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RESEARCH OUTLINE FOR LONGLINE CATCH PER UNIT EFFORT DATA

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Research outline for longline catch per unit effort data

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A. Introduction

Indices of abundance derived from catch and effort data are one of the most influential information sources in stock assessments. For the bigeye, yellowfin, albacore, swordfish and striped marlin stock assessments, the primary CPUE time series are derived from longline fisheries.

This paper a) provides an incomplete list of the history of CPUE indices in the WCPO, b) lists the research recommendations made in recent work, c) summarizes them into research areas, and d) suggests four priority areas for development. The document was prepared for discussion at SPC's 2011 pre-assessment workshop, and focuses on work in the WCPO and by SPC.

B. Background

Recent yellowfin (Langley *et al.* 2007,Langley *et al.* 2009) and bigeye (Harley *et al.* 2009,Harley *et al.* 2010a,Harley *et al.* 2010b) assessments have noted that the signals from the CPUE data and the size distribution data are inconsistent. It can be inferred that there are problems with one or more elements of the CPUE inputs, the size data inputs, and the assumptions used when bringing them together in the stock assessment model. Given this inconsistency, a review (Haddon 2010) of the 2009 WCPFC yellowfin stock assessment concluded that "the methods used to standardize the longline catch rate data, and the relationship between longline catch rates and yellowfin tuna abundance, would benefit greatly from closer examination".

There is a long history of CPUE analysis for fisheries models. In the Pacific, influential work was done in the EPO for purse seine (Punsly 1987) and longline data (Punsly & Nakano 1992). After some discussion (Suzuki 1992), similar work commenced for the WCPO (Table 1), and the first longline and purse seine indices were developed based on Japanese data (Tsuji & Okamoto 1993). Generalized linear models were applied in something close to their current form in 2003, and the resulting abundance indices used in WCPFC stock assessments for bigeye and yellowfin tuna (Langley 2003). Indices have also been developed based on Taiwanese longline data, and using habitat-based standardization (Bigelow *et al.* 1999,Bigelow *et al.* 2002,Langley *et al.* 2005).

From 2003-2005 efforts were focused on the habitat-based standardization method, and GLM analyses were updated (Bigelow et al. 2004).

Since 2003 there has been further progress in the GLM methods applied to indices prepared for the stock assessments. Advances include:

- regional weighting factors (Langley *et al.* 2005);
- analysis of operational data, applied to albacore (Bigelow & Hoyle 2008);
- analysis of operational data for region 3 (Japanese data), applied to bigeye and yellowfin (Hoyle 2009,Hoyle *et al.* 2010,Hoyle & Okamoto 2011);
- investigated factors affecting catchability, including effort creep & targeting (Hoyle 2009,Hoyle *et al.* 2010);

- changed RHS of the GLM equation from f(effort) to f(log(effort)) (Hoyle 2009);
- adjusted the area analyzed in region 3 to compensate for spatiotemporal changes in targeting (Hoyle 2010);
- indices for Taiwanese longline fisheries (Chang *et al.* 2009,Chang *et al.* 2010)

Table 1: Changes through time in approaches for standardizing CPUE data for WCPO stock assessments.

Year	Paper	Species	Main changes	Indices for assessment
1993	(Tsuji & Okamoto 1993)	BET, YFT		
1994	(Miyabe 1994a)	YFT	More factors included: Smaller area factors (10x20), HBF classes	
	(Miyabe 1994b)	BET	None	
	Sun & Yeh 1994			SP
1995	(Miyabe 1995a)	BET	None	
	(Miyabe 1995b)	YFT	None	
1997	(Miyabe 1997)	BET, YFT	None	N
1998	(Uosaki 1998)	ALB	None	
2003	(Langley 2003)	YFT	First YFT application	MFCL
2004	(Bigelow *et al.* 2004)	BET, YFT	First BET application	MFCL
2005	(Langley *et al.* 2005);	BET, YFT	Regional weights	MFCL
2006	(Hampton *et al.* 2006a)	BET	None	MFCL
	(Hampton *et al.* 2006b)	YFT	None	MFCL
	(Langley 2006)	BET, YFT	Investigated spatial patterns	N
2007	(Langley *et al.* 2007)	YFT	None	MFCL
	(Langley 2007)	BET,YFT	Investigated vessel behavior	N
	(Hoyle & Langley 2007)	YFT	New regional weighting scheme	N
2008	(Bigelow & Hoyle 2008)	ALB	First ALB application Operational data	MFCL
	(Langley *et al.* 2008)	BET	None	MFCL
2009	(Hoyle 2009)	BET, YFT	Changed model formula Changed target indicator	MFCL
	(Bigelow & Hoyle 2009)	ALB	Cluster analyses to address target	MFCL
	(Chang *et al.* 2009)	YFT	Taiwanese data, including R6	MFCL sensitivity
2010	(Hoyle 2010)	BET, YFT	Changed target indicator Changed R3 area to account for spatiotemporal target changes	MFCL
	(Hoyle *et al.* 2010)	BET	Operational data	N

C. Recommendations from previous work

This section collates all relevant recommendations made in previous WCPFC-SC documents. These recommendations are summarized into research areas in section C.

Yellowfin review

1. Further investigate the methods used to standardize the longline CPUE data and also the relationship between standardized longline CPUE and yellowfin tuna abundance (Haddon 2010).

Longline CPUE meeting

Recommendations for stock assessments – 2007

1. Regional weighting factors
   1.1. Consider a time period from 1975 to 1986. Re-weight using 1960-1974 and 1975-1986, and compare outcomes. Outcomes may differ between species; e.g. 1960-74 may be better for yellowfin
   1.2. Consider including interaction terms in the model, including region and hooks between floats (HBF).

2. Data resolution and analyses using other datasets
   2.1. Set by set analyses for target species are recommended, both to compare indices with those from aggregated data and to investigate factors that might affect catch rates. Suitable data sources include:
      2.1.1. Hawaii-based longline data: e.g. moon phase, time of day of set, bait type, vessel id, vessel length. Compare with coarser 1º and 5º monthly data..
      2.1.2. Within-EEZ logsheet data for all longline fleets, particularly regarding gear configuration
   2.2. Spatial and effort contraction of the Japanese longline fishery over the past decade makes it important to include other datasets in order to develop CPUE indices relevant for the entire WCPO.
   2.3. Compare nominal indices of the Japanese fleet and other fleets at appropriate spatial and temporal scales.
   2.4. Explore standardization for Korea and Taiwan CPUE for a global CPUE index
   2.5. Where possible, indices for all countries to be made available.

3. Examine sensitivities of the stock assessment models to assumptions in the GLM.
   3.1. Examine sensitivity to the assumption that HBF=5 before 1975.
   3.2. Examine sensitivity to the assumption that HBF effects are equivalent throughout the time period, given that longline material specific gravity may have changed for many vessels during and after 1993.
   3.3. Examine sensitivity to plausible increases in fishing power. Define 'plausible', perhaps via a paper from Peter Ward. See also paper by Miki Ogura on pole and line fishery, presented to SCTB several years ago.
   3.4. Attempt to standardise using data only from main gear configurations – this implies subdividing the CPUE index. Is data for specific gear configurations available? Yokawa-san will ask Okamoto-san, and provide if it is reliable.

Recommendations for stock assessments – Longer term

1. Spatial effects
   1.1. Develop standardization using spatial backfilling – investigate effects of alternative approaches, (e.g. Maunder & Langley 2004,Campbell 2004,Ahrens 2010).
   1.2. Develop methods to include uncertainty in spatial back-filling approaches.

1.3. Model population dynamics of region 3 at a smaller spatial resolution, to examine potential effects of spatial heterogeneity in fishing effort and population structure.
1.4. Compare results of a simple GLM, an area-weighted model, and an abundance-weighted model.
1.5. Given the geographical diversity of region 3, and the limited information regarding the western part of region 3, carry out a sensitivity analysis to removing the western part from the CPUE analysis.

2. Modelling approaches
   2.1. Determine which of the currently available methods for standardizing CPUE are generally applicable and the conditions under which they will perform better than other methods.
   2.2. When using simulation analysis, start with simple models to test the utility of existing methods and test where the methods break down. Build in increasing complexity to determine their performance in realistic applications.
   2.3. Review literature on CPUE standardization, and note covariates and factors for which standardization substantially changes the year effect from nominal CPUE.
   2.4. Combine GLM with pop dynamics model – examine outcomes via simulation

3. Missing covariates,
   3.1. Take a statistical approach to estimating missing observations, using the EM algorithm for example.

4. Time horizon
   4.1. Given uncertainty about the factors affecting pre-1975 CPUE, consider starting assessments in 1975 instead of 1952, or at least use only post-1975 period to infer long-term average recruitment.

5. Targeting
   5.1. Cluster analysis for Japanese data to compare the observed clustering with HBF and area targeting information, in order to see how well the clustering approach works. This can be used to validate the approach for other fleets.
   5.2. Market demand (by species, fish condition, fat content (also affected by area & time of year)) can affect targeting. Consider how market demand can be integrated into the determination of targeting
   5.3. Consider how oceanography can be integrated into the determination of targeting.
   5.4. Review approaches for including data from other species in GLMs.
   5.5. Investigate simultaneous standardization across species to resolve changes in targeting behaviour.
   5.6. Investigate analyses of targeting that include data from multiple fleets.

6. Data resolution and analyses using other datasets
   6.1. Develop CPUE indices for all countries/fleets where longline data exist.

7. Data requirements
   7.1. Determine the status of current data holdings, including identifying the nature and magnitude of deficiencies, and determine the priority for data collection for current model applications.

7.2. Identify what data should be collected in the logbooks for all fleets to improve our ability to capture changes in the relationship between catch and effort, and to ensure the ability to maintain the information context and usefulness of long-term data series.

8. Quantify changes in gear configuration, and time series changes in catchability
   8.1. Further development to include additional species and to estimate actual gear depth using multi-species statHBS approach.
   8.2. Develop alternative likelihoods for multi-species approach.
   8.3. Investigate possibility that major discontinuities (10–25%) in CPUE indices are related to introduction of new technologies.
   8.4. Examine CPUE indices to investigate the possibility of simultaneous changes in catch rates across multiple oceans / species.
   8.5. Investigate the effectiveness of a variety of equipment, such as acoustic Doppler current profiler (ADCP).
   8.6. Review Japanese research reports for information on gear configuration changes in 1975, 1993, and at other times.
   8.7. Investigate possible changes in gear selectivity at 5 HBF pre- and post-1975 for Japanese longline vessels in the Pacific (as noted for similar vessels in the Indian and Atlantic Oceans).

9. Sensitivity analyses to known or potential changes in gear configuration
   9.1. Mainline composition changed with the introduction of monofilament in 1990s. HBF changed, but depth may not have. This change was associated with diversification of gear configurations. Examine potential sensitivity of year effect to this change.
   9.2. Estimate separate catchabilities before and after 1975 in the assessment model, sharing selectivity.

Recommendations relating to PFRP project

1. Data suggestions for observer programs
   1.1. Incorporate details from Table 1 in background paper 10 (see Hoyle *et al.* 2007).
   1.2. Validate longline gear depth with temperature depth recorders (TDR's).
   1.3. Collect gear attributes such as line types, hook types and sizes, weights, weighted swivels, bait type etc.
   1.4. Use more hook timers to validate time of capture.
   1.5. Observers to report which hook each fish was caught on, and time of day caught.
   1.6. Geographical coordinates at start and end of haul.
   1.7. Validate logbooks using observer data.

2. Other data collection recommendations
   2.1. National scientists to describe fishery gear configurations, particularly upon introduction of new gear technologies.
   2.2. Possible provision of Japanese longline data stratified by material type.

3. Oceanographic effects
   3.1. GLM with CPUE as a function of oceanography alone, without temporal and spatial effects, to explore how oceanography (which is confounded with space and time) may affect catch or CPUE.

3.2. Review availability of fine-scale spatial and temporal oceanographic data, especially remotely sensed rather than model-derived data. Compare coherence of both data types, and investigate biases.
3.3. Use existing and develop new algorithms, at appropriate spatio-temporal resolution, to describe the evolution, decay, and persistence of features such as eddies and frontal structures, for both fish accumulation and fishery targeting.

4. Model selection
   4.1. Investigate alternative hypotheses, and use model averaging to integrate over model selection uncertainty where it occurs.
   4.2. Develop tests appropriate for determining which standardization methods provide the best index of relative abundance from a set of candidate methods.
   4.3. Evaluate the performance of candidate tests using simulation analysis.

5. Gear dynamics
   5.1. Further experiments to quantify longline shoaling due to horizontal current shear and changes in sag ratio.
   5.2. Characterize intra-set variability in gear depth, and statistically determine optimum number of TDR's given variability.
   5.3. Investigate functional relationship relating depth fished with HBF/longline material.

SC6-SA-IP1 Pre-assessment workshop (2010)

1. Recommended that the YFT offset not be used in the calculation of indices for the 2010 assessment.
2. Recommended that a CPUE series should be estimated that does not include any targeting variables based on bycatch species, and that a stock assessment run be undertaken using this series to assess sensitivity.
3. Recommended that interaction terms be considered as part of data exploration (noting problems of interpretation).
4. Recommended that for presentation purposes, indices aggregated at the annual level should be presented in addition to those at the same scale used in the assessment (e.g. quarterly in the case of bigeye and yellowfin tuna).
5. Noted that it was preferable to include vessel effects into the CPUE standardization through the use of fine-scale data rather than the post-hoc analyses undertaken in 2009 to adjust the indices derived from 5x5 degree data.
6. Noted that in 2010 the SPC/Japan collaboration will focus on data familiarity and examining the effect of incorporating vessel factors. It is not expected that CPUE indices based on operational data will be developed to replace the 5x5-based indices in the 2010 assessment, but if significant progress is made any such CPUE indices could be used to support sensitivity analyses.
7. Recommended that where possible information on fishing master be incorporated into CPUE indices in addition to vessel effects.
8. Recommended that operational level analyses include consideration of mainline information in conjunction with hooks per basket – drawing on the analyses undertaken by Japanese scientists for the Indian Ocean fishery.

SC6-SA-WP-04 Bigeye stock assessment

1. We suggest that alternative CPUE methodologies be considered that explicitly take into account the spatial extent of fishing activities (e.g. Ahrens 2010).

SC6-SA-WP-01 Bigeye background analyses paper

1. If available, use TW-DW CPUE to calculate standardized effort for region 6 LL fishery.
2. The model results here suggest that the current estimates of regional weightings may not be appropriate and introducing bias into the assessment so further work is required in this area, perhaps using methods that do not rely on CPUE data.
3. Either the catch or CPUE series for region 3 is significantly incorrect with respect to their trends, and the CPUE indices are the most likely candidate. Further research into the estimation of abundance indices from longline data should be the highest priority for the assessment. The initial collaborations on the analysis of operational level data is exciting and should be continued, but the types of CPUE analyses being undertaken need to be expanded to approaches that better account for the large changes in the spatial coverage of the fishery that is evident over the time series.

SC6-SA-WP-03 BET and YFT CPUE

1. If vessels have increasingly targeted bigeye rather than yellowfin tuna, due to their higher value (Langley 2007,Hoyle *et al.* 2010), and that targeting has increased bigeye catch rates at the expense of yellowfin, then the bigeye abundance trend may be too optimistic and the yellowfin trend too pessimistic. This issue is recommended as a high priority for future research.

SC6-SA-WP-02 Bigeye operational longline CPUE paper

1. Multivariate techniques such as principal components analysis and cluster analysis to separate effort targeted at different species and thus identify alternative fishing strategies.

2. The contrast between the declining yellowfin catch rates and comparatively stable bigeye catch rates may be not be due to abundance trends, but due to the increasing ability and/or motivation of vessels to target bigeye tuna. We recommend that further investigation of this issue is given a very high priority.

3. We recommend research to develop better ways to consider changes in individual vessels' catchability.

4. In future it may be useful to separately investigate the area to the west of 180 degrees, in both region 2 and region 4, where much of the effort is carried out by the smaller vessels of the offshore fleet. The offshore fleet should not and generally does not fish east of 180 degrees. There appears to be an area with low effort between 180 and 185 degrees, and it would be useful to investigate any differences in fishing practices on either side of this longitude.

5. Simulation studies to examine bias arising from lack of independence among sets from factors such an increased focus of the fleet on hot spots, changes in fishing location in response to catch rates of different species, catch rates of other vessels, and ability to locate oceanographic features.

6. Investigate why higher bigeye catch rates occur at higher HBF at high latitudes, but the opposite happens near the equator.

7. Abundance indices estimated from operational data should be constructed to extend from the 1950s onward.

8. Both aggregated and operational GLM analyses should be weighted by the number of strata per time-area stratum, and that further research into analysis methods is given a high priority.

9. We cannot assume that all grid squares (or strata) have the same abundance trends, since a) areas with more fishing pressure may be more heavily depleted, or b) the stock may contract into areas with higher quality habitat. The regional abundance trend is the sum of the individual grid squares' abundance trends. An index of regional abundance may take this into account by including a grid square x time term in the analysis and summing the grid effects for each time interval. We recommend research to consider appropriate methods for such analyses.

10. Investigate regional weighting indices.

D. Summary of research options

This section groups and summarizes the research suggestions above into categories. A suggested priority for research from these categories is given in Section D.

Work to improve abundance indices produced by modeling CPUE is generally seen as a top priority for the stock assessments. Work will include both investigating the methods, and investigating the relationship between LL CPUE and tuna abundance (Haddon 2010).

1. Regional weighting factors
   Examine alternative methods for regional weighting, including non-CPUE approaches (SC6-SA-WP-01, SC6-SA-WP-02), alternative datasets, and approaches that avoid constraining catchability but estimate biomass from tagging and size data. For the approach currently used, compare the outcomes of re-weighting using 1960-1974 and 1975-1986. The preferred period may differ between species; e.g. 1960-74 may be better for yellowfin (SC3-ME-IP-1). Consider including interaction terms in the model, including region and hooks between floats (HBF) (SC3-ME-IP-1).

2. Modelling approaches
   2.1. Survey and compare methods for standardizing CPUE (SC3-ME-IP-1).
   2.2. Develop and apply operational set by set analyses to produce CPUE indices for stock assessments, 1950's to the present (SC6-SA-WP-02). Compare indices from operational and aggregated data (SC3-ME-IP-1). Consider goodness of fit and appropriate methods for modelling error distributions.
   2.3. Integrate the GLM with the pop dynamics model, and use simulation to examine the potential benefits and limitations (SC3-ME-IP-1).
   2.4. Further develop the StatHBS and multi-species statHBS methods (SC3-ME-IP-1).

3. Spatial effects and data weighting

3.1. Develop standardization using spatial backfilling – investigate effects of alternative approaches, (e.g. Campbell et al, Ahrens PhD research, and Maunder - combining pop dynamics and GLM) (SC3-ME-IP-1, SC6-SA-WP-4). Develop methods to model uncertainty (SC3-ME-IP-1).

3.2. Not all grid squares (or strata) have the same abundance trends, since a) areas with more fishing pressure may be more heavily depleted, or b) the stock may contract into areas with higher quality habitat. The regional abundance trend is the sum of the individual grid squares' abundance trends. An index of regional abundance may take this into account by including a grid square x time term in the analysis and summing the grid effects for each time interval. We recommend research to consider appropriate methods for spatial heterogeneity (SC6-SA-WP-02, SC3-ME-IP-1).

3.3. The weights given to individual records in the GLM affect the derived abundance index. One approach is to weight both aggregated and operational GLM analyses by the number of strata per time-area stratum (SC6-SA-WP-02). Alternative approaches may work better, if they take into account the relative size of the biomass in different parts of the region. Compare results of a simple GLM, an area-weighted model, and an abundance-weighted model (SC3-ME-IP-1).

3.4. Consider the use of core area CPUE – an area that is consistently fished and has consistent species targeting.

4. Targeting, fishing behaviour, and catchability

Vessels may have increasingly targeted bigeye rather than yellowfin tuna, due to their higher value and possible increased ability to target. This may have increased bigeye catch rates at the expense of yellowfin, making the bigeye abundance trend too optimistic and the yellowfin trend too pessimistic. This issue is recommended as a very high priority for future research (SC6-SA-WP-02, SC6-SA-WP-03).

4.1. Targeting

4.1.1. Examine changes in vessel behaviour related to targeting, which can occur for a variety of reasons, including technological, market, and fleet composition changes. Examine movement choices and searching strategies using fine-scale location data (i.e. some similar issues to purse seine CPUE). SPC holds a suitable dataset with set-by-set locations since 1980. Relevant work includes (Langley 2007), animal searching strategy work, and various simulation models (SC6-SA-WP-02). A related issues is to examine the bias arising from lack of independence among sets, due to factors such as greater fleet focus on hot spots, location changes in response to catch rates (including those of other vessels), and ability to locate oceanographic features (SC6-SA-WP-02).

4.1.2. Apply multivariate techniques such as principal components and cluster analysis to separate effort targeted at different species and thus identify alternative fishing strategies (SC6-SA-WP-02). Test clustering approach by comparison with HBF and area targeting information (SC3-ME-IP-1).

4.1.3. Review approaches for including data from other species in GLMs, including simultaneous standardization across species (SC3-ME-IP-1). Avoid using other species directly in single-species GLM analyses (SC6-SA-IP-1). Also consider comparative analyses using data from multiple fleets.

4.2. Fishing power + targeting: Consider vessel effects and/or fishing master where possible (SC6-SA-IP-1), and include effects directly rather than post-hoc (SC6-SA-IP-1). Develop better statistical methods to consider changes in individual vessels' catchability (SC6-SA-WP-02). Examine sensitivity to increases in fishing power (SC3-ME-IP-1), and define plausible scenarios for these changes (SC3-ME-IP-1).

4.3. Investigate the effects of mainline composition change with the introduction of monofilament in 1990s, and examine year effect sensitivity. HBF changed, but depth may not have. This change was associated with diversification of gear configurations (SC3-ME-IP-1, SC6-SA-IP-1). Also look at catchability changes in 1975 (SC3-ME-IP-1). Perform sensitivity analyses in MULTIFAN-CL to plausible catchability changes.

5. Analyses using other datasets, and with alternative covariates

5.1. Develop CPUE indices using non-Japanese datasets, e.g. TW LL for region 6 (SC3-ME-IP-1, SC6-SA-WP-01).

5.2. Examine use of oceanographic data: Compare effects of oceanographic variables with those of temporal and spatial variables, to explore how oceanography (which is confounded with space and time) may affect catch or CPUE (SC3-ME-IP-1). Review availability of fine-scale spatial and temporal oceanographic data, especially remotely sensed rather than model-derived data. Compare coherence of both data types, and investigate biases (SC3-ME-IP-1). Use existing and develop new algorithms, at appropriate spatio-temporal resolution, to describe the evolution, decay, and persistence of features such as eddies and frontal structures, for both fish accumulation and fishery targeting (SC3-ME-IP-1).

5.3. Compare raw CPUE trends across oceans / species, especially discontinuities (SC3-ME-IP-1).

6. Data

Determine the status of current data holdings, the nature and magnitude of deficiencies (e.g. operational data holdings, fields in logbooks, observer data sheets, meta-data on size data collection protocols), and prioritise data collection for current model applications (SC3-ME-IP-1).

6.1. Quantify changes in gear configuration, and the associated time series changes in catchability. Obtain comprehensive descriptions of fishery gear configurations from national scientists, particularly upon introduction of new gear technologies (SC3-ME-IP-1). Review Japanese research reports for information on gear configuration changes in 1975, 1993, and at other times (SC3-ME-IP-1). Investigate possible changes in gear selectivity at 5 HBF pre- and post-1975 for Japanese longline vessels in the Pacific (as noted for similar vessels in the Indian and Atlantic Oceans) (SC3-ME-IP-1).

6.2. Obtain data on market demand (by species, fish condition, fat content). Integrate these data into analyses of targeting (SC3-ME-IP-1).

6.3. Review sources of oceanographic data and identify data products with the appropriate variables, resolution and accuracy for use in analyses of longline CPUE data. Review fisheries literature for variables likely to influence fish distribution and catchability. Derive ocean front and shear variables from existing data products. Develop R libraries for preparing and manipulating these data, and make them available on the web.

7. Model selection: Investigate alternative hypotheses, and use model averaging to integrate over model selection uncertainty where it occurs (SC3-ME-IP-1). However, model averaging should be done at the level of the stock assessment, rather than averaging alternative hypotheses within a single CPUE trend. Identify tests appropriate for determining which standardization methods provide the best index of relative abundance from a set of candidate methods (SC3-ME-IP-1). Evaluate the performance of candidate tests using simulation analysis (SC3-ME-IP-1).

8. Other
   8.1. Separately investigate the area 170-180 degrees, in both region 2 and region 4, where much of the effort is carried out by the smaller vessels of the offshore fleet. The offshore fleet should not and generally does not fish east of 180 degrees. There appears to be an area with low effort between 180 and 185 degrees, and it would be useful to investigate any differences in fishing practices on either side of this longitude (SC6-SA-WP-02).
   8.2. Investigate why higher bigeye catch rates occur at higher HBF at high latitudes, but the opposite happens near the equator (SC6-SA-WP-02).
   8.3. Consider starting assessments in 1975 instead of 1952, or at least use only post-1975 period to infer long-term average recruitment (SC3-ME-IP-1).

E. Prioritization

Given the range of possible research, we need to prioritize, and group ideas into feasible research projects. This will support efforts to have the work funded and carried out.

From the issues outlined in section C, I suggest the following four with the highest priority.

Weighting given to different strata

The weights given to individual records in the GLM affect the derived abundance index. For example, analyses of the same catch and effort give different indices, depending on whether the data are set-by-set or aggregated (Hoyle *et al.* 2010). One approach to weighting for both aggregated and operational GLM analyses is to give each time-area stratum the same overall weight (SC6-SA-WP-02). However, alternative approaches may work better, if they take into account the relative size of the biomass in different parts of the region. Review possible approaches, with reference to (Walters 2003,Campbell 2004,Ahrens 2010). Compare results of a simple GLM, an area-weighted model, and an abundance-weighted model (SC3-ME-IP-1). Closely associated with this issue is the need to model appropriate error distributions, since overdispersion and (for some species) zero-inflation affect the weights assigned to individual longline sets.

Development work can be carried out using SPC-held data, simulated data, or other operational data datasets. The selected approach can be applied to analyses of operational and aggregated data.

Regional weighting factors

Examine alternative methods for regional weighting, including non-CPUE approaches (SC6-SA-WP-01, SC6-SA-WP-02), alternative datasets, and approaches that avoid constraining catchability but estimate biomass from tagging and size data. For the approach currently used, compare the outcomes of re-weighting using 1960-1974 and 1975-1986. The preferred period may differ between species; e.g. 1960-74 may be better for yellowfin (SC3-ME-IP-1). Consider including interaction terms in the model, including region and hooks between floats (HBF) (SC3-ME-IP-1).

Development work can be carried out using SPC-held data, simulated data, or other operational data datasets. The selected approach can be applied to analyses of operational and aggregated data.

Hidden assumptions about abundance trends in areas not fished early or late

Given the changing spatial distributions of effort, assumptions about abundance trends in unfished areas can have considerable influence on indices. There is a need to develop and apply standardization using spatial backfilling to infer abundance in areas without data, e.g. (e.g. Walters 2003,Maunder & Langley 2004,Campbell 2004,Carruthers *et al.* 2010,Carruthers *et al.* 2011), (SC3-ME-IP-1, SC6-SA-WP-4). Methods to model uncertainty are also required (SC3-ME-IP-1).

This is closely related to the issue of spatial stratification, and the consistency of abundance trends within areas. Not all grid squares (or strata) have the same abundance trends, since areas with more fishing pressure may be more heavily depleted, the stock may contract into areas with higher quality habitat, or mixing between areas may be limited. Some work has already been done to try to define areas with consistent trends (Langley 2006,Langley 2007,Ichinokawa & Brodziak 2010). The regional abundance trend is the sum of the individual grid squares' abundance trends. An index of regional abundance may take this into account by including a grid square x time term in the analysis and summing the grid effects for each time interval. Research should consider appropriate methods for spatial heterogeneity.

Development work can be carried out using SPC-held data, simulated data, or other operational data datasets. The selected approach can be applied to analyses of operational and aggregated data.

Fishing practices changing through time

This may be the most important research area due to its potential to bias the index of abundance. However, it is also is a very large task that would require additional resources. The issues apply across longline tuna fisheries in all oceans so prospects are good for collaborative work and funding. This project warrants consideration for funding as a three year dedicated position.

Changes in targeting and vessel behavior can occur for a variety of reasons, including technological, market, and fleet composition changes. Such changes may have led to higher bigeye catch rates. We would need to examine movement choices and searching strategies using fine-scale location data (i.e. some similar issues to purse seine CPUE). Relevant work includes Langley 2007, animal searching strategy work, and various simulation models. A related issue is the bias arising from lack of independence among sets, due to factors such as greater fleet focus on hot spots, location changes in response to catch rates (including those of other vessels), and ability to locate oceanographic features.

A further related issue is identification of different fishing strategies, so they can be analysed separately (e.g. He *et al.* 1997,Bigelow & Hoyle 2009). SPC holds an excellent study dataset, with a time series of fine-scale location data since 1980.

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