Report on the development of Harvest Strategies for key target species in the SIOFA area (Project code SE2020-01)

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EXECUTIVE SUMMARY

The Terms of Reference for this contract ask for evaluations of use of harvest strategies, and target and limit reference points, by other fishery organisations, and then for recommendations for adoption of similar approaches by SIOFA. Those practices in a number of such organisations are summarised, as are the assessments available for the three major species under harvest in the SIOFA area: alfonsino, orange roughy and Patagonian toothfish. However, for the other main species of commercial interest in this area, because only limited information is currently available, assessments (and hence reference points, and harvest strategies based on those) are not yet possible; hence, a process to move towards developing and then improving these assessments needs to be agreed. This process must include further data collection in particular, especially of catch and effort information.

For alfonsino, orange roughy and Patagonian toothfish, the alternative merits of three different approaches need to be considered:

I) Maintaining catches at present levels (unless there is evidence of a marked downward trend in the resource) until sufficient further data become available for meaningful improvements to the existing assessments.
II) Implementing an $F_{status\text{-}quo}$ harvesting strategy, which varies catches up or down in proportion to the results from continued collection of some measure or index of abundance.
III) Implementing a harvest strategy based primarily on some multiple of a proxy value of F_{MSY}, where this in turn is based on a proxy value for a B_{MSY} reference point whose value is informed by the most recent assessment of the resource.

The choice amongst these for each of the three species separately will come down primarily to the trade-off between likely greater stability of catch limits over time under the first approach, against possibly larger catches in the short term at least under the second and third.

For the other main, but data-poor, species in the SIOFA area, only the first approach is viable at this time, but needs to be augmented by one or more precautionary provisions. For example, the SAFE methodology might be applied to obtain some indication of whether the current catch is leading to an appreciable reduction in abundance – if so, necessitating a reduction in the present catch.

Keywords: *SIOFA, harvest strategies, data-poor, assessment, harvest control rule*

1) Background

A harvest strategy sets out a decision framework necessary to achieve defined biological (and sometimes economic) objectives for commercial fish stocks. Such strategies outline:

- processes for monitoring and assessing the biological status of commercial fish species against fishery-specific reference levels (reference points that generally relate to abundance and/or fishing mortality);
- pre-determined rules that control fishing activity according to the status conditions of the fishery (as defined by monitoring or assessment)—these rules are referred to as harvest control rules (HCRs) or decision rules.

Harvest strategies render broad policy objectives for a fishery operational. Such broad objectives might include:

- ensuring long-term sustainability and productivity;
- recovering heavily depleted stocks; and
- maintaining reasonable stability in catches for the industry.

While such objectives may be set in apparently simply terms, for example to achieve a stock abundance that will provide the maximum sustainable yield (B_{MSY}), such quantities can prove difficult to estimate, even for stocks for which very considerable quantities and types of data are available. Frequently therefore, it is customary to use “proxies” for such quantities (when used as reference points), which though not exactly equal to the quantity of interest, are on the basis of wide experience considered likely to be reasonable approximations to it.

2) ToR

The ToR for this contract ask for evaluations of use of harvest strategies, and target and limit reference points, by other organisations, and then for recommendations for adoption of similar approaches by SIOFA.

Bottom line: The review of those other organisations’ procedures shows generally that *where they use such approaches, they require data which are not available for nearly all (of the top 15[1]) of SIOFA species.*

3) Summary of approaches in other organisations

Appendix 1 summaries the approaches used on the USA west coast, New Zealand and ICES, with a particular emphasis on approaches to data-poor situations. Appendix 2 provides a summary for Australia; this has been separated from Appendix 1, as while providing general guidelines, it is not as explicit regarding specific methods for advising catch limit recommendations as for the cases summarised in Appendix 1.

By way of background, generally these summaries indicate that where an approach to estimation of reference points is given (and in circumstances where one could assess where one is relative to those

[1] This species selection was advised by Alistair Dunn.

for a particular fishery), a pre-requisite is the availability of abundance trend information (typically from surveys or CPUE). However, where only catch time series are available ("data limited"/"data-poor" situations), the information provided is more towards offering approaches to set an appropriate TAC, rather than specifying reference points and/or harvest control rules (HCRs).

There's little specific by way of formulae: ICES and the US west coast offer the DCAC method (see Appendix 1) as a default – this method adjusts recent average catch by an amount that depends on the (gu)estimated extent of some recent reduction in abundance, i.e. it still begs information on abundance trend in some form. Otherwise in worse circumstances still, ICES offer PSA[2] (which Georgeson *et al.* (2020) reject – see below) or adjusting recent average catch by a precautionary buffer (essentially a 20% decrease). Australia and New Zealand ultimately seem to offer little more than "this is difficult" and "be cautious".

In instances where there is better, but nevertheless still not considerable data collected over a long period of time on which to base assessments, the reference points and harvest strategies that may be put in place are generally based on proxies. Thus, for example, for New Zealand orange roughy the target reference point is chosen in the range of 30-50%B_0, while CCAMLR effectively sets this value at 50%B_0. (B_0 is the estimated pristine abundance, i.e. abundance before harvesting commenced.) In both these cases, the limit reference point is 20%B_0; in New Zealand, dropping below that limit reference point triggers a requirement for a formal, time-constrained rebuilding plan. Harvest strategies linked to such reference points are often similarly simple: for example, as long as the biomass is above the corresponding limit reference point, these are based on a constant fishing mortality which is a multiple of a proxy for the fishing mortality that will yield MSY (F_{MSY}). That multiple is often set to a value less than 1 to make some allowance for precaution.

4) SIOFA species

A list of the main 15 species of commercial interest to SIOFA has been developed with the assistance of Alistair Dunn. Appendix 1 includes a Table summarising the values of their demographic parameters (*M*, growth curve etc.) for possible use in developing reference point values.

Current information available pertinent to developing assessment/management advice is as follows:

a) Alfonsino

- Catch and (not very robust) CPUE.
- Simple ASPM assessment and projections.

b) Orange roughy

- Catch plus acoustics estimates of abundance; the latter are better developed for the Walter's Shoal region thus far.
- Uncertainty in absolute values (corresponding to estimates of *q*) is high – at best these are able to indicate qualitatively only regarding, say, whether the stock is currently above 0.5B_0 (a B_{MSY} proxy) or not.

c) Toothfish

- Some assessments exist, but these are based on very limited CPUE data.

[2] See Appendix 1 for more on the DCAC and PSA methods.

d) Others

- "Spotty" catches – their extent (both as regards reliability and period covered) varies by species.

Note that Appendix 3 includes summaries of the assessments available at present for alfonsino, orange roughy and toothfish.

Implications

- All these species/fisheries (including even the top three) could be considered data limited.
- Only for the first three might one realistically consider suggesting reference points and/or HCRs.
- Even there though, a generic approach will be difficult to suggest because the information available for orange roughy is qualitatively different from that for the other two.

5) Moving forward

Overall, in due course for the data-poor species

- Almost certainly for all 12 of these species, the best immediate strategy is to aim to stay at present abundance, and hence likely to set TACs at recent average catches.
- Nothing more elaborate seems merited until more data (both for effort and catch-at-length composition) become available.
- However, there will still be a need to examine data regularly for any signs of "trouble" (catches that may be unsustainable and depleting stocks), in which case the extent of an appropriate reduction in the TAC would need to be debated.
- This regular examination needs to include due consideration of the possible factors that could increase risk because they may bias indices (such as CPUE) that are used to provide insight into trends in stock abundance. This is discussed further in section 6) below.
- Note the Georgeson *et al.* (2020) paper about sharks also provides a basis for detecting such signs:
  - They advocate use of the SAFE[3] (Sustainability Assessment for Fishing Effect) rather than the PSA (Productivity and Susceptibility Analysis) approach.
  - SAFE is nevertheless somewhat speculative, and the reliability of the estimates which it has provided needs independent verification.
  - Importantly, the Georgeson *et al.* (2020) paper does emphasise that management requires better data to allow assessments and their improvement (consistent with the suggestions above).
  - Note that Ecological Risk Assessment (RSA) for SIOFA fish species is to be conducted later this year using both SAFE and PSA.

Overall, in due course for the three species for which assessments are already available

Here, separately for each of the alfonsino, orange roughy and toothfish species, a choice amongst three different approaches would seem to warrant consideration.

[3] See Appendix 1 for more on the SAFE method.

i) As suggested immediately above for the data-poor species, maintain catches at present levels (unless there is evidence of a marked downward trend in the resource) until sufficient further data become available for meaningful improvements to the existing assessments.

ii) Implement a harvest strategy based primarily on some multiple of a proxy value of F_{MSY}, where this in turn is based on a proxy value for a B_{MSY} reference point whose value is informed by the most recent assessment of the resource. Thus, for example, as long as the most recent assessment indicated resource biomass to be above its limit reference point, the TAC could be given by:

$$TAC = p^* F_{MSY}{}^*B_{curr}$$

where B_{curr} is the estimate of biomass for the most recent year in the assessment, and p is a number less than 1 by an amount related to the agreed extent of precaution deemed desirable.

iii) Implement an $F_{status\text{-}quo}$ harvesting strategy, which varies catches up or down in proportion to results from continuing collection of some measure (e.g. acoustic biomass estimate) or index (e.g. CPUE) of abundance. This is a population-model-independent approach, still based on the constant fishing mortality concept, which raises or lowers TACs according as resource abundance rises or falls. Thus, if $I_{now/future}$ is the value of that index now/in some future year:

$$TAC_{future} = k^*TAC_{now} * I_{future}/I_{now}$$

where k is set to a number below/equal to/above 1 depending on whether the aim is to decrease/maintain/increase the current fishing mortality. Hence choosing k=1 amounts to maintaining the "*status-quo* F".

Each of these approaches has its pros and cons, and these would need to be discussed carefully for each species before a choice was made.

Approach i) – Maintain present catch

Pros

- Simple (does the current reliability of the assessment justify anything more elaborate?)
- Relatively low resource risk given the indications of stock status from most current assessments.

Cons

- In a number of cases, current assessments indicate resource abundance likely to be reasonably well above B_{MSY} (e.g. both west and east alfonsino stocks at about 0.6^*B_0), so that there is potential to increase current catches while avoiding the prospect of an overfished resource (abundance dropping below B_{MSY}). Adopting approach i) would mean waiting some time for additional data to become available before that could be done.

Approach ii) – A simple harvest strategy based on B_{MSY}

Pros

- The TAC is automatically raised or lowered in response to the resource abundance increasing or decreasing, thus providing an additional measure of protection of the resource against undue reduction in abundance.
- In some cases, this would allow for an increase in current catches to occur very soon.

Cons

- B_{MSY} and B_{lim} need to be specified. This need not be too much of a concern however, as surrogates in common use elsewhere in the world, such as $B_{MSY} = 0.4*B_0$ and $B_{lim} = 0.2*B_0$, would be perfectly defensible choices to make at this stage. The specific choice for B_{lim} is not of immediate importance, given indications from current assessments that the resource abundances are well above such a level.
- Given that the data available for the assessments is limited, as further data become available estimates of B_0 may change quite appreciably. These changes could be larger still if changes are made to assessment methodology over time (which is preferably avoided unless there are compelling reasons to do this).
- In consequence, this approach may lead to high variability in TACs each time these are set (probably annually), and near independent of any actual change in stock status, leading to undesirable industrial instability.
- Although in cases where CPUE is the primary index of abundance used in the assessment, relatively frequent (annual perhaps) updates of assessments would be possible, frequent acoustic surveys of orange roughy would seem unlikely, so that the advantages of regular adjustment of the TAC in response to changes in abundance would be diminished.

Approach iii) - An $F_{status\text{-}quo}$ harvesting strategy

Pros

- The particular attraction of this approach is that it maintains the benefits (such as the TAC responding in proportion to changes in resource abundance) of approach ii), while ameliorating some of its problems – in particular there is no need to fit a population model to estimate B_0, B_{MSY} and B_{curr} with the attendant potential problems (particularly those related to undesirable variability in TAC outputs over time).
- It is easier to implement than approach ii).
- It retains the advantages approach ii) has over approach i).
- B_0 and hence (proxy-)B_{MSY} are not estimated, so that there is no explicit estimate of the current abundance of the resource relative to B_{MSY}; however, if there are some broad indications that the resource is indeed above B_{MSY}, some increase in catches without undue risk to the resource can be achieved by choosing a value for k that is a little larger than 1.

Cons

- The problem of TAC variability for reasons other than actual changes in resource abundance will not be completely eradicated because of imprecision in indices of abundance, e.g. environmental variability leading to changes in CPUE. This can be ameliorated by basing the TAC formula on averages of recent index values over the past 3 or 5 years, say, but that means that the index is not as responsive to possible recent changes in the resource's abundance.

- Orange roughy surveys seem unlikely to be sufficiently frequent to allow the full benefits of this approach to be realised.

If “good” data were available, certainly approaches ii) or iii) would be clearly preferred to approach i). However, in the cases in question here, it is not obvious that this is the case. The key question is whether the “in principle” benefits of approaches ii) or iii) yet outweigh the disadvantages that may follow of considerable variability in catch limits over time (hardly related to actual abundance trends in the resource) which will be to the detriment of industrial stability.

Before a final choice is made, some computations (at not too complex a level) should be undertaken to quantify this trade-off for each of the three species concerned, so as to provide a more objective basis to underpin a final decision. Note that sometimes these concerns are taken into account in another way, as for example in New Zealand where relatively complex simulation studies might be undertaken to underpin the specific choices for target and limit reference points in cases where the quality of the input data available for the assessment is seen to be somewhat limited; while such computations could be done for these SIOFA cases too, it might prove time-effective to first attempt some simpler approach.

Perhaps more immediately

- Given more details on what catch and effort data are currently available for other than the main three species, it would be possible to add advice on:
  - What data-limited approaches may be workable.
  - What species should have higher priority
  - What future data collection to emphasise.
- However, it seems that it will take some time to reach the stage of the necessary compilation of these data, so that for the moment it appears appropriate to place such further possible investigations on hold until that compilation can be completed. It should be noted that recommendations in this regard clearly need to be based on the data as held by the Secretariat.
- Clearly advice to the Commission on the intensity and duration of the further data collection needed for the various SIOFA fisheries would be desirable to assist to prioritise such collection activities. However, that in turn first needs results from the initial stages of such collection, as that will indicate the extent of variability in each of the various datasets; that needs to be known before computations to indicate the necessary intensity and duration of a complete program of such collection could be conducted.

6) Other aspects

Related to the reliability of CPUE as an index proportional to stock abundance

- Information on the spatial distributions of catches and how these change over time must be collected and examined. For example, if fleets move from aggregation to aggregation, depleting each in turn, then the resultant CPUE will appear steady while in reality the abundance of the resource is dropping steadily.
- Especially when CPUE is being used as the primary basis for management, regular review of data inputs to the evaluation of TAC recommendations must give attention to indications of

the presence of other factors leading to possible questioning of such a proportionality relationship. These include increase in the efficiency of the fishing effort applied and hyper-stability, as these could lead to an increase in risk to the resource if they were overlooked in the process of calculating catch limits.

Effort-limitation rather than Catch-limitation based management

- The discussion in the section 5) is essentially premised on management measures being in the form of catch limits. In principle, limitations could be based on effort rather than catch (such as limitations on the number of vessels allowed to operate in a fishery). However, this may raise difficulties related to the needs then to standardise such effort for the different powers of different fishing vessels, as well as to take account of the concern raised in the preceding bullet.

Related to information that could further improve assessments

- In addition to further and improved catch, effort and catch-at-length data, there are other potential sources of information that could improve assessments, such as surveys and tagging.

- However, the pros and cons of investing in these first need careful consideration for a number of reasons; for example:
    - Surveys usually require the availability of considerable financial and other resources.
    - Some survey methods are in principle very valuable in providing information on biomass in absolute rather than relative terms, but the reliability of the assumptions that need to be made to achieve this may be difficult to confirm.
    - For some species, especially deepwater ones, tagging may not be practical because of the difficulties associated with capturing and then returning the fish alive to the sea.

Possible shared stocks

There may be instances of stocks overlapping into other jurisdictions, e.g. toothfish populations present in both the SIOFA and CCAMLR regions of responsibility. In due course, consideration might need to be given to harmonisation of approaches in such instances, but at this stage of SIOFA's development of harvesting strategies, this would not seem an immediate priority.

7) Core recommendations

- For most SIOFA species of commercial interest, assessments (and hence reference points, and harvest strategies based on those) are not yet possible, and a process to move towards developing and then improving them needs to be agreed.
    - This needs to include further data collection in particular.
    - The priority for such data is more and better catch and effort information.

- For the three species for which some initial assessments are already available (alfonsino, orange roughy and toothfish), the alternative merits (pros and cons) of three different approaches need to be considered:
    IV) Maintaining catches at present levels (unless there is evidence of a marked downward trend in the resource) until sufficient further data become available for meaningful improvements to the existing assessments.
    V) Implementing an $F_{status\text{-}quo}$ harvesting strategy, which varies catches up or down in proportion to the results from continued collection of some measure or index of abundance.
    VI) Implementing a harvest strategy based primarily on some multiple of a proxy value of F_{MSY}, where this in turn is based on a proxy value for a B_{MSY} reference point whose value is informed by the most recent assessment of the resource.

- For the other data-poor SIOFA species, only approach i) is viable at this time, but needs to be augmented by one or more precautionary provisions. One example of such a provision is the reduction of the present level of catch in circumstances where there may be some sound evidence (provided perhaps by, for example, application of the SAFE methodology) that that catch is unsustainable and reducing resource abundance appreciably.

Reference

L. Georgeson, C. L. Rigby, T. J. Emery, M. Fuller, J. Hartog, A. J. Williams, A. J. Hobday, C. A. J. Duffy, C. A. Simpfendorfer, T. Okuda, I. C. Stobutzki and S. J. Nicol. 2020. Ecological risks of demersal fishing on deepwater chondrichthyan populations in the Southern Indian and South Pacific Oceans. *ICES Journal of Marine Science*. doi:10.1093/icesjms/fsaa019.

Appendix 1

Summary of West Coast US, New Zealand and ICES Tier systems used to advise on HCRs, Reference Points and Catch Limits

Summary

A number of countries or organisations have "tier" systems in place which are used to determine the method of management of various fish stocks. The "tier" is determined by the amount and quality of the data available for assessment purposes for the stock in question Analyses of these countries' procedures shows generally that for their top tiers for which HCRs linked to Reference Points are applied, they require data which are not available for nearly all (of the top 15 commercial) SIOFA species.

This document provides a summary of the "tier" methods employed for the US (west coast), New Zealand and ICES for managing their fisheries. Data-poor fishery provisions are listed first, and in more detail, given their greater pertinence to SIOFA stocks. A summary of demographic parameter values for these 15 SIOFA species is also provided.

Overview of approaches used for data-poor fisheries

USA (west coast)

Tier 3: Data-poor

a) No reliable catch history. No basis for establishing OFL. [OFL is the average catch during a period when the stock is considered to be stable and close to B_{MSY} equilibrium on the basis of expert judgment.]
b) Reliable catch estimates only for recent years.
c) Reliable aggregate catches during period of fishery development and approximate values for natural mortality. Default analytical approach depletion-corrected average catch (DCAC).

   The Depletion-Corrected Average Catch is a method for estimating sustainable yields for data-poor fisheries. Based on the idea that the average catch has been sustainable if abundance has not changed, DCAC makes a correction to that average if abundance has increased or decreased (which may be the subject of an educated guess based on subjective impressions). The magnitude of the correction depends on the natural mortality rate, which should be about 0.2 or smaller to apply this model. Uncertainty is recognized in all of the parameters in the model, and is reflected in the output of a probability distribution.
d) Reliable annual historical catches and approximate values for natural mortality and age at 50% maturity are required. The default analytical approach is depletion based stock-reduction analysis.

New Zealand

Data-poor:

- The level of stock productivity (using demographic parameters) is defined (see Table A1.1)
- Recommended default proxies for B_{MSY} (expressed as $\%B_0$) based on productivity level (see Table A1.2).
- For information-limited or information-deficient stocks, a retrospective 3-5 year running average may also be appropriate. For a CPUE proxy, over the 3-5 year period the average CPUE should not fall below the target CPUE level. Similarly, over the preceding 3-5 years, the average reported landings should not exceed the target catch level. This will provide some degree of flexibility for information-limited and information-deficient stocks. A one-off fluctuation should not necessarily result in a change to the TAC. The TAC should be reviewed in the event that the retrospective 3-5 year average is exceeded. Assessment of the available information may indicate that a TAC increase is warranted, although caution may be required so as not to create an incentive to obtain a higher catch level by consistently overcatching the existing TAC. Similarly, some caution is required where the TAC is consistently undercaught. Undercatch of the TAC may not necessarily reflect a decline in abundance.

Table A1.3 provides a list of the 15 most commercially important SIOFA species, along with their values of natural mortality (*M*) and resultant productivity level based on the New Zealand definitions provided in Table A1.2.

Table A1.1. Guidelines for categorising productivity levels for exploited fish species. Numbers outside brackets are from FAO (2001); numbers in brackets are from Musick (1999). M is natural mortality; r is the intrinsic rate of natural increase; k is the Brody growth coefficient; t_{mat} is the average age of maturity; t_{max} is the expected maximum age in the absence of fishing, approximated by the formula corresponding to the age at which a cohort drops to 1% of its original number; and G is the average generation time approximated by the formula given.

Parameter	Productivity		
	Low	Medium	High
M	< 0.2	0.2–0.5	> 0.5
r	< 0.14 (< 0.16)	0.14–0.35 (0.16–0.5)	> 0.35 (> 0.5)
k	< 0.15 (< 0.16)	0.15–0.33 (0.16–0.3)	> 0.33 (> 0.3)
t_{mat} (years)	> 8 (> 4)	3.3–8 (2–4)	< 3.3 (< 1)
t_{max} (years) (t_{max}=4.6/M)	> 25 (> 10)	14–25 (4–10)	< 14 (1–3)
G (years) (G=t_{mat}+1/M)	> 10	5–10	< 5
Examples	orange roughy, many sharks	cod, hake	sardine, anchovy

Table A1.2. Recommended default proxies for B_{MSY} (expressed as $\%B_0$) and F_{MSY} (expressed as $F_{\%SPR}$ levels from spawning biomass per recruit analysis).

Productivity level	$\%B_0$	$F_{\%SPR}$
High productivity	25%	$F_{30\%}$
Medium productivity	35%	$F_{40\%}$
Low productivity	40%	$F_{45\%}$
Very low productivity	≥ 45%	≤ $F_{50\%}$

Table A1.3. A list of the 15 most important SIOFA species, along with their values of natural mortality (*M*) and resultant productivity level based on the New Zealand definitions provided in Table A1.2. Information on the growth parameters Linf and Kappa, as well as the average age of maturity (t_{mat}) and maximum age in the absence of fishing (t_{max}) are also provided. Information on the various parameters are predominantly from FISHBASE. (Cumulative catch values have still to be obtained.)

Species	**Common name**	**Cummulative catch (since 1999)**	**PRODUCTIVITY based on M**	**M**	**Linf**	**Kappa**	**t_{mat} (ave age of maturity)**	**t_{max} (max age)**
Saurida spp	lizard fish		**HIGH**	0.7	42.4 cm	1.2	1	7
Nemipterus spp	bream		**HIGH**	> 0.5	30 cm	0.8	1	3.4
Carangidae	fish		**HIGH**	>0.5	20-75 cm	0.8	2-4	6
Sparidae	porgies		**MEDIUM**	0.2-0.45	27.8 cm	0.573	2	4
Schedophilus velaini	barrel fish		**MEDIUM**	0.41	127 cm	0.198	7	18
Pseudopentaceros richardsoni	boarfish		**MEDIUM**	0.3-0.4	69.21 cm	0.05	6	20
Decapterus spp	scad		**LOW**	<0.2	57.1 cm	0.24	6	86
Beryx spendens	Alfonsino		**MEDIUM**	0.2	80.6 cm	0.384	4	12
Dissostichus elengoides	Patagonian toothfish		**LOW**	0.15	134 cm	0.1	6-9	50
Hoplostethus atlanticus	Orange roughy		**LOW**	0.05	40.1 cm	0.044	32	149
Dalatias licha	kitefin shark		**LOW**	no details	65.1 cm	0.27	2	14
Squalus acanthias	shark		**LOW**	~0.1	120 cm	0.1	7	25
Centroscymnus coelolepis	dogfish shark		**LOW**	<0.2	94.23	0.11	9(m) and 20(f)	34
Epigonus telescopus	fish		**LOW**	<0.2	70.9 cm	0.04	7	100
Ruvettus pretiosus	oilfish		**LOW**	0.11	90 cm	0.2	?	42
	level 1 (have stock assessments)		**HIGH >0.5**					
	level 2 (Sharks - some info)		**MEDIUM 0.2-0.5**					
	level 3 (other fish spp - little info)		**LOW <0.2**					
	scoring on data information level by authors		Scoring: NZ definitions					

ICES

If the data and knowledge requirements are not fulfilled, ICES cannot provide advice consistent with MSY; instead ICES applies an advice rule that is based on precautionary considerations only.

Category 4. Stocks for which reliable catch data are available (This category includes stocks for which a time-series of catch can be used to approximate MSY)**.**
The approach is to use catch information to evaluate whether the stock is fished sustainably, or whether a reduction in catch is required to achieve sustainability. Decreases or increases in catch advice are incremental and slow.

- When only catch or landings data are available, and the data may not be continuous or consistent over time for a variety of reasons.
- The time-series and data used should be recorded and justified;
- The Depletion Corrected Average Catch (DCAC) method requires cumulative total catch over several years, while Catch Curve Analysis requires age or possibly length disaggregated catch numbers;

  Assumptions: The average catch has been sustainable if abundance has not changed. Depletion Corrected Average Catch is an approximation of MSY. However, a catch advice based on MSY is only appropriate to stocks near BMSY. For situations in which DCAC is much greater than recent catch, stock size may be less than BMSY and catch advice should increase slowly toward DCAC.

  Data and information needed to apply the methods

  - The time-series and data used should be recorded and justified;
  - The Depletion Corrected Average Catch (DCAC) method requires cumulative total catch over several years, while Catch Curve Analysis requires age or possibly length disaggregated catch numbers;
  - Auxiliary information, such as historical survey information, may also be helpful, although it should be noted that if survey information is available, then the possibility of "upgrading" the stock to another category (e.g. Category 3) should also be considered.

When a sufficient catch history is available, which need not be continuous, to determine a suitable exploitation rate:

- Apply the Depletion-Corrected Average Catch (DCAC) model;
- Use a stepped approach to catch advice to slowly increase advised catch toward Depletion-Corrected Average Catch, or to quickly reduce advised catch toward Depletion-Corrected Average Catch;
- If catch is less than TAC because of uptake issues, this method of deriving catch advice may not be appropriate.

DCAC is calculated as:

$$DCAC = \frac{\sum C_t}{n + \Delta[B_{peak}(F_{MSY}/M)M]^{-1}} \quad (1)$$

where

- C_t is the catch during year t;
- n is the length of catch time-series in years;
- Δ is the decline in the relative stock status;
- B_{peak} is the biomass that corresponds to maximum sustainable yield relative to carrying capacity (B_{MSY}/B_0);
- M is the instantaneous rate of natural mortality; and

- F_{MSY}/M is the ratio between the fishing mortality rate that corresponds to B_{peak} and M. Catch advice (C_{y+1}) should be a derived using a stepped approach; Apply the 20% Uncertainty Cap (defined below) to the catch advice *If recent catch is greater than DCAC*
$$C_{y+1} = (1-\omega)C_{SQ} + \omega DCAC \quad (2)$$
- Apply the 20% Uncertainty Cap to the catch advice
- C_{SQ} is the status quo catch i.e. the current TAC value.

If recent catch is less than DCAC, advised catch should be based on a slower step increase

$$C_{y+1} = (1+\delta)C_{SQ} \quad (3)$$

- where δ reflects the desired rate of increasing catch to DCAC (e.g. 0.1). This 'slow up-fast down' approach is designed to account for stocks that may be at relatively low biomass that cannot support MSY.
- Apply the 20% Uncertainty Cap to the catch advice.
- Then apply the Precautionary Buffer to the catch advice

Uncertainty Cap. Note that in the Introduction to the ICES Advice this is referred to as the "change limit". A change limit of ±20% is applied in the advice. This change limit is relative to the reference on which it is based and may be, e.g. recent average catches or a projection of a trend. Apply this cap to the catch advice to address uncertainty or noise in the data and its potential influence on the catch advice. If C_{y+1} is 20% greater or less than C_{y-1}, then apply a cap of 20% change to C_{y+1}.

Precautionary Buffer. Note that in the Introduction to the ICES Advice this is referred to as the "precautionary margin". A precautionary margin of -20% has been applied for those cases when the stock status relative to candidate reference points for stock size or exploitation is unknown. Exceptions to this rule have been made in cases where expert judgement determines that the stock is not reproductively impaired, and where there is evidence that the stock size is increasing or that exploitation has reduced significantly; for instance, on basis of survey indices or a reduction in fishing effort in the main fishery if the stock is taken as a bycatch species. Apply this buffer of a 20% reduction to catch advice (C_{y+1}) when reference points are unknown; however, if substantial increases in abundance indices or other stock indices are consistently observed (i.e. not due largely to noise in the data), or there are substantial reductions in fishing mortality (or effort) in the target fishery, this precautionary buffer may not apply to catch advice. For example, if abundance indices (I) increase by 50% or more, so that:

$$\frac{\sum_{i=y-2}^{y-1} I_i/2}{\sum_{i=y-5}^{y-3} I_i/3} > 1.5 \quad (4)$$

then the Precautionary Buffer may not apply to catch advice. In addition, if there are substantial effort decreases in the target fishery, for stocks that are caught mainly as bycatch, the Precautionary Buffer may not apply.

This approach is intended to move in the direction of sustainable exploitation, having due regard for the species' biological characteristics and uncertainty in the information. This implies that advice is applicable to a time frame which is compatible with a measurable response in the metrics used as the basis for the advice; i.e. in the simplest case, and where the least information is available, this would imply multi-annual constant catch advice. Where least information is available, including cases where the 20% precautionary margin has been applied, ICES therefore considers that the advice is not expected to be changed for a fixed and determined period such as, for example, three years, unless important new knowledge emerges regarding a stock which may justify a revision of the advice.

Categories 5 and 6. Landings only stocks or negligible landings stocks and stocks caught in minor amounts as bycatch.

- In situations where only landings/catch data are available, and no relevant life history or fishery information can be gleaned from similar stocks or species in the ecoregion or beyond, ICES will normally provide advice on the basis of previous catches/landings, applying the precautionary buffer.
- If catches have declined significantly over a period of time and this could represent a reduction in stock size, ICES may advise zero catch or the implementation of a management strategy.

Category 5: Data-poor stocks

- This category includes stocks for which only landings data are available.
- In the rare situation that only landings (or catch) data are available and no relevant fishery information can be gleaned from similar stocks or species in the ecoregion or beyond, the situation to address here is biodiversity rather than yield.

Method 1: Productivity and Susceptibility Analysis (PSA) risk assessment

- This method was proposed, but not made available for implementation for the 2012 ICES Advice. The application of PSA in the formation of catch advice is still under development and will be considered in future workshops.
- Conduct a Productivity and Susceptibility Analysis (PSA) risk assessment to determine if reductions in catch are necessary.)

Method 2: If there is no indication of where F is relative to proxies and no marked positive trends in stock indicators

- Calculate the catch advice (C_{y+1}) as Cy-1.
- Apply the Precautionary Buffer to the catch advice.

Further details for each system relating to stocks with more data available:

(1) United States west coast groundfishery

Over 90 species are included in the Pacific Coast Fishery Management Plan, including rockfishes, groundfishes, sharks and skates. The Pacific Fisheries Management Council Science Scientific and Statistical Committee (PFMC SSC) places each stock into one of three ‘categories’ (and one of 11 subcategories) (Table A1.4) depending on the method and reliability of the assessment. Specifically, stocks assessed using data-rich methods may be considered data-moderate if, for example, the assessment is dated, the assessment did not estimate annual deviations in recruitment about the stock–recruitment relationship, or the assessment results were sensitive to plausible changes to the assumptions.

Of 144 stocks for which OFLs are available, 21 stocks are currently in category 1 (the most data-rich), 29 stocks are in category 2, and the remaining stocks (94) are in category 3 (the most data limited. Not all stocks are managed as individual species; several stocks are instead managed as complexes under the assumption the stocks within a complex have roughly the same productivity and vulnerability.

Table A1.4: Tier assignments for USA west coast groundfish assessments.

Tier 1: Data rich

a) Reliable compositional (age and/or size) data sufficient to resolve year-class strength and growth characteristics. Only fishery-dependent trend information available. Age-/size-structured assessment model.
b) As in 1a, but trend information also available from surveys. Age-/size-structured assessment model.
c) Age-/size-structured assessment model with reliable estimation of the stock–recruit relationship.

Tier 2: Data moderate

a) Natural mortality multiplied by survey biomass assessment (as in Rogers 1996).
b) Historical catches, fishery-dependent trend information only. An aggregate population model is fit to the available information.
c) Historical catches, survey trend information, or at least one absolute abundance estimate. An aggregate population model is fit to the available information.
d) Full age-structured assessment, but the results are substantially more uncertain than assessments used in the calculation of the σ used to compute the buffer for category 1 stocks (Rallston *et al.* 2011). [σ is the among-assessment variation, based on estimates of spawning biomass]. Reasons for placing a stocks in this category include that assessment results are very sensitive to model and data assumptions, or that the assessment has not been updated for many years.

Tier 3: Data-poor

See above

(2) New Zealand Harvest Strategy Standard and Guidelines

New Zealand has developed a Harvest Strategy Standard (HSS) = policy statement of best practice in relation to the setting of fishery and stock targets and limits for fish stocks.

- It establishes a consistent and transparent framework for decision making to achieve sustainable utilisation of fish stocks.
- It provides suggested methods for calculating or approximating the biological reference points specified in the HSS.
- The HSS is a key input to the setting of TACs, although other considerations such as environmental principles and economic, social and cultural factors also play a role.
- The MSY-compatible reference points are MSY, B_{MSY} and F_{MSY}.
- The goal is to maintain stocks at or above B_{MSY} and to rebuild stocks that are below this level.

The Harvest Strategy Standard consists of three core elements; specific values for NZ orange roughy stocks are shown in parenthesis, given that orange roughy is the species taken in one of the three major fisheries in the SIOFA area:

- A specified target about which a fishery or stock should fluctuate (30-50%B_0);
- A soft limit that triggers a requirement for a formal, time-constrained rebuilding plan. The default soft limit is ½ B_{MSY} or 20% B_0, whichever is higher (20%B_0); and
- A hard limit below which fisheries should be considered for closure. The default hard limit is 1/4 B_{MSY} or 10% B_0, whichever is higher (10%B_0).

For orange roughy these are implemented through a harvest control rule that recommends an appropriate catch limit which, in the long term, will maintain the stock within the target management range 99% of the time. The harvest control rule is based on 4-yearly adjustments of the TACC (Total Allowable Commercial Catch), and is designed to provide for higher catches when the stock is assessed to be above the midpoint of the target range, and potentially more appreciable catch limit reductions when the stock is assessed to be in the lower half of the management target range.

Information Considerations

In general, fishery and stock targets and limits should be set more conservatively for stocks with lower levels of information or higher levels of uncertainty, due to the higher risks associated with managing such fisheries on a long-term basis to provide for utilisation while ensuring sustainability. It must, however, be noted that the amount of data available for a fishery will not necessarily be well-correlated with the amount of useful information contained in those data and the associated stock assessment models. This will depend on the type of data available and the credibility and robustness of the assessment models.

Application of the Harvest Strategy Standard to Specific Fishery Situations

(1) New or developing fisheries should be managed cautiously because there
is generally little known about the size of the stock, or stock productivity, or stock status, during the development phase.

(2) Established, well-managed fisheries
By definition, well-managed fisheries are those that fluctuate around appropriate targets and remain well above biomass limits. Management action should ensure that this situation continues. The Operational Guidelines specify the types of management actions that should be used to ensure that fisheries fluctuate around appropriate targets, well above biomass limits.

(3) Fisheries on depleted stocks
Depleted stocks are defined as those that have been reduced below ½ B_{MSY} or 20% B_0, whichever is higher.

(4) Fisheries on highly migratory species or fisheries managed under an international agreement.

Conceptual B_{MSY}: In cases where the relationship between CPUE and abundance can be assumed to be more or less proportional, or where some other form of relationship has been derived from data, it may be reasonable to select an appropriate historical period when both CPUE and catches were relatively high and to use this CPUE level as a target. The best example in current use in New Zealand is that for rock lobster. Note, however, that “high CPUE” must be treated with caution in cases where it is known or expected that high CPUE can be maintained even for seriously depleted stocks, or where fishing behaviour or gear efficiency has substantially changed over time.

Stock Productivity

It is generally accepted that fish stocks with low productivity (i.e. those with high age of maturity, high longevity, slow growth rates or low fecundity) tend to be less resilient to fishing. In fact, rather than productivity, the demographic variable of greatest relevance to the risk of stock collapse is population resilience, which can be defined as the "ability [of a stock or population] to rebound after perturbation" (Holling 1973). The problem with the concept of resilience is that it is not an operational concept. There is no reliable way of measuring the ability to rebound, except empirically. Due to the lack of operationality of the concept of resilience, population productivity is often used as a measurable proxy for resilience.

More productive species tend to have rapid growth rates, high fecundity and high turnover of generations. Species with high natural mortality must generally be more productive because they must produce higher numbers of offspring to compensate.

Mace (1994) also found that the ratio of B_{MSY} (the average biomass associated with MSY) to B_0 (the unexploited biomass) declined, but only very slightly, over the range of natural mortalities and growth rates considered (M=0.1-0.3 and the Brody growth coefficient K=0.1-0.3, respectively).

Two sets of guidelines for categorising species in terms of low, medium and high productivity levels are presented in Table 1 (from FAO 2001) – see above.

(3) Summary for ICES advice

This section provides only information not already provided in the data-poor section above.

The ICES MSY advice rule requires a relatively high level of data and knowledge on the dynamics of the stocks concerned. If the data and knowledge requirements are not fulfilled ICES cannot provide advice consistent with MSY; instead ICES applies an advice rule that is based only on precautionary considerations.

For the purposes of identifying the advice rule to be applied when giving advice on fishing possibilities, ICES classifies the stocks into six main categories on the basis of available knowledge.

Category 1 – Stocks with quantitative assessments. Includes stocks with full analytical assessments, and forecasts that are either age-/length-structured or production models.
Category 2 – Stocks with analytical assessments and forecasts that are only treated qualitatively. Includes stocks with quantitative assessments and forecasts which, for a variety of reasons, are considered indicative of trends in fishing mortality, recruitment, and biomass.
Category 3– Stocks for which survey-based assessments or exploratory assessments indicate trends. Includes stocks for which survey, trends-based assessments, or other indices are available that provide reliable indications of trends in stock metrics, such as total mortality, recruitment, and biomass.
Category 4– Nephrops stocks where information on possible abundance can be inferred and stocks for which a reliable time-series of catch can be used to approximate MSY. This is where there are reasonable scientific grounds to use life-history information and density information from neighbouring areas to provide advice.
Category 5– Data-poor stocks
This category includes stocks for which only landings data are available.

In the rare situation that only landings (or catch) data are available and no relevant fishery information can be gleaned from similar stocks or species in the ecoregion or beyond, the situation to address here is biodiversity rather than yield.

Category 6– Negligible landings stocks and stocks caught in minor amounts as bycatch. Includes stocks where landings are negligible in comparison to discards, as well as stocks that are primarily caught as bycatch species in other targeted fisheries.
There are cases when few fish are caught and recorded, either because their abundance is low or because they are simply discarded at sea, that ICES has not traditionally provided catch advice, and such advice may not be appropriate. These stocks may be caught incidentally as bycatch in targeted fisheries with harvest control rules or TACs. Information may or may not be collected by some fleets encountering these stocks, and advice on reducing the catch of these stocks may be irrelevant as they are simply discarded or not landed in large quantities.

For category 1 and 2 stocks, ICES provides advice in accordance with agreed management plans/strategies evaluated to be consistent with the precautionary approach when requested. If such plans/strategies are not agreed or have been evaluated by ICES as not being precautionary, ICES will give advice on the basis of the ICES MSY approach.

Data and information needed to apply the methods depending on category

Category 2: Stocks with analytical assessments and forecasts that are only treated qualitatively

(A quantitative assessment is available, but for a variety of reasons is being treated as merely indicative of trends in fishing mortality, recruitment, biomass and future catches, rather than as an analytical assessment with catch forecast.)

- The forecast and an explanation of current year assumptions (basis of forecast);
- Trends information and estimates of potential reference points for each stock (e.g. $F_{0.1}$ and MSY $B_{trigger}$). $F_{0.1}$ should be estimated to be consistent with the quantitative assessment. MSY $B_{trigger}$ should represent a stock size below which more conservative catch advice is needed to avoid impaired productivity (e.g. B_{loss}, 25th percentile of estimated biomass).

Category 3: Stocks for which survey-based assessments indicate trends

(Surveys or other relative abundance or biomass indices are available for these stocks and they provide reliable indications of trends in total mortality, recruitment and abundance or biomass, but no quantitative, analytic assessment is available for the stock)

- The time-series of the biomass index (or abundance) that should be used to determine the status of the stock and provide catch advice as methods are developed needs to be identified;
- When a biomass index is available, it should be used rather than an abundance index;
- Determination of whether or not the resource is over exploited:
    - Agreed upon stock-specific life-history traits (Le Quesne and Jennings, 2012) (e.g. L_{MAX} values, r, k, M) and the corresponding proxies for sustainable fishing mortalities. Any other information that the EG deems relevant to categorizing the stock or providing an analytical assessment;
    - Approximations of current exploitation rate or fishing mortality based on size structure of fully exploited or mature sizes are needed to determine if overfishing is occurring (e.g. size based estimates of total mortality, equilibrium size distribution of the population);
    - Ideally, this method requires a quantification of current fishing mortality and $F_{0.1}$, but this determination may be based on expert opinion.

- A survey-based proxy for MSY $B_{trigger}$ should be estimated to represent a survey index below which more conservative catch advice is needed to avoid impaired productivity (e.g. lowest observed survey index or 25th percentile of survey indices). Ideally this would be an index of exploitable biomass;
- Survey-adjusted *status quo* catch should be applied only when the stock does not appear to be overfished and is at an appropriate stock size. To address this concern, the recommended method for advised catch includes a biomass trigger and a determination of overfishing;
- Situations in which catch is less than TAC because of uptake issues should also be considered because this method may not be appropriate to those situations.

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Appendix 2

Overview of Harvest Strategy Guidelines for Australia

Note: The information from Australia has been presented differently from that for the other organisations/nations for which summaries are provided. The reason for this is that while as for those other cases, the extracts below have been chosen to emphasise data-poor situations as are the most pertinent to SIOFA, in the Australian case what is provided for those situations is more of the nature of broad general guidelines than specific suggestions for bases to compute TAC recommendations.

Background

In developing their National Guidelines, Australia acknowledged that ESD (Ecologically Sustainable Development) is a common high-level legislative objective across Australian fishery management jurisdictions. In this context, they considered that Australian fishery harvest strategies should adopt an ESD approach and must also balance the need for flexibility (to allow for changing circumstances) with providing certainty to stakeholders for how a fishery will be managed. What is presented below are extracts from Sloan *et al*. (2014) and (Australian Government 2018).

Defined operational objectives for the fishery

For Australian Commonwealth fisheries, operational objectives are defined by adoption of the MEY target and the limit reference point whose default value is half the biomass corresponding to MSY. A key factor in developing operational objectives for a harvest strategy is the status of the fishery. The 'Status of key Australian Fish Stocks Report 2012' (Flood *et al*. 2012) provides a national framework for classifying fish stock status and uses a limit reference point of recruitment overfishing. There are five classifications of status relative to this reference point:

- Sustainable stock;
- Transitional – recovering stock;
- Transitional – depleting stock;
- Overfished stock; and
- Undefined stock. — This indicates that not enough information exists to determine stock status.

Reference points for performance indicators

There are three main types of reference point against which fishery performance can be measured. These are commonly referred to as 'target', 'limit' and 'trigger' reference points. In the case of data-poor or multi-species fisheries, reference levels may instead refer to trends (e.g. if catch exceeds the historical catch for 3 consecutive years, then a management action is triggered).

The *Commonwealth Fisheries Harvest Strategy Policy* stipulates that the **limit reference point** for biomass is equal to or greater than half of the biomass estimated for maximum sustainable yield (MSY), which defaults to 20% of the unfished biomass where B_{MSY} cannot be calculated (Australian Government 2007). All stocks must be maintained above their biomass limit reference point (B_{LIM}) at least 90 per cent of the time.

Target reference points (TRP's) typically relate to desired economic and/or social outcomes. A common economic objective is MEY. Target reference points for MEY are generally based on harvest rates, biomass targets or biomass proxies such as CPUE. In cases where stock-specific B_{MEY} is unknown or not estimated, a proxy of 0.48 times the unfished biomass, or 1.2 times the biomass at maximum sustainable yield (B_{MSY}), should be used. Where B_{MSY} is unknown or poorly estimated, a proxy of 0.4 times unfished biomass should be used. Alternative target proxies may be applied provided they can be demonstrated to be compliant with the policy objective. Historical levels of CPUE that occurred during periods of high economic yield have also been used as Target reference points.

Trigger reference points (TrRPs) identify a point (such as a biomass level) at which a substantial change in the exploitation rate occurs. Various values are used for different stocks.

WHAT DESIGN PRINCIPLES SHOULD BE APPLIED WHEN DEVELOPING A HARVEST STRATEGY?

The design principles listed in this section build on earlier work undertaken to establish the *Commonwealth Fisheries Harvest Strategy Policy and Guidelines* (Australian Government 2007) and guidelines developed for application in data-poor fishery scenarios (Dichmont et al. 2011).

WHAT CONSIDERATIONS SHOULD BE TAKEN INTO ACCOUNT FOR SPECIFIC FISHERY SCENARIOS?

To date, most formal harvest strategies in Australia have typically been developed and applied to high value, data-rich fisheries (Dowling *et al.* 2008). To a certain extent, this reflects the challenges (some perceived and some real) faced by fishery managers when developing harvest strategies in other situations such as in data-poor fisheries, recreational fisheries and multi-jurisdiction fisheries etc. To help support the development of tailored fishery-specific harvest strategies, the following set of considerations has been developed to assist fishery managers, fishers and key stakeholders to develop fishery harvest strategies in the following specific fishery scenarios, particularly where challenges or complexities may have created barriers to their development and implementation in the past. These include:

- Multi-jurisdictional fisheries;
- Recreational fisheries (including as part of multi-sector fisheries);
- Customary/ cultural/ traditional fisheries;
- Multi-species fisheries;
- Data-poor fisheries;
- Fisheries based on fluctuating stocks (includes regime shifts, climate change, environmental flows and estuarine fisheries, highly productive stocks etc.);
- Multi-gear fisheries;
- Enhanced fisheries;
- Keystone species;
- Exploratory and Developing fisheries;
- Fisheries based on low productivity species;
- Spatially structured fisheries; and
- Fisheries recovering from overfishing or unfavourable environmental conditions.

Note that the following considerations do not provide an exhaustive list of all considerations, but aim to capture key issues specific to each fishery scenario.

Data-poor fisheries

The term 'data-poor' is a relative term and can cover a range of conditions. For the purposes of the National Guidelines, data-poor fisheries are typically characterised by the following (Dichmont *et al.* 2011):

1. Classic (quantitative) stock assessment models are unable to be used, for reasons either of data availability, data quality and/ or analytical capacity;

2. A large uncertainty in the status and dynamics of the stock due to poor data;
3. uncertainty in the nature of fishing (e.g. in terms of fleet dynamics and targeting practices); or
4. Have a low gross value of production (GVP).

The development of harvest strategies for data-poor fisheries represents a significant challenge, that of reconciling available information and capacity against a formal and defensible harvest strategy that achieves the desired objectives for the resource and fishery (Dichmont *et al.* 2011; Dowling *et al.* 2011). The challenge, therefore, is developing harvest strategies that reconcile the reality and limitations of these fisheries with fishery objectives or policy. These objectives may include, but are not limited to, ceasing or avoiding overfishing, rebuilding overfished stocks and maintaining stocks at some target level (Bence *et al.* 2008). These objectives all imply some knowledge of the stock size or biomass (relative or absolute). However, a difficulty in managing by biomass-based decision rules is that, while the intention is to constrain risks to the stocks through fishery management, stocks often do not have adequate data and/or capacity to be managed in this way.

Data-poor fisheries should be managed cautiously because there is generally little known about the size of the stock, stock productivity or stock status. Explicit fishing down phases should be avoided because these are unsustainable in the long-term and result in a build-up of fishing capacity that often cannot easily be re-directed. The combination of poor information, high pressure and overcapacity frequently results in targets being overshot, particularly for low productivity species.

Management approaches based around empirical harvest decision rules are beginning to be accepted in a growing range of data-poor fisheries (Davies *et al*. 2007; Dowling et al. 2008; Dichmont and Brown 2010). There has also been some theoretical work done on the relative robustness and particular sensitivities associated with the different types of empirical indicators (Smith *et al.* 2009; Punt *et al.* 2002; Dowling *et al.* 2011). Dichmont *et al.* (2011) developed a set of guidelines for harvest strategy development in data-poor situations, which should be referred to when developing harvest strategies in this fishery scenario.

The following are useful summary considerations in developing harvest strategies for data-poor fisheries:

1. Risk should be reduced in data-poor fisheries, by limiting fishing intensity to conservative levels.
2. A cost-catch-risk analysis is required, where explicit consideration should be given to the trade-off between the intensity of monitoring, the level of harvest and the risk to the stock.
3. Where conservative trigger levels for catch or effort are exceeded, additional data should be collected at a level appropriate to inform both current and likely future assessment and harvest strategy needs (this requires that some mechanism for monitoring mortality is adopted).
4. A risk-based approach is required when ‘developing’ data-poor fisheries (i.e. one that is based on species productivity and susceptibility to fishing rather than on quantitative stock assessment).
5. A tiered/stepped approach to developing data-poor fisheries is required. The harvest strategy should specify the timeframes for the different phases of fishing.

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Appendix 3

Overview of available assessments and results for the three main fisheries in the SIOFA area

Alfonsino (*Beryx splendens*) assessments

Summary

An Age-Structured Production Model has been applied (Brandão *et al*. 2020) to assess the Alfonsino (*Beryx splendens*) resource in the West and East SIOFA areas. The data used in the models are the total catch, standardised CPUE series and a single year of commercial catch length distribution information. Both West and East stocks are estimated to be at about 60% of their pre-exploitation spawning stock biomass levels, and well above the levels corresponding to MSY (B_{MSY}). These results are not insensitive to changes in the value assumed for natural mortality (*M*). Twenty-year projections under various constant catch scenarios are available for the Base case as well as for sensitivity tests that make a different assumption of the value of *M*.

Overview

Separate management units: West and East

Data

- Total catch for each fleet (effectively nation) from 1977
- Standardised CPUE (relative abundance indices)
- Catch-at-length data available for one fleet in 2018.

Model

- Deterministic model
- Same selectivity function assumed for all fleets.
- Key assumptions: Beverton-Holt stock-recruitment function, steepness h = 0.75, M = 0.2, age at maturity = 6.

Results

Table A3.1 shows a summary of the results for the Base case (M=0.20) and the sensitivity that assumes M= 0.15. Results are shown for the West and the East areas. Figure A3.1 compares the spawning biomass depletion trajectory for the Base case with those for the two sensitivity tests (which assume different M values) for the West area. Figure A3.2 shows spawning biomass depletion trajectories for the Base case for the West area, together with twenty-year projections under constant future annual catches equal to the 2018 catch as well as for several variants of this value: ±10%, ±20%, ±30% and ±40%. Corresponding results for Figures A3.1 and A3.2 but for the East area are given in Figures A3.3 and A3.4.

Table A3.1. Summary results for the Base case and the *M*= 0.15 sensitivity (F* is the fishing proportion – the ratio of annual catch to start-year biomass).

Parameter estimates	West		East	
	Base case	M = 0.15	Base case	M = 0.15
B^{sp}_{2019} (tonnes)	29 827	19 864	9 203	6 347
B^{sp}_{2019}/B_{MSY}	2.078	1.385	2.053	1.354
B^{sp}_{2019}/K^{sp}	0.607	0.451	0.599	0.437
F^{*}_{2019}	0.072	0.109	0.108	0.156
F^{*}_{2019}/F^{*}_{MSY}	0.312	0.733	0.479	1.052
MSY (tonnes)	3 325	2 123	1 010	696

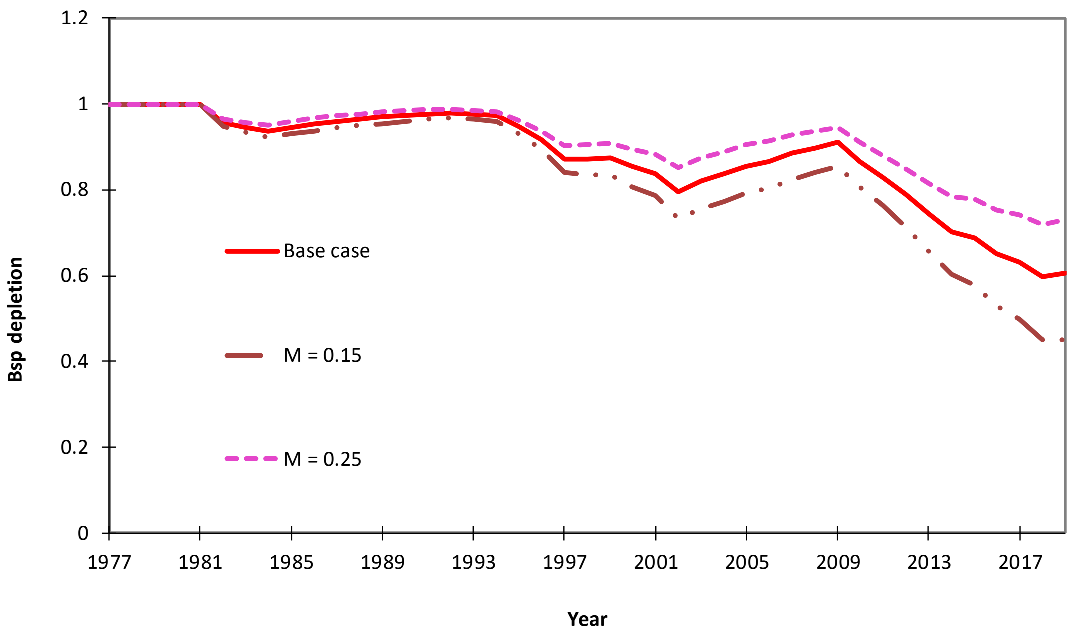

Figure A3.1. Spawning biomass depletion estimates for the **Base case** for the **West** as well as for two **sensitivity tests:** 1) *M* = 0.15 and 2) *M* = 0.15.

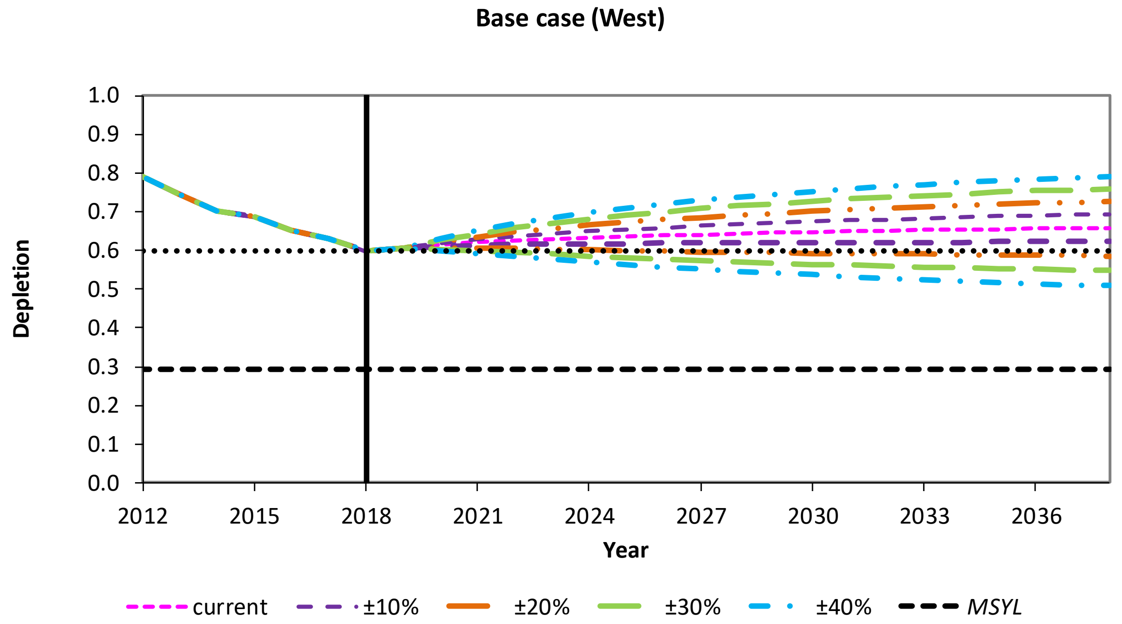

Figure A3.2. Spawning biomass depletion projections (shown after the vertical line) under future annual catches of 2 157 tonnes (as for 2018) for the **Base case** for the **West** as well as for several variants of this catch: ±10%, ±20%, ±30% and ±40%. The dotted horizontal line shows the current (2018) depletion value for this assessment model and the dashed horizontal line shows the *MSYL* value.

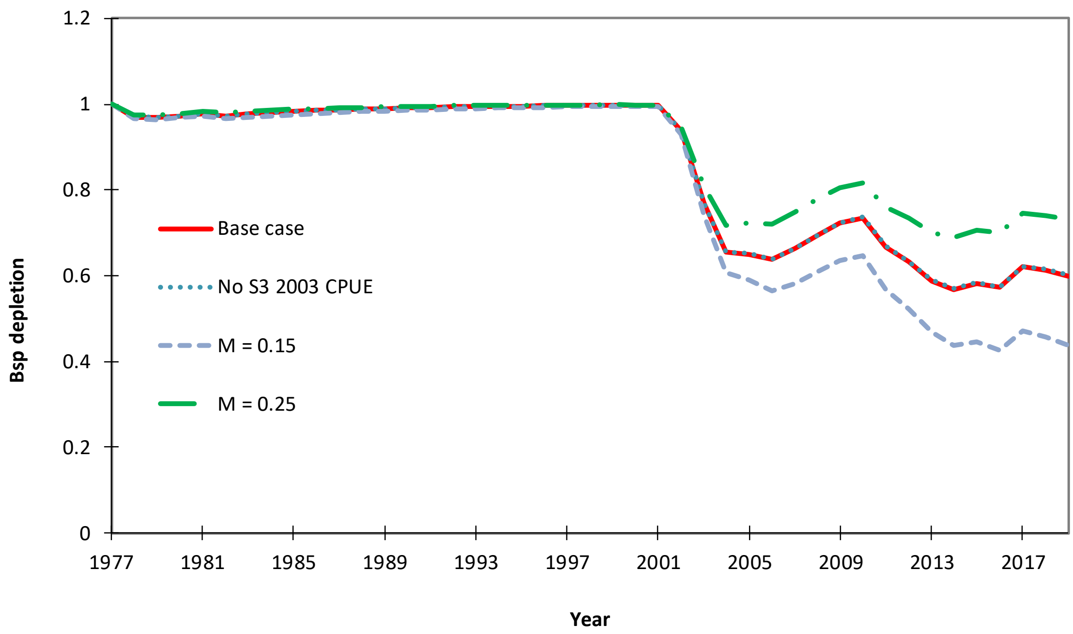

Figure A3.3. Spawning biomass depletion estimates for the **Base case** for the **East** as well as for three **sensitivity tests:** 1) omit S3 2003 CPUE index, 2) $M = 0.15$ and 3) $M = 0.25$.

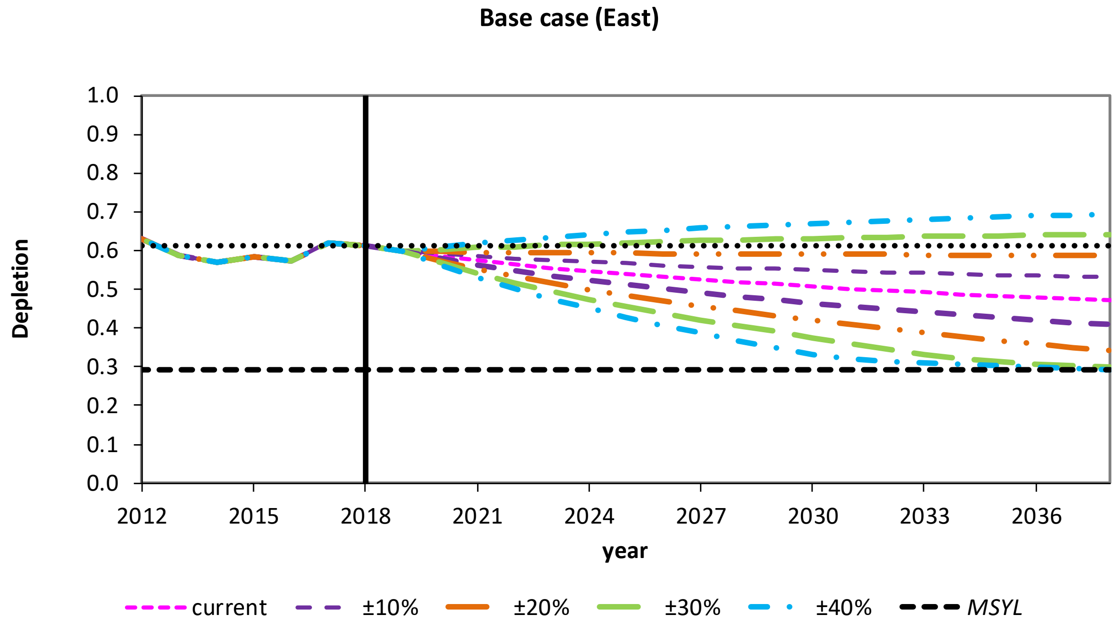

Figure A3.4. Spawning biomass depletion projections (shown after the vertical line) under future annual catches of 992 tonnes (as for 2018) for the **Base case** for the **East** as well as for several variants of this catch: ±10%, ±20%, ±30% and ±40%. The dotted horizontal line shows the current (2018) depletion value for this assessment model and the dashed horizontal line shows the *MSYL* value.

Conclusions

- Both West and East stocks are at healthy levels of about 60% of their pre-exploitation spawning biomasses
- Neither stock is overfished (i.e. B is not below B_{MSY}) nor is overfishing taking place (i.e. F is not above F_{MSY})
- The only sensitivity test with much impact and importance is that for a lower value of M, which indicates poorer stock status and productivity.

Reference

Brandão, A., Butterworth, D.S. and Johnston, S. 2020. Age-Structured Production Model (ASPM) assessments of the Alfonsino (*Beryx splendens*) resource in the SIOFA area of the Southern Indian Ocean. 2nd Meeting of the Stock and Ecological Risk Assessment Working Group (SERAWG2). SERAWG2-02-14, 39pp.

Orange roughy (*Hoplostethus atlanticus*) assessments

Summary

Stock assessments are available for two regions, the Walter's Shoal region (WSR) and SIOFA statistical areas 1, 2, 3a and 3b. Orange roughy from Walter's Shoal region has been assessed using a Bayesian single-sex, multi-area (7 areas) model. The data used in the model are the catch history and acoustic biomass estimates. The absolute scale of the WSR stock is very uncertain because the true scale of the acoustic biomass estimates is poorly known. Virgin biomass (B_0) is very likely to be in the range of 25 000 – 90 000 t. However, the current stock status is very healthy according to the model results with certainty (within the model) that current spawning biomass is above 50% B_0. Stochastic five-year projections are available for the Base model and the more conservative "Low" model.

Seven stocks are considered in SIOFA statistical areas 1, 2, 3a and 3b. One stock has hardly been fished and no acoustic biomass estimates are available, so no assessment was attempted. A catch-history based assessment is performed on six stocks (for this method only total catch for each year is required as the value of a maximum exploitation rate achieved is assumed). For three of those simple Bayesian assessments, this is also carried out using acoustic biomass estimates (although these have not been revised/refined) and some inferences from the WSR assessment. Under the catch-history based method, stock size was very uncertain for all stocks, but current stock status was at least 40% of the virgin size for five of the six stocks. The remaining stock (Walter's Seamounts) had a minimum status of 22% of the virgin size. The model-based estimates, for the three stocks that had acoustic estimates (including Walter's Seamounts), were also very uncertain as regards stock size in absolute terms, but indicated that current stock status was at least 70% of virgin stock size.

Overview

Separate assessments for:

1. Walter's Shoal Region
2. SIOFA areas 1, 2, 3a and 3b.

Walter's Shoal (11 named features) [in SIOFA area 2] (Cordue, 2018a)

- Well defined catch history from 2002 (guesstimates used for 2000 and 2001 – sensitivity run on these values – half and double guesstimate)
- Sexed length-weight data from 2004
- Sexed age-length data in 2017 from the Sleeping beauty feature
- Acoustic biomass estimates of spawning aggregations (8 estimates from different features in years 2007 to 2015). There are more acoustic estimates, but these have not been reviewed or refined. Three different treatment of acoustic estimates are used.

  In commenting on the acoustic biomass estimates, the SIOFA SC-SAWG state (SIOFA SC-SAWG, 2018): "Eight acoustic survey biomass estimates were available that have been reviewed and refined; these were from five different features collected from 2007 to 2015 during peak spawning. A much larger set of acoustic estimates were available but had not be reviewed and refined; these were used in a sensitivity run."

Biological parameters:

- Growth parameters
- Length-weight parameters
- M (constant across ages), estimated with a highly informative prior
- Stock-recruitment relationship with h = 0.75 (Beverton-Holt)
- Maturation parameters (model estimates).

Model (Bayesian) – 8 model runs in addition to base/middle

- Single-sex
- Seven areas: home, other and 5 numbered features. Home: only immature fish. Migrate as soon as mature
- Model starts in 1885
- Fishing is at the end of the year.

Estimated model parameters

- B_0
- YCS (1987-1992): the cohort strengths
- M (informed by prior)
- Maturation: a_{50} = age at 50% maturity and a_{to95} = number of years after 50% maturity that 95% maturity occurs
- 5 migration parameters
- Acoustic q.

Table A3.2 reports the median and 95% CIs for the estimates of some of the Base model parameters, while Table A3.3 reports the median virgin spawning biomass, the current spawning biomass, the current stock status, and the probability of current biomass being above 30%B_0 or 50%B_0 for the Base model and several sensitivities. Figure 5 shows Base model projections of the spawning biomass under a constant catch at the current level.

Conclusions

1. Absolute scale of the WSR stock is very uncertain because the true scale of the acoustic biomass estimates is very uncertain.
2. Very probably B_0 is in the range: 25 000 – 90 000t
3. Stock status is certainly above 50% B_0
4. Local depletion may be an issue for some un-numbered features if they were heavily fished in 2000/2001 and have not yet recovered
5. Current catches with the current spatial distribution are fine (except perhaps for Feature 4)
6. The challenge is to devise a practical management regime that maintains the stock at sustainable levels and avoids local depletion of any of thesub-stocks.

Table A3.2. Base model: MCMC estimates of the parameters (excluding YCS parameters). The median and 95% CI is given for each parameter. The second row are the migration proportions for mature fish from Home to the given ground expressed as percentages. This Table is reproduced from Table 4 of Cordue (2018a).

B_0 (000 t)	Acoustic q	M	a_{50} (years)	a_{to95} (years)	
43 29-64	0.68 0.44-1.05	0.043 0.033-0.055	37 29-47	14 5-25	
Other	**Feature 1**	**Feature 2**	**Feature 3**	**Feature 4**	**Feature 5**
20 16-24	13 11-16	11 9-14	15 11-20	31 27-36	9 7-12

Table A3.3. MCMC estimates: medians and 95% Cis for virgin spawning biomass (B_0), current spawning biomass (B_{17}), and current stock status ($ss_{17} = B_{17}/B_0$) for the base model and sensitivities (see Cordue (2018a) for the description of each run). The estimated probability (%) of current spawning biomass being above 30%B_0 or 50%B_0 is also given. This Table is reproduced from Table 8 of Cordue (2018a).

	B_0 (000 t)	B_{17} (000 t)	ss_{17} (%B_0)	P(B_{17} > 30%B_0)	P(B_{17} > 50%B_0)
Base	43 29-64	32 19-53	76 63-87	100	100
Low	29 22-42	19 12-31	65 53-77	100	100
High	71 46-97	61 37-86	85 76-94	100	100
Uniform	42 29-64	32 19-53	75 63-86	100	100
AF80	43 30-67	32 19-55	74 62-85	100	100
Low catch	42 28-65	32 18-55	77 65-88	100	100
High catch	43 29-66	32 18-53	73 60-84	100	100
Low and low M	29 23-42	19 12-31	63 53-75	100	99
More acoustics	44 30-69	34 20-58	76 64-87	100	100

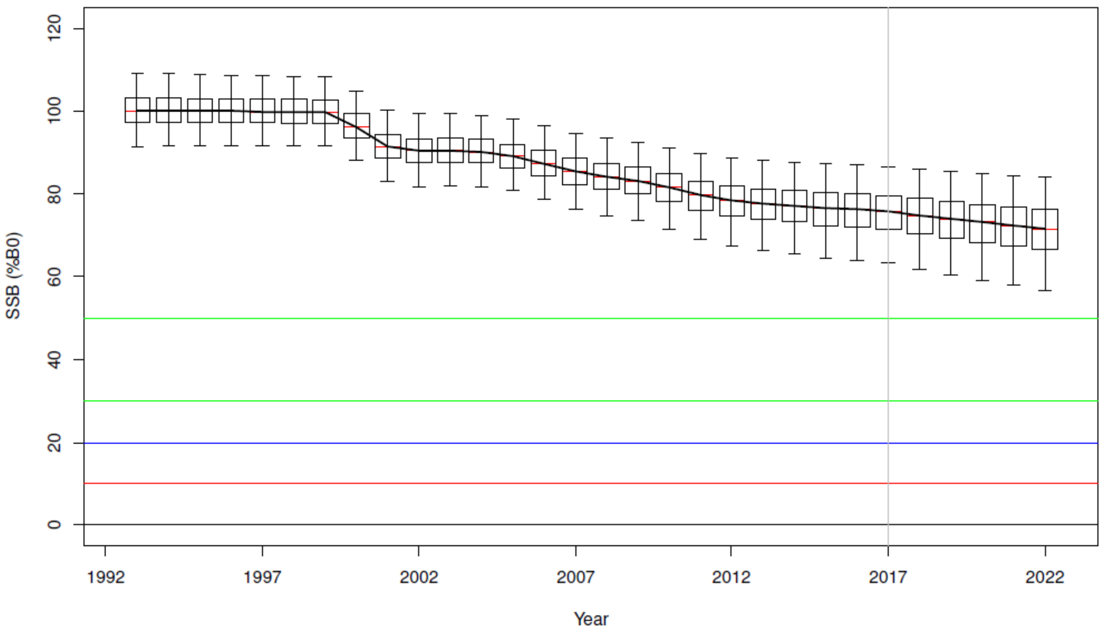

Figure A3.5. Base model MCMC: constant catch projection at current levels: box and whiskers plot of the spawning biomass trajectory for the whole stock. Each box covers the middle 50% of the distribution and the whiskers extend to a 95% CI. This Figure is reproduced from Figure 19 of Cordue (2018a).

SIOFA areas 1, 2, 3a and 3b (6 stocks assessed using a catch-history based method, 3 of these have acoustic estimates and are also assessed with a simple model – borrow from WSR assessment; 1 stock has almost no catch and no acoustic so not assessed) **(Cordue, 2018b)**

Acoustics:

Regarding these acoustic biomass estimates, the SIOFA SC-SAWG report states (SIOFA SC-SAWG, 2018): ”…. none of the acoustic estimates that were used had been reviewed or refined. Surveys with large CVs (>60%) were not used. Only surveys noted to be at peak spawning were used.”

- None of the acoustic survey estimates for these areas have been reviewed, revised or refined
- Estimates from surveys over “large” areas (e.g., more than 20 sq. n.m.) have been ignored because of potential double counting issues
- Surveys with very large CVs (e.g., >60%) have been ignored
- All surveys are noted to be at “peak spawning”.

Models

Catch-history based method:

- Single area, single sex, ages (1-120+), keeping track of maturity (immature, mature categories)
- Fishery at the end of the year on spawning fish
- Length-weight, growth from the Sleeping Beauty feature (results insensitive to these parameters)
- M=0.045, Beverton-Holt, h=0.75
- Maturity from WSR middle assessment
- Three different maximum exploitation rates considered: 50%, 20%, 10%
- Calculate the B_0‘s which satisfy each maximum exploitation rate (achieved by a manual search running the model at different B_0‘s and inspecting the annual exploitation rates).

Current stock status is estimated to be above 40% B_0 for every stock except Walter’s Seamounts. Fortunately, for Walter’s Seamounts acoustic estimates are available and there is an alternative Mode of the Posterior Distribution (MPD) assessment available.

Bayesian MPD estimates model inputs/assumptions:

- – Single sex, ages (1-120+), keeping track of maturity
- – Fishery at the end of the year on spawning fish
- – Migration model (two stocks), single area (one stock)
- – Length-weight, growth from the Sleeping Beauty feature (results insensitive to these parameters)
- – M=0.045, Beverton-Holt, h=0.75
- – Three different treatments of the acoustic estimates: Low, Middle, High
- – Use the WSR estimates for maturity (Low, Middle, High)
- – Use the WSR posteriors of the acoustic q as informed priors for the acoustic q (Low, Middle, and High).

Results

Catch-history based method: for each of 3 maximum exploitation rates:

- B_0, B_{2017} and hence current stock status (B_{2017}/B_0). Maximum exploitation rates of 5% and 40% are used to bound stock size and stock status.
- Current stock status feeds into the HCR to give UHCR. Stock size is very uncertain for all stocks.
- Catch Limit = UHCR × B_{begin_2018} . Current stock status is at least 40% of the virgin for five of the six stocks. The remaining stock (Walter's Seamounts) had a minimum status of 22% of the virgin size.

MPD estimates: for each of 3 treatments of the acoustic estimates (including Walter's Seamounts):

- As above to get a catch limit based on the MPD estimate of B_0, B_{2017}, stock status, B_{begin_2018} . Stock size is very uncertain.
- Comparison of the two sets of results for the three stocks with acoustic estimates. There is an indication that current stock status is at least 70% of virgin stock size.

MPD estimates of virgin biomass (B_0), current biomass, and current stock status for each assessed stock and each of the three different treatments of the acoustic biomass estimates are given in Table A3.4.

Table A3.4. The MPD estimates of virgin biomass (B_0), current biomass (B_{17}), and current stock status (ss_{17}) for each assessed stock and each of the three different treatments of the acoustic biomass estimates. This Table is reproduced from Table 5 of Cordue (2018b).

		B_0 (000 t)	B_{17} (000 t)	ss_{17} (% B_0)
N. Walters	Low	9.7	8.5	88
	Middle	13	12	91
	High	19	17	94
Seamounts	Low	24	17	70
	Middle	31	24	77
	High	45	38	84
M. Ridge	Low	55	46	84
	Middle	75	66	88
	High	108	99	92

References

Cordue, P.L. 2018a. Stock assessment of orange roughy in the Walter's Shoal Region. 1st Meeting of SIOFA Stock Assessment Working Group. SAWG(2018)-01-05 Rev1, 57pp.

Cordue, P.L. 2018b. Assessments of orange roughy stocks in SIOFA statistical areas 1, 2, 3a, and 3b. 1st Meeting of SIOFA Stock Assessment Working Group. SAWG(2018)-01-06 Rev1, 11pp.

SIOFA SC-SAWG. 2018. Report of the First Meeting of the Southern Indian Ocean Fisheries Agreement (SIOFA) Scientific Committee Stock Assessment Working Group (SAWG), 15-18 March 2018, Saint-Denis, La Reunion, France.

Patagonian toothfish (*Dissostichus eleginoides*) assessments

Summary

Two populations fall within the SIOFA convention area: associated with the Del Cano Rise in the FAO area 51.7 near the Crozet Islands (CCAMLR Division 58.6) and the Prince Edward and Marion Islands (CCAMLR Division 58.6 and 58.7), and with the William's Ridge in the Kerguelen Plateau in the FAO area 57.4 near the Kerguelen Islands (CCAMLR Division 58.5.1) and Heard Island and McDonald Islands (CCAMLR Division 58.5.2).

A preliminary assessment has been attempted for the Del Cano Rise population only. CPUE and cumulative catch were used for a depletion analysis and two data-poor stock assessment models were applied. A Catch-MSY stock reduction analysis method that use informative priors for some demographic parameters and a State-Space Surplus Production Model (JABBA) that links the standardised CPUE to the biomass level were used. The depletion analysis estimates the initial biomass by the end of 2017 at 470 t (with a standard error of 104 t). The fraction of the biomass estimated to have been captured by the vessels is large over this period (274 t), representing more than 55% of the estimated initial biomass. The depletion approaches showed that at the scale of the Del Cano SIOFA area, CPUE declined during the 8 months of continuous exploitation in 2017 and 2018 and did not recover to pre-2017 levels one year later in 2019. This suggests that the exploitation rate did not allow for repletion of toothfish biomass in the local area within one year. The authors of the analysis comment that it is not currently clear what the natural repletion rate of toothfish biomass in this region would be (Sarralde *et al*., 2020). Results for the CMSY model estimated median values for *K*[4] change from less than 500 t to over 800 t depending on the assumptions made concerning the proportion of catches during the 2009 to 2013 period which occurred in the Del Cano SIOFA area, while the JABBA model estimates the median size of the pristine biomass to range from 300 to 700 t depending on the assumptions made concerning the proportion of catches during the 2009 to 2013 period occurring in the Del Cano SIOFA area. The authors conclude that:

1) these preliminary data-poor population models' results confirm a decrease of biomass following the initial period of higher exploitation (2009 – 2013), after which the stock has not (yet) returned to its level prior to exploitation,
2) Some models also infer a toothfish biomass decrease following the second phase of higher exploitation (2017-2019), suggesting that had this level of fishing pressure been maintained over a longer time period, the stock would likely have decreased beyond the point of replenishing itself, and
3) these approaches are in an early stage of development at this time, and would need more development and further data in order to estimate sustainable catch limits reliably (Sarralde *et al*., 2020).

[4] In this section, authors' use of K or B_0 has been duplicated as it appears in their documents. However, it is not clear whether in all such cases these symbols have their conventional meanings of (an estimate of) abundance prior to **any** harvesting of the resource.

Overview

Preliminary analysis of the Patagonian toothfish in Del Cano Rise SIOFA (Sarralde *et al*. (2020))

Data

- Catch data: Intermittent fishing effort since 2003, with two periods of higher effort between 2009-2013 and 2017-2019.
- Effort data: this region can be considered as data-poor in this respect due to the limited temporal and spatial coverage of fishing effort; where fishing effort information is available, there is some divergence in data collection approaches.

Models

- **Depletion analysis** (for the period 2017 – 2018)
- **CPUE standardisation** (only data for two of the four fisheries were used as these had information on explanatory covariates – analysis limited to 2010-2019)
- **Data-poor stock assessments:**
  - **CMSY:** Catch-MSY model (reconstruct historical abundance and exploitation rates by simulating biomass trajectories that could produce the observed catch time series given informative priors on initial and final year depletion and stock dynamics such as carrying capacity (*K)* or intrinsic growth rate (*r)* in the Schaefer model)
  - **JABBA:** State-space Surplus Production model – relationship between standardised CPUE and the biomass level is used.

Results

- **Depletion analysis:** estimate the initial biomass by the end of 2017 at 470 t (with a standard error of 104 t). The fraction estimated to be captured by the vessels is large over this period (274 t) representing more than 55% of the estimated initial biomass.
- **CPUE standardisation:**
  The CPUE (kh/1000hooks) and the standardized CPUE series are shown in Figure A3.6.

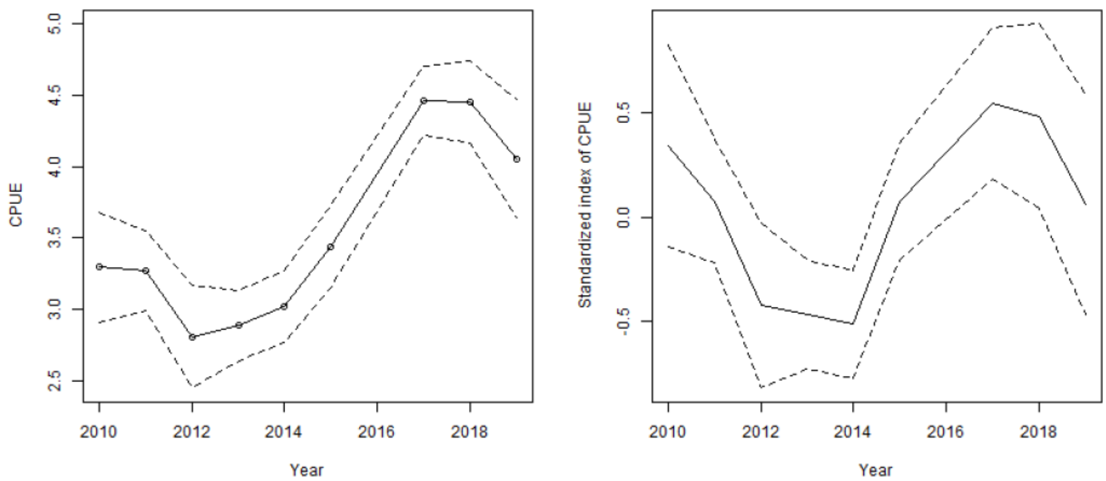

Figure A3.6. CPUE (left, kg/1000 hooks) and standardized index of CPUE scaled to a geometric mean of 1 (right). This Figure is reproduced from Figure 5 of Sarralde *et al*. (2020).

- **CMSY model:**
  The estimated median values for *K* change from less than 500 t to over 800 t depending on the assumptions made concerning the proportion of catches occurring during the 2009 to 2013 period in the Del Cano SIOFA area. Uniform priors are assumed for the intrinsic growth rate (U[0.1, 0.3]), initial rate of biomass depletion (U[0.8, 1]) and the final rate of biomass depletion (U[0.1, 0.6]).

  The relative biomass depletion and the viable pairs of intrinsic growth rate (r) and carrying capacity (K) parameters obtained from the CMSY model are shown in Figure A3.7.

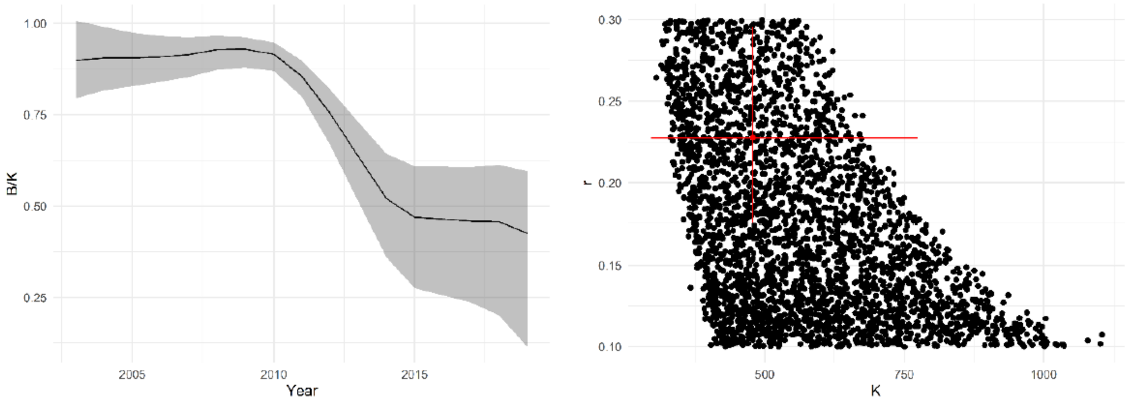

Figure A3.7. CMSY predictions of relative biomass B/K (bold curve) from 2003 to 2019 with 2.5th and 95th percentiles (left), and viable r-K pairs for Del Cano Rise toothfish (right). This Figure is reproduced from Figure 6 of Sarralde *et al*. (2020).

- **JABBA model:**
  The median size of the pristine biomass ranges from 300 to 700 t depending on the assumptions made concerning the proportion of catches occurring during the 2009 to 2013 period in the Del Cano SIOFA area.

  The relative biomass depletion and the viable pairs of intrinsic growth (r) and carrying capacity (K) parameters obtained from the JABBA model are shown in Figure A3.8.

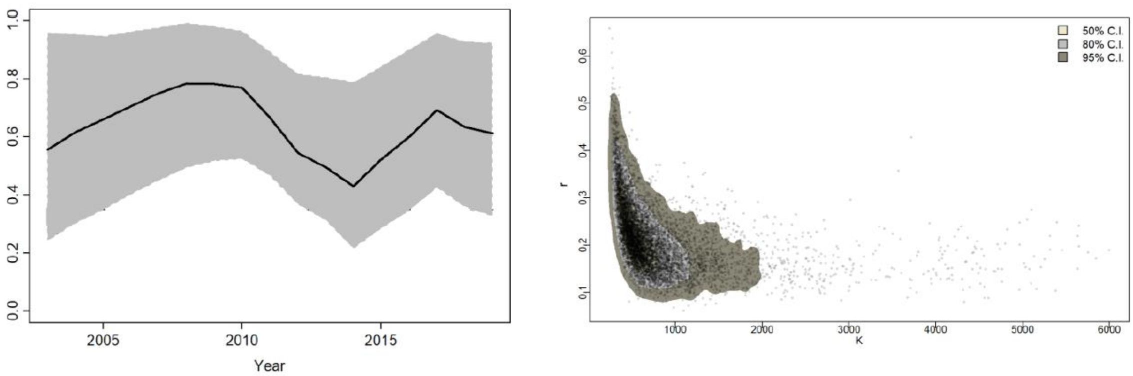

Figure A3.8. JABBA estimates of relative biomass *B/K* (bold curve) with 2.5th and 95th percentiles (left from 2003 to 2019), and posterior distributions of r-k pairs for Del Cano Rise toothfish (right). This Figure is reproduced from Figure 7 of Sarralde *et al*. (2020).

Management: In absence of a stock assessment model/harvest control rule for the Del Cano-SIOFA region, at the 2019 SIOFA Meeting of the Parties (MoP), a regional catch limit in the Del Cano Rise area of 55 tonnes was adopted, with reference to the average catches from 2003 to 2015.

Extracts from CCAMLR abstracts of assessments or results in the FSA report for surrounding areas

Kerguelen Plateau (58.5.1)

2017 - SC-CAMLR (2017)

The updated assessment model estimated B_0 at 223 980 tonnes (95% CI: 205 030–245 900 tonnes), with the biomass in 2017 at 143 700 tonnes (123 060–167 030 tonnes). Estimated SSB status was 0.64 (0.60–0.68).

The Working Group agreed that the catch limit set by France of 5 050 tonnes in 2017/18, which allows for average depredation rates[5] (313 tonnes, based on the average of the estimated depredation from the 2003/04 season to the 2015/16 season), is consistent with the CCAMLR decision rules[6] for the model runs presented.

2019 - SC-CAMLR (2019)

The Working Group noted the development of two integrated CASAL assessment models (WG-FSA-2019/58), including updated data (up to August 2019), growth parameters and year-class strength (YCS) priors and estimation period. The reference assessment model (M1) estimated virgin spawning stock biomass, B0, at 206 200 tonnes (95% confidence interval (CI): 194 130–218 380 tonnes), with the biomass in 2019 at 124 940 tonnes (95% CI: 112 910–136 490 tonnes) for the model with revised growth and YCS fixed at 1 (constant recruitment). Estimated spawning stock biomass (SSB) status in 2019 was 61% (95% CI: 57–65%).

The Working Group agreed that the catch limit set by France of 5 200 tonnes for 2019/20 that accounts for depredation was consistent with the CCAMLR decision rules for the model runs presented.

Heard Islands and McDonald Islands (58.5.2)

2017 - Ziegler (2017)

The updated assessment model leads to a smaller estimate of the virgin spawning stock biomass B_0 than that obtained in 2015, with an MCMC estimate of 77 286 tonnes (95% CI: 71 492-84 210 tonnes). Estimated *SSB* status was 0.61 (95% CI: 0.58-0.64). Despite the smaller biomass, changes to the model compared to 2015 in particular its higher productivity with the updated maturity parameters, meant

[5] The proportion of toothfish lost because of whale predation on the toothfish catch to the total catch.
[6] The CCAMLR decision rules state that over a 35 year projection period 1) the future spawning stock biomass (SSB) must not drop below 20% of the median B_0 more than 10% of the time, and 2) the final SSB must have a probability of 0.5 or greater of being above 50% of the median B_0. The maximum catch which satisfies both these conditions is the estimate of the precautionary yield.

that the catch limit that satisfies the CCAMLR decision rules has increased from 3405 tonnes to 3525 tonnes.

<u>2019</u> –Ziegler (2019)

The updated assessment model leads to a smaller estimate of the virgin spawning stock biomass B_0 than that obtained in 2017, with an MCMC estimate of 70 519 tonnes (95% CI: 65 634 - 76 626 tonnes). The estimated *SSB* status at the end of 2019 was 0.51 (95% CI: 0.49-0.53). The smaller biomass meant that the catch limit that satisfies the CCAMLR decision rules decreased from 3525 tonnes to 3030 tonnes.

Over the course of the projection period the median *SSB* status reaches a minimum of 40% before increasing to the target level at the end of the 35-year projection period, a pattern that is driven by the switch of the fishery from trawl to longline and below-average year class strength since 1998. The level of the predicted drop in *SSB* status by 2021, the time of the next stock assessment, was largely independent of the *YCS* period chosen as reference for the projections. With a comprehensive monitoring program of the fishery until then which include annual trawl surveys and extensive fish ageing to consolidate and estimate recent trends in *YCS*, the 2021 assessment will inform any decision whether further catch reductions will be necessary.

As the result of this assessment, we recommend a reduction of the catch limit from currently 3525 tonnes to 3030 tonnes for the Patagonian toothfish fishery in Division 58.5.2.

Crozet Islands (58.6)

<u>2017</u> – SC-CAMLR (2017): The updated assessment model estimated B_0 at 56 810 tonnes (95% CI: 50 750–63 060 tonnes), with the biomass in 2017 at 37 900 tonnes (32 030–44 400 tonnes). Estimated SSB status was 0.67 (0.63–0.70).

The Working Group agreed that the catch limit set by France of 1 100 tonnes in 2017/18, which allows for average depredation rates (527 tonnes, based on the average of the last three years), is consistent with the CCAMLR decision rules for the model runs presented.

<u>2019</u> - Massiot-Granier *et al*. (2019)

The updated model leads to smaller estimate of the virgin spawning stock biomass B_0 than the one obtained in 2017, with an estimate of 54 610 tons (48 560-60 880). The estimate of the current *SSB* status of the stock is 63% (58.2%-66.6%) and the current catch limit satisfies the CCAMLR decision rules.

<u>2019</u> - SC-CAMLR (2019): The Working Group agreed that the catch limit set by France of 800 tonnes in 2019/20, which accounts for depredation, was consistent with the CCAMLR decision rules for the model runs presented.

Overall summary results

Table A3.4 gives an overall summary of the available estimates of virgin spawning stock biomass B_0 and estimates of the current *SSB* status of the toothfish stock of the SIOFA region as well as those of the CCAMLR surrounding regions.

Table A3.4. Summary of results from CCAMLR and SIOFA

	B_0 (mt)	SSB depletion	TAC (mt)
CCAMLR Division			
Kerguelen (58.5.1)			
2017 2019	223 980 (205 030; 245 900) 206 200 (194 130; 218 380)	0.64 (0.60; 0.68) 0.606 (0.581; 0.609)	5 050 5 200
Heard Islands and McDonald Islands (58.5.2)			
2017 2019	77 286 (71 492; 84 210) 70 519 (65 634; 76 626)	0.61 (0.58; 0.64) 0.51 (0.49; 0.53)	3 525 3 030
Crozet (58.6)			
2017 2019	56 810 (50 750; 63 060) 54 610 (48 560; 60 880)	0.67 (0.63; 0.70) 0.63 (0.58; 0.67)	1 100 800
SIOFA			
Del Cano Rise (FAO Subarea 51.7)			55[7]
Depletion analysis	B_0 at 470 t (se 104 t) by the end of 2017		
CMSY	Range from less than 500 t to over 800 t depending on the assumptions made concerning the proportion of catches during the 2009 to 2013 period		
JABBA	Ranges from 300 to 700 t depending on the assumptions made concerning the proportion of catches during the 2009 to 2013 period		
Williams Ridge (FAO Subarea 57.4)			140[8]
No assessment	—	—	—

References

Massiot-Granier, F., Duhamel, G. and Péron, C. 2019. An integrated stock assessment for the Crozet Islands Patagonian toothfish (*Dissostichus eleginoides*) fishery in Subarea 58.6. Document WG-FSA-2019/57 Rev. 1. CCAMLR, Hobart, Australia.

Sarralde, R., Massiot-Granier, F., Selles, J. and Soeffker, M. 2020. Preliminary analysis of the Patagonian toothfish fishing data of the Del Cano Rise SIOFA. 2nd Meeting of the Stock and Ecological Risk Assessment Working Group (SERAWG2). SERAWG2-02-11, 32pp.

[7] Not based on a stock assessment.
[8] Not based on a stock assessment.

SC-CAMLR. 2017. Report of the Working Group on Fish Stock Assessment. In: Report of the Thirty-Sixth Meeting of the Scientific Committee (SC-CAMLR-XXXVI), Annex 7. CCAMLR, Hobart, Australia: 243–343.

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