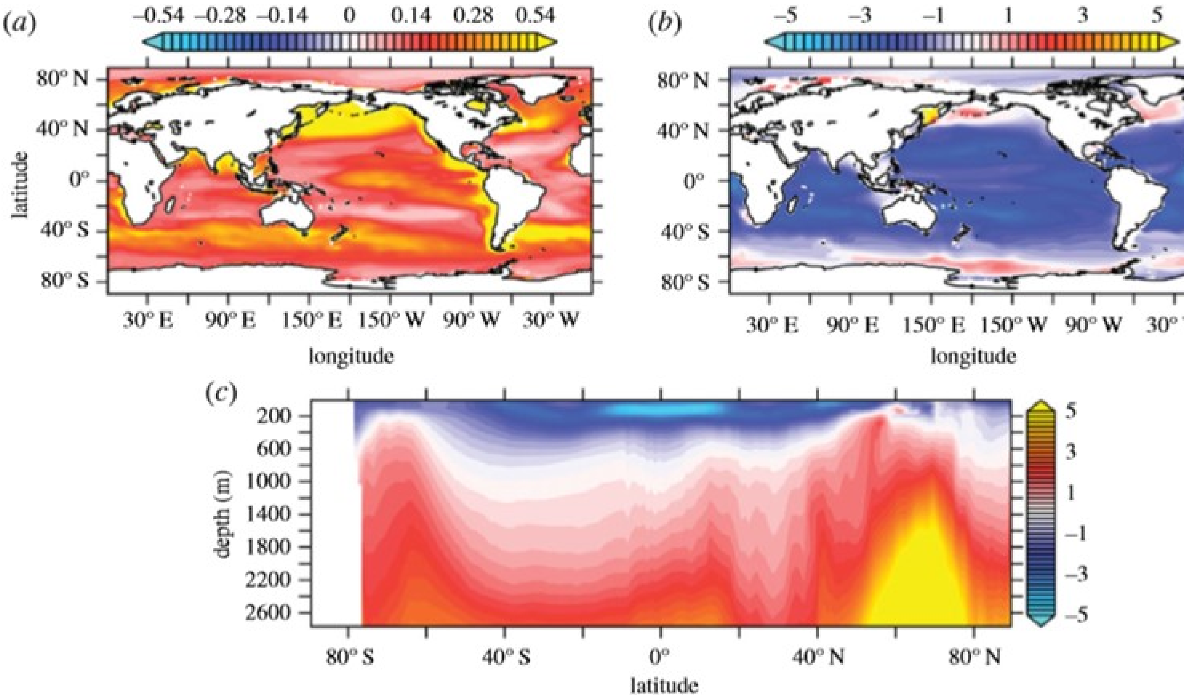

Figure 4. Differences in modelled ocean carbon cycle variables (STO10 simulation minus REF) averaged over 2003–2013. (a) POC export ($molCm^{-2}\ yr^{-1}$) at 100 m depth, (b) concentration of DIC ($\mu moll^{-1}$) at 100 m depth and (c) zonal mean DIC concentration.

Modelling the vorticity of the ocean

Carton X. (2001). Hydrodynamical Modeling Of Oceanic Vortices. *Surveys in Geophysics 22(3):* 179-263.

Mesoscale coherent vortices are numerous in the ocean. Though they possess various structures in temperature and salinity, they are all long-lived, fairly intense and mostly circular. The physical variable which best describes the rotation and the density anomaly associated with coherent vortices is the potential vorticity. It is diagnostically related to velocity and pressure, when the vortex is stationary. Stationary vortices can be monopolar (circular or elliptical) or multipolar; their stability analysis shows that transitions between the various stationary shapes are possible when they become unstable. But stable vortices can also undergo unsteady evolutions when perturbed by environmental effects, such as large scale shear or strain fields, effect or topography. Changes in vortex shapes can also result from vortex interactions, such as the pairing, merger or vertical alignment of two vortices, which depend on their relative polarities and depths. Such interactions transfer energy and enstrophy between scales, and are essential in two-dimensional and in geostrophic turbulence.

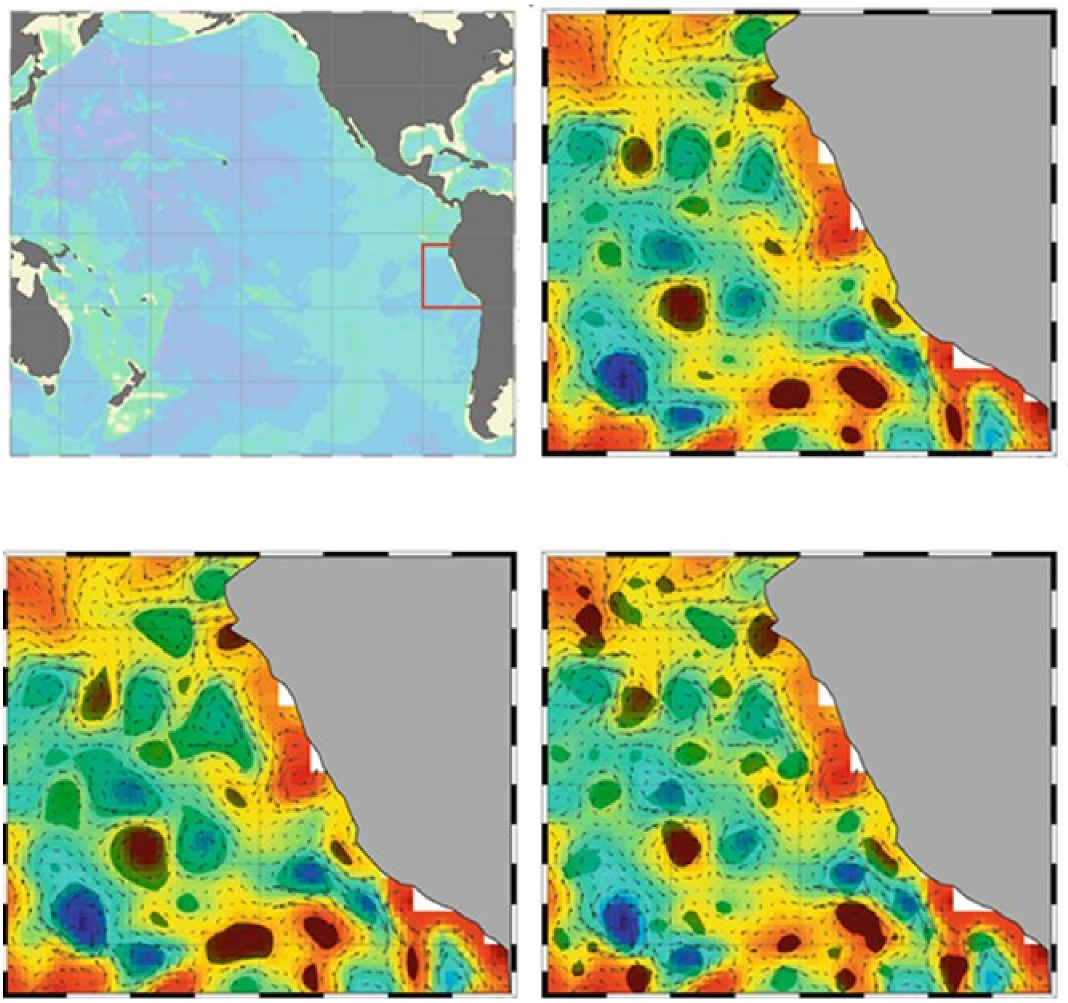

Figure 5. Study region (a) (red box) and illustrative example for the detection of vortices by (b) one of the experts, (c) the ‘‘winding-angle method” and (d) the ‘‘Okubo–Weiss method”. Shown are the SLAs (colour shading), the associated geostrophic currents (black quivers) and the identified eddies (light shading). Clockwise rotating structures correspond to cyclonic eddies in the southern hemisphere. The numbers of identified eddies and success and excess detection rates are also indicated. [9]

Echosounder and quantitative measurement of prey

(source: Demer et al. 2017; 2016 USA–Norway EK80 Workshop Report: Evaluation of a wideband echosounder for fisheries and marine ecosystem science)[10]

Narrow-bandwidth echosounders such as EK60/ES60 and ES70 transmit pulses containing a single frequency continuous wave signal. Wide-bandwidth echosounders such as EK80/ES80 can transmit CW pulses or pulses containing a range of frequency modulated (FM) signals. EK80/ES80 may emulate EK60/ES60/ES70 by transmitting at multiple frequencies so that both technologies provide equivalent measures of volume backscattering coefficients, which supports the transition from EK60 to EK80.

Besides, wideband frequency responses may be used to improve target identification, thereby reducing uncertainty in estimates of fish abundance. A multifrequency workshop was recently conducted by Dr Paul Fernandes (University of Aberdeen) in IMARPE to develop unsupervised algorithms to perform an automated identification and classification of acoustic echotraces by species or group of species. Developments made under

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[9] A. Chaigneau, A. Gizolme, C. Grados (2008). Mesoscale eddies off Peru in altimeter records: Identification algorithms and eddy spatio-temporal patterns. *Progress in Oceanography 79*: 106–119.

[10] D. Demer, L. Andersen, C. Bassett, L. Berger, D. Chu, J. Condiotty, G. Jr, B. Hutton, R. Korneliussen, N. Bouffant, G. Macaulay, W. Michaels, D. Murfin, A. Pobitzer, J. Renfree, T. Sessions, K. Stierhoff, C. Thompson (2017). Evaluation of a wideband echosounder for fisheries and marine ecosystem science. 10.17895/ices.pub.2318.

the cooperation between IMARPE and IRD permitted the design of algorithms to identify and quantify the abundance of macrozooplankton (e.g. euphausiids) and migrant fish (mesopelagic fish) using 38 and 120 kHz.

However, the advantages of wideband echosounders come with additional complexities related to calibration, data storage, processing speed, signal processing and analyses, and interpretation. The most important challenge consists in the fact that EK80/ES80 may collect 1–2 orders of magnitude more data than EK60 depending on the configuration. However, the additional EK80 data may allow better detection of single targets, enabling the use of other quantitative methods such as echocounting.

Applications of acoustic methods to characterise ecosystems

(source: ICES WGFAST 2019 report[11])

The use of acoustic methods to characterise ecosystems cover a wide range of applications. Studies ranged in scale from small spots to large regional studies, from hourly to annual time-series, and from sizing single species to analysing the distribution patterns of large communities.

The majority of applications focussed on mid-trophic-level species (e.g. small fish, zooplankton etc.) found both in the epipelagic (0-200 m) or mesopelagic (200-1000 m) depth zones using narrowband systems and/or broadband acoustics. Acoustic data is typically combined with CTD profiles and trawl/net samples but it is highlighted that optics/eDNA data could potentially improve species classification methods and/or reduce uncertainty in estimates of species biomass/abundance.

Machine learning techniques, e.g. supervised and unsupervised learning, geo-statistics (e.g. kriging), and frequency response methods (e.g. dB differencing) are being used to categorise species/groups of organisms. Biological features such as schools and sound scattering layers (SSLs) were identified in echosounder data and summarised using biometrics, describing their size, shape, vertical arrangement and dynamics (e.g. migration), to characterise ecosystems. Echo energy was also modelled and linked to environmental drivers (e.g. chl-a) to map backscattering intensity in space and time. To convert echo energy to abundance/biomass, some studies used acoustic scattering models (e.g. DWBA and SDWBA models) to predict target strength. Drivers of uncertainty in biomass estimates were also explored including avoidance behaviour (e.g. of krill), acoustic properties of organisms and TS model error (Ressler et al.[12]).

Some applications are focused on the horizontal and vertical arrangement of prey species and links to predator-prey studies. Summary metrics of water-column echo intensity, SSLs and schools provide important information for conservation and can support environmental assessments (e.g. evaluating the impact of methane gas bubble release on surrounding ecosystems).

It is emphasised that to characterise ecosystems, acoustic observations alone are not enough, and that other types of observations are needed (e.g. optics, eDNA, trawl samples etc.). It was noted that echosounders, like any other survey method, are both selective and biased, and that present/previous studies have typically focused on the dominant scattering groups (e.g. fish), whilst mixed species assemblages can be difficult to resolve. Acoustic data is additive, and therefore it is possible to estimate the biomass of weaker scattering groups.

It is also possible to link echosounder observations with ecological models, providing either a means of constraining or assessing the mid-trophic-level components of these models. However, it is not clear how exactly this could be achieved since modellers typically group organisms in ecosystem models at very coarse taxonomic scales, which would be difficult to replicate using acoustic methods.

Sonar and fish avoidance

There is a long history of concern over how the noise radiated by vessels affects fish. This appears to have been first recorded by Shishkova (1958) at a time when diesel propulsion was replacing steam for most vessels. The

[11] ICES. (2019). Working group on Fisheries Acoustics, Science and Technology (WGFAST). *ICES Scientific Reports*. 1:35. 89 p. http://doi.org/10.17895/ices.pub.5355

[12] P.H. Ressler, J.D. Warren, B.M. Lucca, H.R. Harvey, G.A. Gibson How many krill are there in the eastern Bering Sea and Gulf of Alaska? In ICES (2019)

background to this was that several interests had pointed out that noise may scare fish; make it difficult to find fish or be uncomfortable for the crew.

A list of items considered to cause noise was produced, but with the comment, “There is not sufficient quantitative knowledge about how these items influence the noise level.” And furthermore that “Many avoidance reaction reports are from the herring fisheries, but it is not known which frequencies and levels cause the reactions.” The opinion was that changes in noise level caused by RPM and change of propeller pitch were the stimulus, but that fish adjusted relatively quickly to high but constant levels. The report also made it clear that vessel noise was impeding acoustic assessment: “Noise from the vessel makes it very difficult to use echo sounders and sonar effectively to detect weak echoes and it is hard to predict performance of these instruments because of lack of measurements of vessel noise.”

In 1968 Simrad conducted measurements using a sonar on the Peruvian research vessel SNP-1 and three other publications on this subject were also seen that year.

Lateral avoidance of approaching vessels has been inferred primarily from tracking schools from sonars (Misund et al., 1996), counting the number of detected schools in the athwarthship direction (Soria et al., 1996), or tracking individual fish using split beam echo sounders (Handegard & Tjøstheim, 2005). Elevated densities of fish schools are often observed by lateral-looking sonars compared to downward-looking echo sounders (e.g. Pitcher et al., 1996; O'Driscoll, 1998), suggesting that lateral avoidance was occurring. In particular, small pelagic fishes can exhibit strong reactions to approaching vessels, as one might expect for shallowly distributed species. Soria et al. (1996) studied the fraction of anchovy, *Engraulis encrasicholus*, and sardine, *Sardina pilchardus*, schools available to a downward looking echo sounder in the Mediterranean Sea with multibeam sonar and estimated that only 41% of the schools detected by the sonar would be available to the echo sounder due to a lateral shift of fish schools away from the vessel. In contrast, Gerlotto et al. (2004) reported no difference in Peruvian anchovy and common sardine school counts in Chile as a function of athwartship distance, indicating that no lateral avoidance occurred in this case.

The availability of digital multibeam omnidirectional sonars aboard modern fishing vessels provide the opportunity of exploring and quantifying the possible avoidance reaction of the species being studied in the south Pacific. There are however a number of challenges and goals to achieve: the lack of experience in using this kind of technology; developing software for quantitative purposes; the increasing volume of the signal according to the distance to every target; the tilt angle which makes the acoustic reflectivity different depending on the relative orientation of targets; the large amount of stored data.

However, some progress has been made by manufacturers of acoustic devices, software designers and scientists in some countries. It enables also the opportunity of using complementary technologies such as high-resolution submersible cameras to study the identity and behaviour of target species.

Top predator observations

It must be highlighted that data on interactions between top predators and fishing vessels is needed not only in terms of a possible quantification of top predator species as part of the ecosystem approach to fisheries. We need to determine whether the presence of other species, and particularly species directly observable from the fishing vessels, might be indicative of jack mackerel and other species’ habitat, either because the species shares an attraction to certain features of habitat (e.g. physical tolerance range, prey type), and/or the other species are attracted to the fishing operation. If associations between jack mackerel and other species is robust and independent of fishing, it may be possible to create indicators of the likely presence of the fish through observation of surface phenomena. At least two types of indicators are possible from the analysis of sightings made aboard fishing vessels:

- Positive Indicators: Sightings associated with a higher probability of the presence of target species, and/or a higher proportion of target species.
- Negative Indicators: Sightings associated with a higher probability of by catch species, smaller (i.e., juveniles) target individuals, smaller schools, or other less desirable aspects of the fishery.

Sightings data must be standardised and collected by trained crews on a half an hour intervals over the entire fishing trip. Sightings data can be separated into two general categories, according to whether the observation is of something on the surface, or from the echosounder (that is, in sub-surface). Surface sightings included the larger taxonomic categories of whales, dolphin (small cetaceans), pinnipeds, sea turtles and marine birds. For each of these categories, species level information should ideally be available for almost every observation. Observations are constrained to daylight hours which are variable according to the latitude and season.

An observation protocol is needed to dictate a complete set of observations to be recorded in a specific logbook for each half hour the vessel sails. In addition, it would be necessary to include information about estimated abundance of as much species as possible. However, it must be considered too an approach in which an interpretation can be given as presence/absence.

Parasites, fat content, diet composition

Parasites

Fish parasites represent a large proportion of marine biodiversity, they can be affected directly by the environment and/or through their hosts; most of fish species host parasites (protozoans and metazoans) in all life stages. However, parasites can be used as biological indicators of the feeding and migration ecology of their hosts, also can reveal aspects of their population structure. Parasite metrics are connected to specific environmental conditions, including pollution, eutrophication and to anthropogenic impacts on marine habitats.

Fat content

Fat content (as % of total body wet) of fish and invertebrates can be determined seasonally or annually during peak feeding or spawning periods. It is expected that variations of this parameter can be high, so that fat content can be used as an indicator of food supply and/or food quality. It is also expected to be able to identify different periods regarding food supply, and link them to different regimes in trophic competition, eutrophication and even pollution. They might also be expected to find relationships between variations of fat content with phytoplankton and/or zooplankton concentrations.

Diet composition

Dietary differences and diet composition can be studied for every target species including the dietary overlap between species. The proportion of fullness of stomachs can be tracked seasonally in order to find ecological differences between species through the diversity of diet composition. Also diet breadth can be different between species along the years, and can tend to be higher or lower depending on the occurrence of events such as El Niño, including implications for competitive interactions that can favour groups of species against others. This kind of approach can conduce to measure the plasticity of the feeding behaviour of studied species. Obtaining knowledge on the time variations of the various target species diets can be relevant to fisheries management under an ecosystem approach since special protective management rules might be supported from the point of view of feeding ecology.