Food and Agriculture Organization of the United Nations

Report of the
Workshop to review orange roughy acoustic data
30 January - 3 February 2017 • Rome, Italy

ABNJ Deep Seas Project

Sustainable Fisheries Management and Biodiversity Conservation of Deep-sea Living Marine Resources and Ecosystems in the Areas Beyond National Jurisdiction

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Food and Agriculture Organization of the United Nations

Rome, 2017

EXECUTIVE SUMMARY

Scientists and observers from the deep-sea fishing industry, academia, regional fisheries organizations, and non-governmental organizations met at the FAO headquarters from 30 January to February 2017 to review the performance of acoustics data in the assessment of orange roughy (*Hoplostethus atlanticus*) in the southern Indian Ocean.

The workshop was organized in partnership with the ABNJ Deep Seas Project which has activities to improve knowledge on key deep-sea species and the methods and technologies for their study and assessment. The outputs of the workshop would also be forwarded to the Southern Indian Ocean Fisheries Agreement's Scientific Committee, for consideration during its deliberations on the assessment of orange roughy.

Contents

ABBREVIATIONS AND ACRONYMS

ABNJ	Areas beyond national jurisdiction	F/V	Fishing vessel
AOS	Acoustic optical system	ICES	The International Council for the Exploration of the Sea
BD	Boulder fishing ground	MSC	Marine Stewardship Council
CCAMLR	Conservation of Antarctic Marine Living Resources	NL	Noise level
CPUE	Catch per unit effort	RFMO/A	Regional Fisheries Management Organizations or Arrangements
CSIRO	Commonwealth Scientific Industrial Research Organization (Australia	SB	Sleeping Beauty fishing ground
CV	Coefficient of variation	SIOFA	Southern Indian Ocean Fisheries Agreement
EEZ	Exclusive economic zone	SL	Standard length
FAO	Food and Agriculture Organization of the United Nations	TS	Target strength

Opening of the meeting

1. Scientists and observers from the fishing industry, regional fisheries organizations, academia, and non-governmental organizations met at FAO headquarters in Rome, Italy, from 30 January to 3 February to review acoustics data for orange roughy (*Hoplostethus atlanticus*) in the southern Indian Ocean. The workshop aimed to respond to the outcomes of the ABNJ Deep Sea Project's workshop on the biology and assessment of orange roughy held Auckland, New Zealand in June 2016, and a request by the Southern Indian Ocean Fisheries Agreement (SIOFA) Meeting of the Parties to further review orange roughy information for the southern Indian Ocean.

2. Mr Chris O'Brien (ABNJ Deep Seas Project Coordinator) provided welcoming remarks and the meeting was chaired by Mr Graham Patchell (Sealord Group). The list of participants is given in Appendix 1.

Background

3. The workshop was organized in partnership with the ABNJ Deep Seas Project which has activities to improve knowledge on key deep-sea species and the methods and technologies for their study and assessment. The output of the workshop is intended to be a report to be submitted by the Cook Islands to the 2nd Scientific Committee meeting of the Southern Indian Ocean Fisheries Agreement (SIOFA) in March 2017.

4. Mr Patchell provided a presentation on the southern Indian Ocean orange roughy fishery and the extent of the biological and acoustic data collected by the fishing industry, which had been collected primarily on the vessel F/V *Will Watch*, to ensure quality stock assessments could be undertaken to provide for a sustainable fishery. This information was synthesized from a recent 2015 report[1] presented to the SIOFA Scientific Committee.

5. Mr Patchell also reported on the recent Marine Stewardship Council (MSC) certification of three New Zealand orange roughy stocks, of which the stock assessments had been underpinned by robust acoustic survey data. He noted the June 2016 FAO workshop on orange roughy covered historical information on the regional development of the fisheries, biology, stock assessment, and key management issues. The June 2016 workshop highlighted recent developments in science and approaches to management, and one of the main recommendations from the workshop was that CPUE indices should be avoided where possible and when assessing deep-water stocks. The preferred methods thus involved fishery independent data, which is normally derived from acoustic technology.

6. Mr Rudy Kloser presented on the 2016 St. Helens (East Tasmania) net attached Acoustic Optical System (C-AOS) biomass survey, which found approximately 20 000 tonnes of orange roughy. It was noted that this reported biomass is of similar size to that reported for the Sleeping Beauty stock in the Indian Ocean. Thus, these reports could allow for useful comparisons between the datasets.

7. The workshop participants also noted that all orange roughy surveys in Australia and New Zealand have been carried out on commercial fishing vessels over many years. Furthermore, several examples for other areas and species were highlighted for combining fishing operations with acoustic surveys conducted by fishing vessels (e.g. Norwegian vessels in CCAMLR[2] and Chilean vessels in the Chile EEZ for a range of deep-water species including orange roughy).

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[1] Niklitschek, E.J. & Patchell, G. 2015. *Acoustic abundance indexes for orange roughy and alfonsino in the Indian Ocean (SIOFA) from industry acoustics 2004 – 2008*. Southern Indian Ocean fisheries Agreement Scientific Committee Report. SIOFA SC-01-INFO-15.

[2] Niklitschek, E.J. & Skaret, G. 2016. *Distribution, density and relative abundance of Antarctic krill estimated by maximum likelihood geostatistics on acoustic data collected during commercial fishing operations*. Fisheries Research 114–121.

Agreement on the work plan

8. The following work plan was agreed for the workshop:

1. Select data for review and testing purposes;

2. Review the 2015 report (addressing questions, clarifying procedures, etc.);

3. Review of main uncertainty and bias sources:

     3.1 Absorption

     3.2 Deadzone

     3.3 Survey (inference) area

     3.4 Echotrace identification and delineation

     3.5 Biological noise

     3.6 Vessel noise

     3.7 Target strength

     3.8 Statistical methods

4. Disentangling observation and process errors in available surveys;

5. Defining observations (practical management) units;

6. Potential uses of available/new data series;

7. Recommendations.

1. Select data for review and testing purposes:

9. Three datasets from the Sleeping Beauty (SB) ground were selected, based on the biomass, the 12-year annual time series, and a high number of within-year surveys. The data were made available in a shared drive. In addition, there was a net-attached S-AOS survey and target strength tow. There was also evidence this stock had not been fished prior to 2004, and there was a known time series of catches (which is critical for a robust stock assessment). Detailed bathymetry from sidescan mapping was also provided for this ground:

    SB Surveys 2005(-14.1) and 2009(-1202) for single frequency hull-mounted analysis; and

    SB 2014 Survey – S-AOS for addressing species identification issues and comparing hull-mounted with AOS.

10. It was noted there was an alternative dataset of comparable data quality from the Boulder (BD) ground, with a smaller size of fish.

11. Data identified as needed to be made available:

    Length-weight relationships by sex for SB; and

    Length distribution by sex for SB (precision = 1 cm).

2. Review of the 2015 report[3] (addressing questions, clarifying procedures, etc.):

12. The original 2015 report only included surveys carried out until 2008. For this orange roughy acoustics workshop, additional analyses were made available including surveys up until 2015. A detailed analysis of the report was undertaken by selecting the surveys from the Sleeping Beauty bank south of Walter's Shoal and reworking those surveys based on different protocols for estimating absorption, dead zone, survey area, and school delineation. This area has the longest time series of surveys in the SIOFA region, and has had zero bycatch of oreo dory (*Pseudocyttus maculatus*) and insignificant catches of other species. During the

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[3] Niklitschek, E.J. & Patchell, G. 2015. *Acoustic abundance indexes for orange roughy and alfonsino in the Indian Ocean (SIOFA) from industry acoustics 2004 – 2008.* Southern Indian Ocean fisheries Agreement Scientific Committee Report. SIOFA SC-01-INFO-15.

workshop, several surveys were reviewed and estimates of reported biomass changed by factors of 2 to 4 depending on corrections or methodological assumptions. This highlighted the need for a further review of the estimates for stock assessment purposes.

3. Review of main uncertainty sources:

3.1 Absorption:

13. The workshop noted there are two main equations for computing sound absorption in the water column found in François and Garrison (1982)[4] and Doonan et al. (2003)[5], FG and D respectively. Algorithm selection changing from D to FG resulted in a 31 percent increase in the biomass estimates when using the Sleeping Beauty environmental data (CTD) and mean school depth of 1 050 m. However, there was no solid ground to favour the use of either of these options until further verification is available. A potential means of verification would be to contrast hull vs. Acoustic Optical System (AOS) data, and it was identified that this could be done at SB. The precision of the estimate to investigate this will need to be 0.9 dB.

3.2 Deadzone:

14. The workshop discussed two different approaches for estimating the height of the deadzone at each sampling interval:

    1. A theoretical approach based on a 2001 report[6]; or

    2. An empirical approach based on defining a true bottom line from maximum S_v per ping[7].

15. The consequences of choosing one of these two approaches become relevant when the fish were close to the bottom. For example, in the 2009 test survey the empirical method produced biomass values ~10 percent higher than those values produced by the theoretical method.

3.3 Survey area:

16. Most acoustic time series are based on a nearly constant survey area being targeted each year. Given the opportunistic nature of most available surveys and the observed variable movement patterns of the aggregations, the surface areas being surveyed within each ground have not been highly consistent over time. Changes in surface areas have several implications both in terms of the estimated mean and the corresponding coefficient of variation of yearly estimates.

17. As a result, the workshop suggested establishing target survey areas for each ground and to define a minimum coverage criterion for accepting surveys as valid for analysis. It was also recommended to produce and report separate estimates for observed abundance/biomass (restricted to the observed area) and potential abundance/biomass values (extrapolation of an assumed habitat area).

3.4 Echotrace identification and delineation:

18. An example of an echogram showing an orange roughy aggregation is provided in Appendix 3. Echotrace identification and delineation is one of the most important sources of uncertainty in standard (single-frequency) acoustic surveys, which can lead to errors up to a factor of 6 in orange roughy biomass estimates[8].

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[4] Francois, R.E. & Garrison, G.R. 1982. *Sound absorption based on ocean measurements: Part 1: Pure water and magnesium sulfate contributions*. The Journal of the Acoustical Society of America, 72(3), 896-907.

[5] Doonan, I.J., Coombs, R.F. & McClatchie, S. 2003. *The absorption of sound in seawater in relation to the estimation of deep-water fish biomass*. ICES Journal of Marine Science, 60(5), 1047-1055.

[6] Barr, R. 2001. *A design study of an acoustic system suitable for differentiating between orange roughy and other New Zealand deep-water species*. The Journal of the Acoustical Society of America. 109: 164–178.

[7] Kloser, R.J. 1996. *Improved precision of acoustic surveys of benthopelagic fish by means of a deep-towed transducer*. ICES Journal of Marine Science, 53(2), 407-413.

[8] Kloser, R.J., Ryan, T.E., Sakov, P., Williams, A. & Koslow, A.J. 2002. *Species identification in deep waters using multiple acoustic frequencies*. Canadian Journal of fisheries and Aquatic Science, 59, 1065-1077.

This is due to the low target strength of orange roughy compared to many other gas-bladdered species. Echotrace identification and delineation are manual processes, which can be strongly affected by analyst judgement and has a direct impact on biomass estimates. In standard surveys with scientists on board, species composition in sampling tows is combined with qualitative and quantitative observations on fish echotraces and fish behaviour (school dynamics) to assist with the interpretation of echograms. In terms of delineation, defining echotrace limits becomes a challenging task when the stock is not properly aggregated and individual fish are scattered around main aggregations. Delineation can be also affected by diminished visualization due to biased physical parameters and/or custom settings affecting the echogram appearance, including both visualization and school identification thresholds.

19. A major problem in the SIOFA region is that there is only a small area suitable for trawling, which limits sampling to a small number of fishable trawl paths per ground and the very limited surface area sampled by tows within each ground. For example, the SB ground has an area of over 36 m^2, but has only three limited trawl lanes in the whole region. Therefore, both empirical and statistical approaches to identify echotraces from catch data are of limited use within and beyond the survey period. As scientists are not present on board, access to the skipper knowledge can be critical to facilitate expert judgement on echotraces.

20. In order to reduce subjectivity, several suggestions were made:

   - Incorporate all available physical corrections (calibration, sound speed, absorption) into the echogram before school delineation.

   - Consider the use of 3D school visualizations to improve the spatial understanding of the surveyed aggregations.

   - Whenever possible, a consistent S_v threshold should be used for echotrace identification, within a tentative range between -72 and -76 dB.

   - To improve replicability and facilitate verification, a complementary database should be produced to keep track of mean positions for all detected echotraces.

   - Cross-checking between at least two experienced analysts should be performed on a regular basis.

21. The analysis of SB sample datasets confirmed that echotrace delineation was a complex task, with delineation being affected by visualization changes produced by absorption and/or calibration parameters input to the post-processing software, as well as by thresholds selected for visualization and/or school identification. Nonetheless, some tests conducted during the workshop showed visualization effects that produced changes less than 2 percent in estimated biomass for the Sleeping Beauty fishing ground.

22. The issues related to echotrace identification in vessel-mounted acoustic surveys have led to the use of multi-frequency methods in deep-towed bodies and net-attached acoustic optical systems[9]. Sealord Group (New Zealand) acquired a net-attached acoustic optical system (S-AOS), which was used on the Sleeping Beauty ground and other areas, notably the Southwest Indian Ridge, where the species identification issues were noted as much greater than at SB. Therefore, a sample AOS dataset was selected and groomed for assessing the magnitude of the bias that could be affecting current hull-mounted/single-frequency biomass estimates for SB. It was noted that some S-AOS data are available (Appendix 2) for further exploration of these issues in other regions.

3.5 Biological noise:

23. Biological noise corresponds to the additive effect upon backscatter from other species occurring within the identified orange roughy marks. The 2015 report[10] applied a correction factor for biological noise based on

[9] Ryan, T.E., Kloser, R.J. & Macaulay, G.J. 2009. *Measurement and visual verification of fish target strength using an acoustic-optical system attached to a trawlnet*. ICES Journal of Marine Science, 66(6), 1238-1244. doi: 10.1093/icesjms/fsp122.

Kloser, R.J., Macaulay, G.J., Ryan, T.E. & Lewis, M. 2013. *Identification and target strength of orange roughy (Hoplostethus atlanticus) measured in situ*. Journal of the Acoustical Society of America, 134(1), 97-108. doi: 10.1121/1.4807748.

[10] Niklitschek, E.J. & Patchell, G. 2015. *Acoustic abundance indexes for orange roughy and alfonsino in the Indian Ocean (SIOFA) from industry acoustics 2004 – 2008*. Southern Indian Ocean fisheries Agreement Scientific Committee Report. SIOFA SC-01-INFO-15.

discounting backscattered energy from rectangular areas adjacent to each identified orange roughy school. There was evidence this procedure could produce an overestimation of the true biological noise, particularly when orange roughy aggregation edges are diffuse.

24. In the text examples processed during the workshop, correcting by the apparent biological noise, could reduce the estimated biomass by up to 18 percent. While the risk for underestimating the biomass was considered higher than the risk for overestimating it, it was considered reasonable to assume the increase in backscattering produced by biological noise was cancelled out by the reduction produced by excluding orange roughy individuals scattered outside delineated echotraces.

3.6 Vessel noise:

25. From an analysis of vessel noise using Simrad, the F/V Will Watch (while carrying out the surveys under analysis), had low vessel noise at noise level (NL)=30 dB at 4.1 knots, increasing to NL=53 dB at 11.3 knots. At low speed the noise level is on par with the Norwegian research vessel GO Sars, but at maximum speed it is more like older research vessels. It is important to ensure that all vessels carry out noise tests, and surveys are conducted at speeds that maximise the signal to noise ratio in deep water.

3.7 Target strength:

26. The target strength (TS) to length equation was updated from the 2015 paper[11] for the larger Indian Ocean orange roughy that ranged from 35 to 60 cm. To extrapolate to the larger orange roughy found in the Indian Ocean at 38 kHz, the following TS equation of the form $TS=A*\log_{10}SL-B$ was proposed:

$$TS = 16.37*\log_{10}(SL) - 77.17$$

Where A is the slope derived from a 1999 paper[12], SL is standard length (of the fish) and B is the intercept derived from a 2013 paper[13]. This new TS equation alters the estimates of biomass by a factor of 1.28 compared to that reported in the 2015 paper for a mean 44.7 cm SL fish found at Sleeping Beauty fishing ground.

27. Most historical target strength work has been done on orange roughy with a mean standard length of ~35 cm. It is important to verify the estimate of the larger mean standard length orange roughy (40–55 cm) in the Indian Ocean as errors of up to 3 dB (factor of 2) may occur (Appendix 4).

28. To verify the target strength of the larger Indian Ocean orange roughy, a preliminary review of the Acoustic Optical System (AOS) data from the Sleeping Beauty region was undertaken. A dedicated tow that had the net-attached AOS recorded suitable targets and video data for ~44 cm mean-sized fish. Analysis of these data will be done subject to a verified calibration to estimate target strength of orange roughy. Other examples exist for larger fish in other regions (Appendix 2) which could also be analysed.

3.8 Statistical methods being used for producing biomass/abundance estimates:

29. There is a preliminary assessment on the effects of the statistical method being chosen for estimating biomass. i.e. geostatistics[14] vs. regular transect methods[15]. This assessment shows that the geostatistical approach tends to produce lower estimates than the regular transects method. Both methods have relative advantages and disadvantages, however, it is unclear which method produces more accurate estimates for both the mean and the variance. Further assessment is needed and needs to be progressed during the 2017.

[11] Niklitschek, E.J. & Patchell, G. 2015. *Acoustic abundance indexes for orange roughy and alfonsino in the Indian Ocean (SIOFA) from industry acoustics 2004 – 2008*. Southern Indian Ocean fisheries Agreement Scientific Committee Report. SIOFA SC-01-INFO-15.

[12] McClatchie, S., Macaulay, G., Coombs, R. F., Grimes, P. & Hart, A. 1999. *Target strength of an oily deep-water fish, orange roughy (Hoplostethus atlanticus) I. Experiments*. Journal of the Acoustical Society of America, 106(1), 131-142.

[13] Kloser, R.J., Macaulay, G.J., Ryan, T.E. & Lewis, M. 2013. *Identification and target strength of orange roughy (Hoplostethus atlanticus) measured in situ*. Journal of the Acoustical Society of America, 134(1), 97-108. doi: 10.1121/1.4807748.

[14] Roa-Ureta, R. & Niklitschek, E. 2007. *Biomass estimation from surveys with likelihood-based geostatistics*. ICES Journal of Marine Science 64: 1723–1734.

[15] Jolly, G.M. & Hampton, I. 1990. *A stratified random transect design for acoustic surveys of fish stocks*. Canadian Journal of Fisheries and Aquatic Sciences 47: 1282–1291.

4. Disentangling process and observation errors:

30. A major source of variability in acoustic surveys can be the availability of the fish to the acoustic instrument. Changes to fish availability can be due to species mixing masking the weaker orange roughy targets, fish movement into and out of the seabed deadzone, movement of fish into and out of the survey area or thresholding of dispersed orange roughy. This represents a process error and leads to variable biomass estimates. Methods to identify when the process error is dominant compared to the observation error are needed. Commonly several surveys (typically three) are carried out on a ground that have similar maximum fish availability, to ensure the process error and observation error are minimized.

31. To provide comparable results and a better understanding about the relative importance of different uncertainty sources, the panel recommended clearly separating sampling error, deadzone uncertainty and other sources of variability in the results.

5. Defining observation (practical management) units:

32. Initial discussions of survey results and a review of more extensive biological data suggested there was a need to develop stock management areas taking into account recent assessments in both New Zealand and Australia. In particular, the variability in biomass estimates between spawning aggregations from year to year in St. Helens and Paddy's in Australia, and in Morgue/Graveyard in Northwest Chatham Rise in New Zealand. Noting that the mean length of fish in the Sleeping Beauty spawning aggregation (44.7 cm) was the same as in the nearby Porky's and Sleepy Hollows aggregations, survey estimates could be combined for these.

33. The mean length of fish on Boulder Bank to the southeast of this area was 40 cm, and the two areas were separated by water deeper than 2 000 m. On another 300 m^2 bank further south the mean length increased to 47 cm, and on another bank nearby the mean length of orange roughy increased to 51 cm. With a range of mean size from 40–55 cm across the SIOFA region, it will be important to use a formal method to discriminate and propose practical management units, which could be based on size composition analysis until information from other stock identification methods becomes available. Size composition should be separated by sex, and the paper on *Biological Data on orange roughy stocks* that was presented as a background paper to the 1st SIOFA Scientific Committee meeting should be updated.

34. The discussion highlighted the need for age composition data for all these stocks prior to any stock assessment, and the likely cost of dealing with so many stocks in the SIOFA regions. Discussion of recent work in Australian waters and historical work in Chile and New Zealand led to a recommendation for otolith weight distribution to be established for each area, supported by sub-samples of otolith ageing to test for differences in age composition between areas, and for any differences in growth rates. It was noted that the orange roughy ageing protocol agreed between New Zealand (National institute for Water and Atmospheric Research) and Australia (Central Ageing Facility) should be followed.

6. Potential uses of available/new data series for stock assessments:

35. There are a total of 95 snapshots available for 24 fishing grounds carried out by the F/V Will Watch from 2004–2015 (Appendix 2). Several approaches for using these data for management purposes were discussed:

Average abundance/biomass estimations per ground or management units:

36. Considering the low exploitation rate on a number of stocks, it would be possible to combine biomass estimates from multiple years in order to produce reference biomass/abundance estimates suitable for serving as references (baseline) values for future management decisions. Averaging estimates across years would have the advantage of reducing uncertainty, which can be of particular relevance given the uneven coverage of different grounds across years. It is important to consider that, given the incomplete coverage of most areas, absolute (mean) biomass estimates could be produced only for a few specific grounds. For most grounds and probably all management units, estimates would instead correspond to minimum biomass estimates. Using these data for absolute snapshot estimates will increase the error/bias surrounding the estimate.

Yearly abundance/biomass time series per ground or management unit:

37. Some grounds and/or management units, such as Sleep Beauty and the Sleep Beauty complex, that have been consistently sampled across years could be suitable for producing time series adequate for detecting abundance changes over time and to support a formal stock assessment procedure. This would highlight both natural and fishing induced changes to the fish availability to the survey. As an example, the closed St. Helens hill spawning region (with no fishing) showed a natural cycle over four years reducing by 41 percent and then increasing by 50 percent[16]. Another complex, Boulder (near Sleeping Beauty) was noted to have a different size composition, and also a long time series of surveys, with low fishing intensity but high inter-annual variability. Using these data in a time series reduces the error and bias of some of the factors associated with estimating biomass (e.g. absorption, target strength).

38. Given the current uncertainties in target strength and other relevant factors affecting biomass estimates (in this and other deep-sea fisheries) and the irregular spatial coverage of several areas, we recommend exploration of alternative abundance indices based on stock distribution and/or backscatter intensity variables which could be suitable for tracking abundance/biomass changes over time without providing actual biomass/abundance estimates. How to use this type of index in a harvest strategy and stock assessment should also be explored.

7. Recommendations:

1. Selection criteria for undertaking a survey

- Surveys should be conducted/included only when fish are aggregated for spawning and become available to the acoustic observation system.

- Some preliminary criteria proposed were:

  o GSI should be above 10 percent (this preliminary number needs to be reviewed).

  o Prioritize survey times to when aggregations are stable and off the seabed.

2. Selection criteria for including a survey in the analysis

- An aggregation or density index should be investigated to provide an aggregation criteria to select suitable surveys.

- Ground coverage greater than 10 percent of the targeted stock distribution area.

3. Recommendations for reporting

- Include all relevant parameters: including target strength and mean length.

- Report separated CVs for sampling error, deadzone and other sources of uncertainty.

- Report separated deadzone estimaes.

4. Recommendations for analysis

- Use length-weight relationships instead of mean weight for scaling abundance to biomass.

- It might be useful to estimate length-weight by sex even if they get combined using a constant sex ratio across years.

5. Recommendations for future sampling work and acoustic data collection

- Define a target survey area (where the stock is expected to be present) for each ground.

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[16] Kloser, R.J., Sutton, C., Krusic-Golub, K. & Ryan, T.E. 2015. *Indicators of recovery for orange roughy (Hoplostethus atlanticus) in eastern Australian waters fished from 1987*. Fisheries Research, 167, 225-235.

- Target a minimum of three surveys per ground within a year to reduce overall CV below 20 percent.

- The priority is for consistent and precise estimates in a limited number of areas over an extensive but imprecise coverage of many grounds.

- A protocol has been defined for undertaking acoustic surveys in the SIOFA region[17]. Noting that the signal:noise ratio is strongly reduced in deep waters, and following a discussion at the workshop, participants recommended increasing the pulse duration to 2.048 ms. To do so, the echosounder must be calibrated for operating at both 1.024 and 2.048 ms.

- For consistency between survey years and grounds, and given recent equipment changes across fishing vessels globally (Simrad EK60 to EK80 and new ceramic transducers), continuous wave (CW) at 38 kHz should be used in all subsequent assessment surveys.

6. Recommendations for uptake into a stock assessment

- A review of the use of these data and how they can be used in a stock assessment for orange roughy needs to be undertaken. Ideally this review would be guided by a SIOFA agreed harvest strategy for orange roughy.

- The workshop recommended strong guidance be taken from the Global review of orange roughy (*Hoplostethus atlanticus*) biology, fisheries and management[18].

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[17] FAO. 2012. *Fishing vessel execution of acoustic surveys of deep-sea species: main issues and way forward*. FAO Fisheries and Aquaculture Circular. No. 1059. Rome. 91pp.
[18] FAO. In prep. *Global review of orange roughy (Hoplostethus atlanticus) biology, fisheries and management*. Geoffrey Tingley ed. FAO Fisheries and Aquaculture Technical Paper No. 622. Rome, Italy.

Appendix 1. Meeting participants

PARTICIPANTS

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Appendix 2. Indian Ocean F/V Will Watch acoustic surveys for orange roughy

Year	Zone	Feature	Survey	Type	Area	SA	N	B	CVB
2004	BD	Boulder	1	Hull Mounted	13	249	3	7,459	0.51
2004	BD	Boulder	2	Hull Mounted	5	292	2	6,114	0.44
2004	BD	Boulder	3	Hull Mounted	19	164	3	8,923	0.37
2004	BD	Boulder	6	Hull Mounted	23	148	4	9,308	0.25
2004	HV	Harvey's	1	Hull Mounted	7	184	1	1,817	0.74
2004	SB	Sleeping Beauty	3	Hull Mounted	12	260	5	13,232	0.81
2004	ER	Eric's	1	Hull Mounted	4	1114	4	11,291	0.73
2004	HL	Harlot	1	Hull Mounted	10	854	2	8,463	0.58
2004	MM	M.M	1	Hull Mounted	8	770	2	7,050	0.66
2004	MM	M.M	2	Hull Mounted	6	568	2	5,843	0.46
2004	MM	M.M	3	Hull Mounted	7	582	2	7,616	0.69
2004	MM	M.M	4	Hull Mounted	8	596	2	6,274	0.59
2004	MM	M.M	5	Hull Mounted	6	780	2	7,676	0.45
2004	SC	Scud	4	Hull Mounted	13	426	3	9,311	0.57
2005	AN	Angelo's	12	Hull Mounted	25	68	0	802	
2005	AN	Angelo's	14	Hull Mounted	15	144	1	3,461	0.51
2005	AN	Angelo's	June-18	Hull Mounted	9.7	141	1	2,310	0.30
2005	AN	Angelo's	19	Hull Mounted	10	57	0	605	0.42
2005	AN	Angelo's	21	Hull Mounted	16	228	1	5,310	0.37
2005	BD	Boulder	14	Hull Mounted	16	122	3	7,884	0.27
2005	BD	Boulder	15	Hull Mounted	13	143	2	6,108	0.48
2005	DV	Da Vinci	14.1	Hull Mounted	7	173	0	1,093	0.49
2005	DV	Da Vinci	14.2	Hull Mounted	8	167	0	1,838	0.38
2005	HV	Harvey's	11	Hull Mounted	7	135	0	864	0.53
2005	SB	Sleeping Beauty	11	Hull Mounted	25	112	2	7,040	0.26
2005	SB	Sleeping Beauty	12.1	Hull Mounted	13	371	7	18,911	0.28
2005	SB	Sleeping Beauty	12.2	Hull Mounted	23	253	8	23,090	0.23
2005	SB	Sleeping Beauty	12.3	Hull Mounted	42	177	7	20,511	0.24
2005	SB	Sleeping Beauty	14.1	Hull Mounted	17	245	5	13,806	0.34
2005	SB	Sleeping Beauty	14.2	Hull Mounted	28	77	1	3,279	0.33
2005	SB	Sleeping Beauty	19	Hull Mounted	45	202	8	22,000	0.23
2005	SB	Sleeping Beauty	21	Hull Mounted	56	139	10	29,085	0.22
2005	SH	Sleepy Hollows	10	Hull Mounted	14	150	1	1,665	0.29
2005	DA	David's	20050908	Hull Mounted	5	260	1	2,075	0.64
2005	ZE	Zedric	20050908	Hull Mounted	33	324	4	13,030	0.41
2008	BD	Boulder	0	Hull Mounted	3.7	140	1	2,004	0.67
2008	DA	David's	0	Hull Mounted	4.9	268	1	2,451	0.37
2008	MM	M.M	0	Hull Mounted	2.4	281	0	945	0.46
2008	SA	Saddle	0	Hull Mounted	0.7	121	0	85	0.96
2008	SB	Sleeping Beauty	0	Hull Mounted	6.7	133	1	3,179	0.25
2008	SU	Sugarol	0	Hull Mounted	0.6	135	0	187	0.85
2008	WR	Wrongford's	0	Hull Mounted	14.8	223	2	8,324	0.92
2008	DT	Dreamtime	0	Hull Mounted	1.1	304	0	463	0.56
2008	SC	Scud	0	Hull Mounted	2.1	245	0	412	0.51
2008	BB	Bill and Ben	0	Hull Mounted	4.8	198	0	1,549	0.39
2009	BD	Boulder	14	Hull Mounted	6.6	302	1	3,327	0.34
2009	BD	Boulder	21	Hull Mounted	5.8	244	1	3,163	0.30
2009	DV	Da Vinci	19	Hull Mounted	3.6	192	0	381	0.55
2009	GR	Grover	24	Hull Mounted	4.1	358	0	1,173	0.51
2009	RB	Robb's	17	Hull Mounted	5.8	1354	2	7,321	0.47
2009	ZE	Zedric	16	Hull Mounted	4.2	725	2	6,528	0.34
2009	ZE	Zedric	17	Hull Mounted	7.7	698	2	4,841	0.36
2009	AN	Angelo's	12	Hull Mounted	4.6	469	0	1,249	0.59
2009	SB	Sleeping Beauty	1	Hull Mounted	8.3	297	2	5,752	0.30
2009	SB	Sleeping Beauty	13	Hull Mounted	5.4	584	6	17,289	0.36
2009	SB	Sleeping Beauty	14	Hull Mounted	4.9	474	3	9,108	0.33
2009	SB	Sleeping Beauty	1201	Hull Mounted	5.9	370	3	9,137	0.29
2009	SB	Sleeping Beauty	1202	Hull Mounted	9.3	285	3	9,562	0.40
2009	SH	Sleepy Hollows	8	Hull Mounted	5.4	305	1	1,417	0.51
2009	SH	Sleepy Hollows	14	Hull Mounted	8.1	268	1	2,501	0.34
2009	WR	Wrongford's	5	Hull Mounted	5.3	368	3	10,012	0.31
2009	WR	Wrongford's	60	Hull Mounted	13.4	352	3	10,522	0.27
2009	WR	Wrongford's	68	Hull Mounted	13.5	274	2	8,371	0.23

Year	Code	Name	Date	Type					
2010	AB	Abby Road	23.1	Hull Mounted	2.6	368	0	858	0.15
2010	BD	Boulder	7.1	Hull Mounted	12.3	221	2	4,542	0.32
2010	BD	Boulder	30.1	Hull Mounted	12.3	229	2	6,447	0.22
2010	EP	El Paso	23.1	Hull Mounted	1.3	337	0	611	0.22
2010	GR	Grover	14.1	Hull Mounted	11.3	193	0	1,345	0.35
2010	NV	Novel	12.1	Hull Mounted	8.9	134	1	3,331	0.18
2010	SB	Sleeping Beauty	July afternoon-7	Hull Mounted	13.24	335	5	13,542	0.26
2010	SB	Sleeping Beauty	July morning-7	Hull Mounted	5.92	425	3	8,240	0.23
2010	SH	Sleepy Hollows	30.1	Hull Mounted	1.5	334	0	367	0.72
2010	WR	Wrongford's	27.11	Hull Mounted	33.4	132	4	12,728	0.16
2010	WR	Wrongford's	27.12	Hull Mounted	33.4	183	5	16,044	0.21
2010	WR	Wrongford's	28.1	Hull Mounted	33.4	264	9	29,546	0.18
2010	WR	Wrongford's	28.11	Hull Mounted	33.4	209	11	38,532	0.12
2011	SH	Sleepy Hollows	July-15	Hull Mounted	1.12	594	0	910	0.58
2011	ZE	Zedric	August-13	Hull Mounted	3.32	2952	5	15,635	0.34
2011	SB	Sleeping Beauty	1-Jul	Hull Mounted					
2012	BD	Boulder	8-Jul	Hull Mounted					
2012	NV	Novel	1-Jul	Hull Mounted					
2012		Danilo	1-Jun	Hull Mounted					
2013	SB	Sleeping Beauty	1-Jun	Hull Mounted					
2013	SB	Sleeping Beauty	1-Jul	Hull Mounted					
2013	BD	Boulder	1-Jun	Hull Mounted					
2013	BD	Boulder	1-Jul	Hull Mounted					
2014	SB	Sleeping Beauty	1-Jul	AOS- ID					
2014	SB	Sleeping Beauty	1-Jul	AOS					
2014	SB	Sleeping Beauty	1-Jul	AOS					
2014	BD	Boulder	1-Jul	AOS					
2014	DA	David's	1-Sep	AOS					
2014	FR	Freon	1-Oct	AOS-ID					
2014	PO	Pots	22-Mar	AOS-ID					
2014	SA	Saddle	1-Mar	AOS					
2014	SA	Saddle	1-Mar	AOS					
2014	RA	Rat	1-Mar	AOS-ID					
2014	RA	Rat	1-Mar	AOS-ID					
2014	CO	Commodore	1-Mar	AOS-ID					
2014	CO	Commodore	1-Mar	AOS-ID					
2014	CO	Commodore	1-Mar	AOS-ID					
2014	FR	Freon	31-Mar	AOS-ID					
2014	FR	Freon	31-Mar	AOS-ID					
2014	FR	Freon	31-Mar	AOS-ID					
2014	BT	Big Ted's	1-Apr	AOS-ID					
2014	BT	Big Ted's	1-Apr	AOS-ID					
2014	ER	Eric's	1-Sep	AOS					
2014	NV	Novel	1-Apr	AOS -ID					
2015	BD	Boulder	28-Jun	Hull Mounted	4.1	287	1	3,419	0.56
2015	BD	Boulder	4-Jul	Hull Mounted	8.9	590	8	19,572	0.35
2015	OK	OK Coral	2-Jul	Hull Mounted	4.6	260	1	4,043	0.21
2015	PK	Porky's	29-Jun	Hull Mounted	10.9	177	2	5,648	0.27
2015	SB	Sleeping Beauty	27-Jun	Hull Mounted					
2015	SB	Sleeping Beauty	29-Jun	Hull Mounted	7	300	2	5,269	0.30
2015	WR	Wrongford's	21-Jun	Hull Mounted	27.3	334	6	21,335	0.23

Appendix 3. Echogram showing orange roughy aggregation
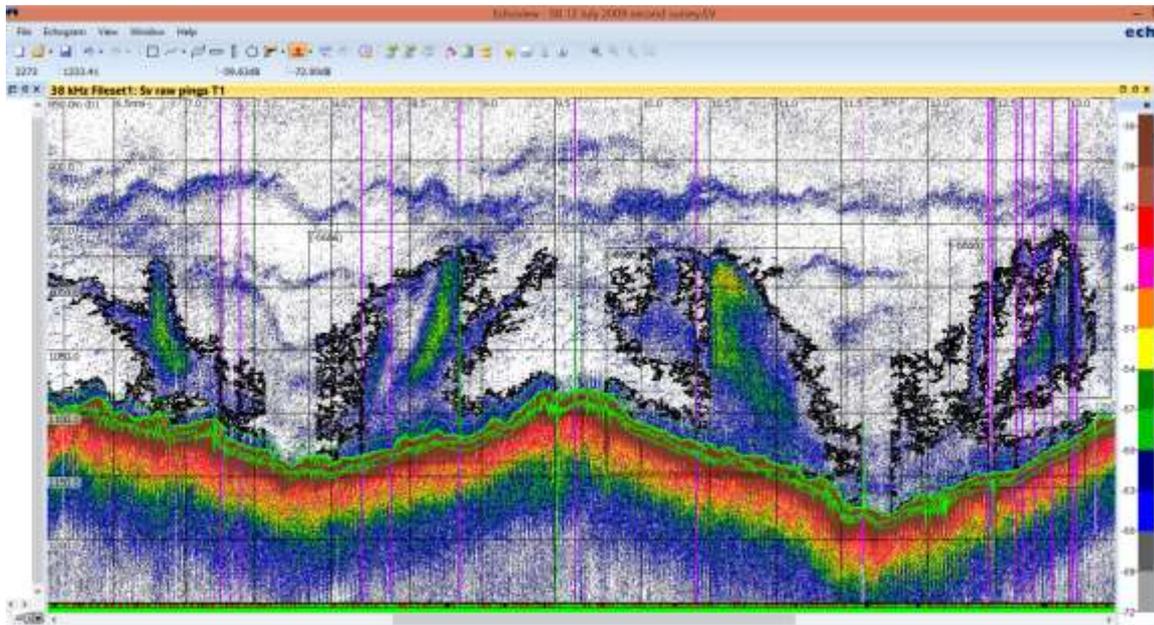
Appendix 4. Orange roughy target strength measurement examples

The figure below shows an image of a 45–55 cm orange roughy detected on 38 and 120 kHz frequencies at 987 m water depth, suitable for further analysis. This was detected on the Southwest Indian Ridge, and is in addition to the samples collected from the Sleeping Beauty fishing ground. A number of other acoustic optical system datasets available are listed in Appendix 2.

The *Sustainable Fisheries Management and Biodiversity Conservation of Deep Sea Living Resources in Areas Beyond National Jurisdiction* Project (ABNJ Deep Seas Project for short) is a five year project supported by the Global Environment Facility, and implemented jointly by the Food and Agriculture Organization of the United Nations, and the United Nations Environment Programme. The UNEP project component is executed though the UNEP World Conservation and Monitoring Centre.

The Project is designed to enhance sustainability in the use of deep-sea living resources and biodiversity conservation in the ABNJ through the systematic application of an ecosystem approach. It brings together over 20 partners who work on deep-sea fisheries and conservation issues in the ABNJ globally. The partnership includes regional organizations responsible for the management of deep-sea fisheries, Regional Seas Programmes, the fishing industry and international organizations. The Project aims to:

- strengthen policy and legal frameworks for sustainable fisheries and biodiversity conservation in the ABNJ deep seas;

- reduce adverse impacts on VMEs and enhanced conservation and management of components of EBSAs;

- improve planning and adaptive management for deep sea fisheries in ABNJ; and

- develop and test methods for area-based planning.

The ABNJ Deep Seas Project started in September 2015 and is one of four projects under the GEF Common Oceans Programme. More information is available from www.commonoceans.org