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Acoustic Abundance Indexes for Orange Roughy and Alfonsino in the Indian Sea from Industry Acoustics 2004-2008

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CONFIDENTIAL REPORT

ACOUSTIC ABUNDANCE INDEXES FOR ORANGE ROUGHY AND ALFONSINO IN THE INDIAN SEA FROM INDUSTRY ACOUSTICS 2004-2008

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I. INTRODUCTION

Management of high-seas fisheries has been of increasing concern in the international community and has been one of the major motivations to promote the creation of regional fisheries management organizations worldwide. Governmental interest to coordinate management actions for the Indian Ocean deep-sea fisheries can be traced back to 2001 (Shotton 2006), but no fisheries agreement has been ratified yet. After a media covered fishing rush in the early 2000´s concern increased among the more stable fishing operators in the area, who started to work on private agreements aimed to assure a long-term exploitation of the Indian Ocean deep-sea resources.

Orange roughy (*Hoplostethus atlanticus*) and alfonsino (*Beryx splendens*) sustain the two most important deep-sea fisheries in the Indian Ocean, with annual catches between 2004 and 2009 estimated in the order of 3,000 and 8,000 tonnes respectively. No formal biomass estimates are available for either of these two species, in part due to the lack of management organizations and also because the extension of the area and the methodological difficulties inherent to deep-water resources. Regarding the later issue, acoustics methods have become the standard approach to evaluate orange roughy and alfonsino biomass in more developed orange roughy fisheries: New Zealand, Australia, Chile and Ireland. In all these countries, industry vessels have played very important roles, from passive acoustic data logging to taking full responsibility for yearly evaluations (Boyer & Hampton 2001, Honkalehto & Ryan 2003, Niklitschek et al. 2007c, Hampton et al. 2008).

In order to start reverting the knowledge gap for these fisheries, Sealord Group implemented in 2004 an orange roughy surveying program from its factory vessel *Will Watch*, which has covered 17 of the 35 main orange roughy spawning aggregations (stocks) believed to exist in the SW Indian Ocean. In 2007, the program was extended to include alfonsino fishing grounds with a primary objective of assessing the feasibility of producing reliable abundance or biomass indexes for this fishery. This confidential data set was analyzed to estimate biomass of surveyed aggregations and to evaluate the feasibility of conducting a formal (larger scale-planned) biomass assessment in this area, using one or more commercial vessels. Our primary goal at this stage was to produce minimum biomass estimates for each of these reporting zones, although we also produced some indexes oriented to assess inter-annual changes within zones.

II. MATERIAL AND METHODS

1. *Survey platform, study area and period*

All acoustic and biological data were collected aboard the F/V Will Watch. The vessel was equipped with a SIMRAD ES60 echosounder system that included an ES38B 38 kHz split beam transducer. The system operated at standardized settings of 2 kW (power) and 1,024 ms (pulse duration). It was calibrated in Port Louis (Mauritius) following standard methods on February 2004, October 2005 and September 2008 by Fisheries Resource Surveys, South Africa (calibration reports available on request). The system transceiver was replaced due to technical problems in November 26, 2008, and subsequently calibrated.

Geographic location, detailed bathymetry and raw data for individual acoustic information were considered confidential by the study counterpart, at the time this report was written. General descriptions of the study areas for each species follow.

1.1. *Orange roughy*

A group of 46 opportunistic[1] surveys were selected from data sets recorded by the *Will Watch* between 2004 and 2008. They covered 17 different fishing grounds or features, which were grouped in six fishing areas (Table 1) according to their relative proximity, accepting a maximum distance of 250 km between grouped features. All these six fishing areas were located in the South West Indian Ocean, along the South West Indian Ridge and Walter's Shoal areas. Survey period ranged from mid-June to early September across areas and years (Table 1).

1.2. *Alfonsino*

Acoustic data analyzed for alfonsino corresponded to 14 snapshots obtained in 2007 and 2008 from a total number of 7 fishing grounds grouped by us into 3 fishing areas, located in both the SW and the SE portions of the Indian Ocean. Survey period ranged from mid December to early February across areas and years during the spawning season for Alfonsino (Table 2).

2. *Echointegration*

Recorded data echograms were scrutinized manually, being orange roughy echotraces identified from either catch records or expert judgment[2] based upon its shape, size, depth, capture records and empirical information from the field. Cruise tracks were divided into 100 m intervals (elemental sampling units or ESU), which were integrated in Echoview 4.5© according to standard procedures, where,

2.1. *Nautical area scattering coefficient in each integration interval k (S_{Ak}):*

$$S_{A_k} = 4\pi \cdot 1852^2 \cdot \left(\sum_{p=1}^{m} \delta \sum_{d=1}^{\frac{h}{\delta}} 10^{\frac{Sv_{dp}}{10}} \right) \cdot \prod cf \quad (\mathrm{m}^2 \cdot \mathrm{m}^{-2})$$

where,

m : number of pings (p) en in section k

δ : height of the digitized quanta *d*

h : height of the echotrace.

Sv_{dp} : Volume backscattering coefficient for quanta *d* in ping *p*.

cf : correction factors (see section 5 below)

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[1] Most surveys approached parallel transect designs, being conducted using catch processing time.

[2] Edwin Niklitschek, Graham Patchell

Table 1: Number of orange roughy surveys and total surveyed area by feature and year. Zone code correspond to mean latitude and longitude for each cluster; n=number of surveys.

Fishing area	Feature code	2004			2005			2006			2007			2008		
		n	Survey period	Survey area (Km^2)	n	Survey period	Survey area (Km^2)	n	Survey period	Survey area (Km^2)	n	Survey period	Survey area (Km^2)	n	Survey period	Survey area (Km^2)
3046	AN				5	Jun 12-Jun 21	38									
	DV				2	Jun-14	8									
3544	WR													2	Jun 22-Jun 25	14.8
	BD	4	Jul 19-Jul 21	33	2	Jul 14- Jul 15	25				1	Jul-05	39	1	Jul-01	3.7
	HV	1	Jul-17	7	1	Jul 10-Jul 11	7									
	SB	1	Jul-21	12	5	Jul 11- Jul 21	87	2	Jul-15	27	1	Jul-05	33	1	Jul-02	6.7
	SH				1	Jul-10	14									
	DT													1	Jun 25	1.1
3654	ER	1	Jun 21-Jun22	4												
3751	HA	1	Jul-28	10												
	MM	5	Aug 2-Aug 4	9										1	Jul-29	2.4
	SC	1	Jul-28	13										1	Aug-05	2.1
	BB													1	Aug-22	4.8
	SA													1	Jul-25	0.7
3947	ZE				1	Sep 8	5									
	DA				1	Sep 7-Sep 8	33							1	Aug-14	4.9
	SU													1	Aug-21	0.6
		14		88	18		217	2		27	2		72	11		32.4

Table 2: Number of alfonsino surveys and total surveyed area by feature and year. Zone code correspond to mean latitude and longitude for each cluster; n=number of surveys.

Zone code	Feature code	2007			2008		
		N° surveys	Survey period	Surveyed area (Km2)	N° surveys	Survey period	Surveyed area (Km2)
3654	EURO				1	Oct 15	2.2
2787	ENNO	4	Dec 14-Feb 08,2008	43.3			
	ENSO	2	Jan 08,2008	9.9			
	CRNE				1	Dec 28	1.1
	TB2E				2	Dec 30-Jan 06, 2009	1.5
	TB2W				2	Dec 30-Jan 06, 2009	3.3
3357	FREO				2	Aug 27-Aug 30	4.1
Total		6		53.2	8		12.2

3. *Abundance estimation*

Orange roughy have a highly aggregated patchy distribution, where significant spatial correlation is expected and most of the observed area is unoccupied by the stock. Besides this fact, a model-based data analysis strategy is much more flexible to accommodate opportunistic sampling designs or even the lack of it. Here we adopted the maximum likelihood geo-statistical approach of Roa-Ureta & Niklitschek (2007), where the null density observations are treated separately from the positive density observations. Let *a* be size of the surveyed area A, *p* the probability of a positive observation in A, and $\bar{Z}$ the mean S_A attributed to the targeted stock in A, then a maximum likelihood estimator of the relative abundance is defined by,

$$\hat{\varphi}_A = \hat{z} \cdot a \cdot \hat{p}$$

with estimated variance,

$$\hat{v}(\hat{N}_A) = a^2 \left[\hat{p}^2 \cdot \hat{v}(\hat{z}) + \hat{z}^2 \cdot \hat{v}(\hat{p})\right]$$

3.1. *Geo-statistical estimation of Mean S_A*

Under the basic stationary and isotropic Gaussian model, the random variable $\tilde{Z}(x,y)$ is a function $f(Z_i)$ and an approximate description of the true density (Z_i)in each of the *m* discrete samples with positive density. It is expected to follow the generalized mixed model,

$$\tilde{Z} = \breve{Z}(x_i, y_i) + Fw + \varepsilon_i$$

where ϵ_i are independent identically distributed normal variables with mean zero and variance τ^2. $\boldsymbol{F}$ is the random effects[1] design matrix and $\boldsymbol{w}$ is a vector of realizations of a random variable $\boldsymbol{W}$, which is distributed multivariate normal with mean zero and covariance matrix $\boldsymbol{G}$. Under this generalized mixed model the distribution of $\tilde{Z}$ is given by,

$$\tilde{Z} \sim MVN\left(\beta\mathbf{1}, \sigma^2 R + \tau^2 I + F'GF\right)$$

where $\mathbf{1}$ is an m times 1 vector of 1s, $\boldsymbol{R}$ is a matrix whose (i,i')th element is $\varrho(h_{i,i'} \mid \varkappa, \varphi)$, and $\boldsymbol{I}$ is the m times m identity matrix (Diggle et al., 2003). The log-likelihood function in relation to the original observations for the vector of parameters $\boldsymbol{\theta}'=[\beta\ \sigma^2\ \tau^2\ \varkappa\ \varphi]$ is,

$$l(\theta \mid z_i) \propto \sum_{i=1}^{m} \ln(z_i) - 0.5\ln\left|\sigma^2 R + \tau^2 I + F'GF\right| - 0.5\left(f(z_i) - \beta\mathbf{1}\right)'\left(\sigma^2 R + \tau^2 I + F'GF\right)^{-1}\left(f(z_i) - \beta\mathbf{1}\right)$$

From the traditional intrinsic geostatistics, parameters σ^2, τ^2 and φ are equivalent to the sill, the nugget and the range.

3.2. *Surveyed area*

When a formal survey design was applied the surface area a was assumed to be known exactly from it. Otherwise, the total area was calculated from adding up the number of 1 km^2 cells included in the survey. If none of the previous methods was feasible, we calculated the area inside the convex hull defined by the whole set of observations.

3.3. *Probability of stock presence at the surveyed area*

For estimating $\hat{p}$, we computed the number m_k of successes (positive observations) in observing the school out of the number of n_k observations made at each of the k (k=1,K) 150×150 m cells included in the survey. This is a binomial process with spatially correlated observations, where,

$$M_k \quad Bin(p, N_k)$$

linked to the underlying Gaussian process through the logit function

$$g(p) = \ln(p/(1-p))$$

Under a geo-statistical generalized linear mixed model equivalent to the one used for the mean density, the distribution of $\tilde{M}_k$ can be modeled as,

$$\tilde{M}_k \approx MVN\left(\beta_M, \sigma_M^2 R_M + \tau_M^2 I + F'GF\right)$$

The likelihood function for this type of generalized linear spatial model is, in general, not expressible in closed form but only as a high-dimensional integral that can be evaluated by Monte Carlo Markov Chain Maximum Likelihood (Diggle et al. 2003). The output of the model is related to the parameter of interest, p, through the inverse link function, g^{-1}. By the property of functional invariance of MLEs (Zhena, 1966; Berk 1967) and by Taylor series approximation, we have, respectively,

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[1] Random variables allow for sources of dependence in the data in addition to spatial proximity. For example when several acoustic surveys are carried out over the same stock, and/or when several vessels are used to cover a large field.

$$\hat{p} = \frac{e^{\hat{\beta}_M}}{1+e^{\hat{\beta}_M}}, \quad \hat{v}(\hat{p}) = \hat{v}(\hat{\beta}_M) \cdot \left(\frac{e^{\hat{\beta}_M}}{(1+e^{\hat{\beta}_M})^2} \right)^2$$

3.4. *Total abundance index*

Relative abundance ($\hat{\varphi}$) was transformed into "absolute" abundance, dividing the first quantity by the spherical scattering cross-section $(\hat{\sigma}_{sp})$ calculated for each ground and assessment period as follows,

$$\hat{N}_A = \frac{\hat{\varphi}}{10^6 \cdot \hat{\sigma}_{sp}} \ (10^6 \, ind)$$

where,

$\sigma_{sp} = 4 \cdot \pi \cdot 10^{(0.1 \cdot TS)}$ (m)

$TS = 18.5 \cdot \overline{\log(SL)} - 79.4$ (Niklitschek et al. 2007a)

$\overline{\log(SL)}$= $\log_{10}$-transformed standard length standard length in cm

3.5. *Total biomass index*

Total biomass estimates were obtained directly from total abundance N_A and mean weight $\hat{w}$ estimated for the inference area A, following the equation,

$$\hat{B}_A = \hat{N}_A \cdot \hat{w}$$

with estimated variance,

$$\hat{v}(\hat{B}_A) = \hat{N}_A^{\,2} \cdot \hat{v}(\hat{w}) + \hat{w}^2 \cdot \hat{v}(\hat{N}_A)$$

3.6. *Relative abundance index (corrected density)*

Analyzing the Will Watch data series presented two major challenges, mostly related to the inconsistency between surveyed areas across year. Neither all features within fishing areas, nor all fishing areas were consistently surveyed every year. Moreover, surface area surveyed within each feature changed very much across years, more than an order of magnitude in some cases (Table 1).

To address the issue of high variability in surveyed surface area we were forced to choose a relative abundance index based upon fish density, therefore, relatively independent from the magnitude of the surveyed area. Hence, we computed corrected densities in number (dn_c) and biomass (db_c), which corresponded to the product between density at positive sampling units (S_A >0) and the probability of observing the stock at a given location,

$$dn_c = \frac{\hat{z} \cdot \hat{p}}{\hat{\sigma}_{sp}}; db_c = \frac{\hat{z} \cdot \hat{p} \cdot \hat{w}}{\hat{\sigma}_{sp}}$$

To account for the inconsistency in surveyed features within fishing areas, we assumed sampled features were randomly selected, each year, from the universe of features existing within each fishing area. Thus, we applied a mixed model approach (Searle 1987, Littel et al. 1996) were the correlation within features was incorporated in the ***G*** matrix of variance-covariance for the random effects. Thus,

$$E(y) = X\beta + Zu + \mathrm{e}$$

where,

X = Fixed effects design matrix (year, fishing areas)

β = Vector of fixed effects coefficients

Z = Random effects matrix (features within fishing areas)

u = Vector of random effects coefficients, MVN(0,**G**)

e = vector of sampling errors, MVN(0,**R**)

4. Target strength (TS)

In the absence of TS estimates or TS-length relationships for both orange roughy and alfonsino Indian Ocean stocks, we used Hampton & Soule's (2002) equation for orange roughy and Niklitschek et al's (2007b) equation for alfonsino. Mean log-transformed standard lengths and mean weights were provided by Sealord Group for several years and zones. Standard errors for length and weight data were assumed equal to 10% when not provided. Data gathered in a different year or a close feature (within zone) were sometimes used to fill in data gaps (Tables 3 and 4).

5. Correction for bias:

Although data availability was limited in some cases, several standard bias correction procedures were applied (Table 5 and Table 6), according to the following details:

5.1. *Echosounder calibration:*

An ex-post survey correction factor of 1.51 was derived from consistent calibrations conducted on 2004 and 2005, and applied to SA data collected from 2004 to 2007. In 2008, nonetheless, an obvious drop in transducer gain was detected before the orange roughy season, which became confirmed after assessing the 2008 calibration results, which indicated a drop in gain from the factory nominal value of 26.5 dB to 22.51 dB. Such drop was attributed to transceiver malfunctioning, being this unit replaced in December 2008.

We also compared bottom echo integration results from the damaged GPT against the brand new one while the vessel was docked in Port Louis. Data was logged at a net depth of 5 m, using 2 kW and 0.25 ms (pulse duration). The bottom was integrated between 5.2 and 5.4 m below the transducer, yielding mean SA values of 69666 (n=62) and 127776 (n=192), for the old and the new transceiver, respectively, which corresponded to an apparent drop of 46% in the old GPT performance.

In order to get a more realistic correction factor under conditions closer to orange roughy operations (>1000 m depth, 1 ms pulse duration), we integrated, averaged and compared bottom echo from 135 100×100-m cells, that were repeatedly surveyed in 2 or more years between 2005 and 2008. This followed the approach used by O'Driscoll and Macauley (2009) who compared results of acoustic surveys between R/V Kaharoa and F/V Thomas Harrison. The latter vessel had a transducer with reduced gain, and a comparison of the bottom showed it to be 78% weaker on average in 2008 compared to 2007.

Table 3: Mean standard length (SL), weight (W) and log-transformed standard length (LOGL) used for producing orange roughy abundance and biomass indexes by year and reporting zone.

YEAR	ZONE	SL	LOGL	EE (LOGL)	PT	EE (PT)
2004	3544		1.633	0.1633	2486	248.6
	3654		1.696	0.1696	3848	384.8
	3751		1.691	0.1691	3712	384.8
2005	3046	50.7	1.700	0.1700	4155	422.0
	3544	46.9	1.672	0.1672	3240	398.0
	3654	49.9	1.697	0.1697	3980	398.0
	3751	49.3	1.692	0.1692	3847	398.0
2006	3046	50.7	1.700	0.1700	4155	422.0
	3544	46.9	1.672	0.1672	3240	398.0
	3654	49.9	1.697	0.1697	3980	398.0
	3751	49.3	1.692	0.1692	3847	398.0
2007	3046	50.7	1.700	0.1700	4155	422.0
	3544	46.9	1.672	0.1672	3240	398.0
	3654	49.9	1.697	0.1697	3980	398.0
	3751	49.3	1.692	0.1692	3847	398.0
2008	3046	51.4	1.714	0.0012	4232	428.5
	3544	47.2	1.675	0.0018	3369	419.5
	3654	45.6	1.660	0.0027	3040	304.0
	3751	48.2	1.684	0.0016	3553	385.0
	3947	49.3	1.693	0.0024	3783	400.0

Table 4: Mean standard length (SL), weight (W) and log-transformed standard length (LOGL) used for producing alfonsino abundance and biomass indexes by year and reporting zone.

YEAR	ZONE	SL	LOGL	EE (LOGL)	PT	EE (PT)
2007	2787	51.2	1.72	0.0018	2210	180
2008	2787	51.2	1.72	0.0018	2210	180
	3357	41.8	1.619	0.0025	1706	21
	3654	41.8	1.619	0.0025	1706	21
	3947	51.2	1.72	0.0018	2210	180

Bottom was integrated between 0 and 10 m below the automatic sounder detected bottom (manually verified). Mean SA values were highly consistent among years for the 2005-2007 period (Figure 1), with an overall mean of 6.0 ×106 m2·nm-2 ±0.17 (SE). The evident drop observed in 2008 corresponded to a reduction of 71 % in mean bottom echo, equivalent to a correction factor of 3.19±0.099 (SE). Spearman correlation was, however, significant ($p<0.05$) for all year pairs in the series 2005-2008. Derivation of calibration settings followed the next three basic steps,

i. TS correction factor computed from on axis records from standard target (TS_{cf})

$$TS_{cf} = TS_o - TS_t$$

where,

TS_o : Mean observed TS (dB)

TS_t : Theoretical target TS (-33.6 dB).

ii. Adjusted gain (G_{adj}) computed from nominal gain (G_0) as follows,

$$G_{adj} = G_0 + \left(\frac{TS_{cf}}{2}\right)$$

iii. Empirical S_A correction factor (SA_{cf}) computed from integrated bottom echo as follows,

$$SA_{cf} = \frac{(SV_{adj} - SV_{0507})}{2}$$

where,

SV_{adj} : Mean volume backscatter coefficient computed for 2008 bottom cells using the new adjusted gain (G_{adj}).

SV_{0508} : Mean volume backscatter coefficient computed across years (2005-2007) for each matching bottom cell using the corresponding adjusted gains for each year (G_{adj}).

Empirical values for adjusted gain and S_A correction factor reached -22.51 dB and 0.66, respectively. After applying these values in a post-calibration fashion, mean bottom S_A values from 2008 became equivalent to 0.98 times the overall mean across years for the 2005-2007 series (Figure 2). Calibration correction factor after the GPT replacement

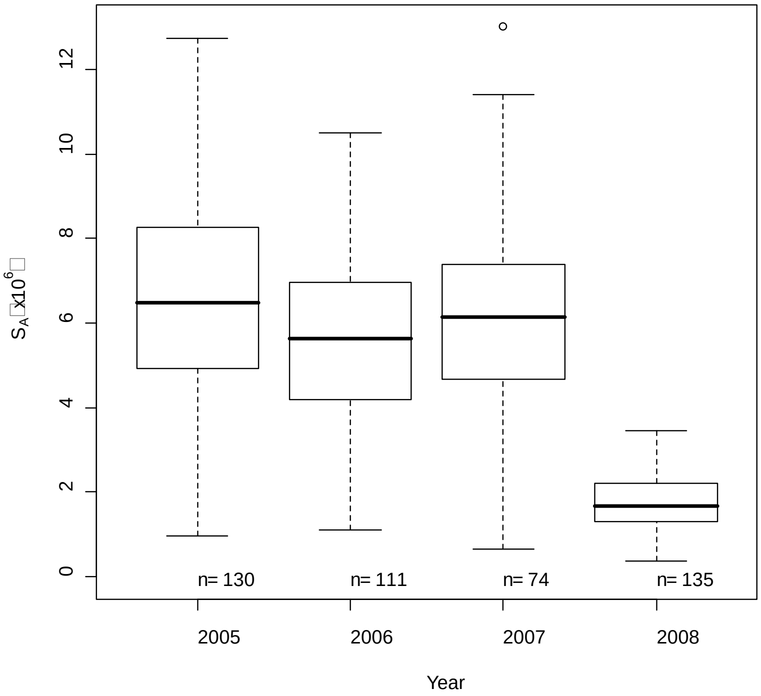

Figure 1: Mean S_A (1×10^6 $m^2\cdot nm^{-2}$) corresponding to bottom echo integrated between 0 and 10 m from the automatic detected bottom line, in selected 100×100 m cells consistently surveyed across years (2005-2008).

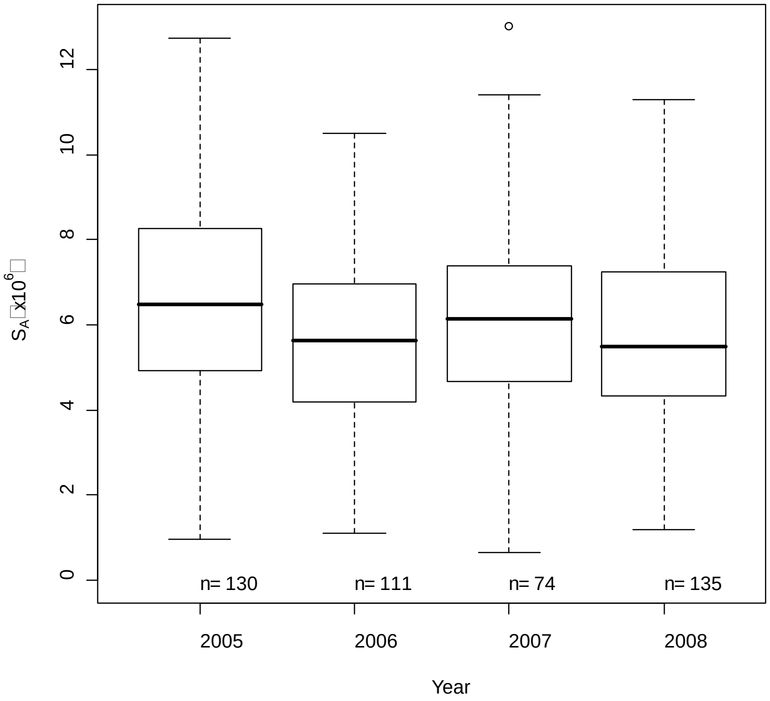

Figure 2: Mean S_A (1×10^6 $m^2\cdot nm^{-2}$) corresponding to bottom echo integrated between 0 and 10 m from the automatic detected bottom line, in selected 100×100 m cells consistently surveyed across years (2005-2008), after applying an empirical S_A correction factor of +1.04 and a measured on-axis gain of 22.51 dB.

Table 5: Mean correction factors applied to orange roughy surveys 2004-2008

Year	Dead zone (m)	Dead zone correction factor	Absorption correction factor	Backscatter	Sample size (IBM|S_A>0)
2004	16.9	1.34	0.53	1	1979
2005	4.5	1.10	0.54	1	7569
2006	2.5	1.06	0.53	1	831
2007	2.4	1.08	0.52	1	1460
2008	4.3	1.06	0.49	0.91	2125

Table 6: Mean correction factors applied to alfonsino surveys 2007-2008

Year	Dead zone (m)	Dead zone correction factor	Absorption correction factor	Backscatter	Sample size (IBM|S_A>0)
2007	20.3	1.08	0.52	1.0	208
2008	4.3	1.06	0.49	0.91	2125

5.2. *Missing and corrupted pings:*

An automatic procedure was applied to filter out missing and corrupted pings (Appendix 1). Additional ones missed by the filtering algorithm were manually excluded if present. In the first case missing/corrected pings were properly excluded from S_A calculations. In the latter case, a correction factor was calculated and applied under the assumption that each missing or corrupted ping had an S_A value equivalent to the average from the remaining quanta in the same ESU.

5.3. *Sound absorption:*

Fixed absorption coefficients of 9.4-10.0 x10^{-3} dB/m^{-1} were used to collect the acoustic data. Correction factors at depth were calculated at 50 m intervals, applying Doonan et al (2003)'s sound absorption algorithm to CTD profiles available from NOAA's Operational Oceanography Group (2006).

5.4. *Dead zone:*

A death zone correction factor was computed and applied assuming S_V within the dead zone was equivalent to S_V in the 10 m above it. Dead zone height was estimated from average bottom range and slope within each echotrace, using Barr's (1999) approximation, where,

$$h_{eq} \approx \left(1.2 + 0.16\alpha^2\right) \cdot d \cdot 10^{-3} + \frac{c \cdot \tau}{4}$$

where,

d : depth (m)

α : bottom slope (degrees)

c : sound speed ($m \cdot s^{-1}$)

τ : pulse duration (s).

6. *Sensitivity to post-processing and data analysis methodological approaches.*

Concern existed about the potential impact from differences in post-processing protocols between the Quantitative Marine Biology Lab (Coyhaique) and other institutions, as well as the possible effects of applying a maximum likelihood geo-statistical analysis to estimate abundance and biomass, instead of the more classical sampling design approach used in orange roughy surveys elsewhere (New Zealand, Australia). To address this issue, we conducted a series of verification and exploratory analysis that included inter-laboratory comparisons of post-processing results applied upon a common data set (Chatham Rise spawning plume, 2004), and a comparison of biomass estimates obtained applying two design-based approaches against those produced by our model-based approach. These sensitivity tests are detailed in Appendix 1.

7. *Species composition*

According to empirical results from commercial catches in this area and elsewhere (Boyer et al. 2003, Niklitschek et al. 2007a, Niklitschek et al. 2007d) orange roughy tend to form mono-specific aggregations. Nonetheless, in some areas orange roughy can distribute closely underneath black oreo and cardinal fish aggregations. Hence, there is a risk to include part of the neighboring school when delineating the orange roughy echotraces. Such a risk was considered higher for black oreo in SC and ER fishing grounds, where species composition was assumed to be 95% orange roughy (OR) and 5% black oreo (BO). For the latter cases, S_A was allocated to orange roughy as follows,

$$S_{A(SP1)} = \frac{F_{SP1} \cdot \sigma_{SP1}}{F_{SP1} \cdot \sigma_{SP1} + F_{SP2} \cdot \sigma_{SP2}}$$

where,

F_{SP} : species proportion

σ_{SP} : $4 \cdot \pi \cdot 10^{TS/10}$

TS : target strength; computed as above for orange roughy, and assumed equal to -38.73 dB for (24 cm) black oreo after McClatchie et al. (2003).

III. RESULTS and DISSCUSSION

1. *Data quality*

In general, the quality of the acoustic data recorded by the FV *Will Watch* was adequate for post-processing and analysis of orange roughy aggregations. Signal to noise ratio was acceptable and allowed for school detection, bottom delineation and overall echogram interpretation. Therefore, it made possible to obtain a preliminary idea of the minimum biomass existing in the study area at each recorded snapshot. Uncertainty for assessments based upon single snapshots showed a large variability with coefficients of variation ranging from 12 to 80% of estimated means. Mean uncertainty (for single features) decreased with sample effort dropping below 20% when the assessment was based upon ≥4 repeated surveys.

Available acoustic data for was, however, much more limited in terms of the number of surveyed areas and years, as well as in terms of temporal and spatial coverage within surveyed areas, and consistency between results from repeated surveys in a given area. Our experience assessing this species acoustically in Chile indicates multiple surveys are frequently required to observe this species that presents high variability in terms if it acoustical detectability. This is affected by major changes in its vertical distribution, within very short periods of times (<1 day), including large vertical migrations and massive dives into the acoustic dead zone (Niklitschek et al. 2008).

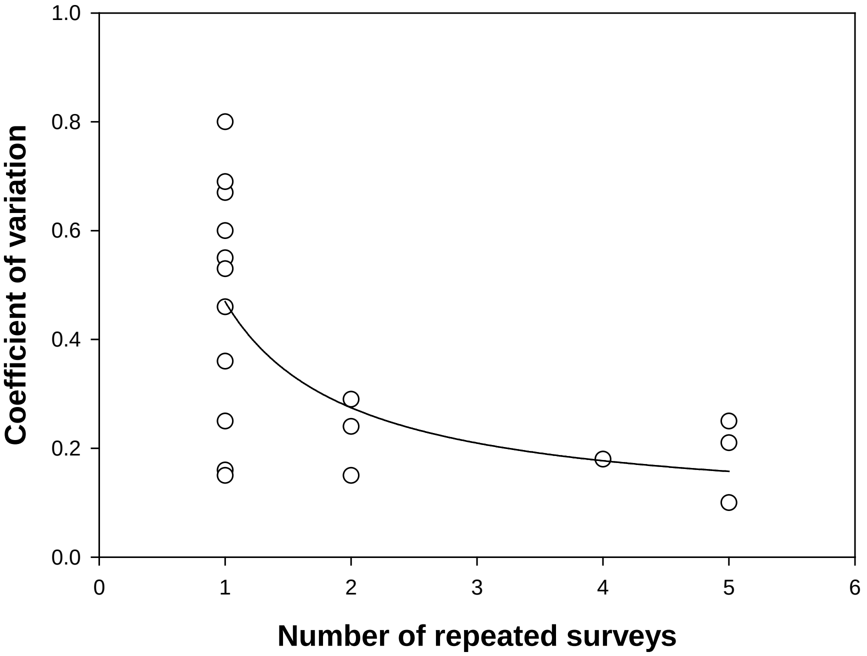

Figure 3: Relationship between coefficient of variation and the number of repeated surveys used for estimating total biomass index at each feature and year.

2. *Minimum biomass estimates*

2.1. *Orange roughy*

After pooling data across years to obtain mean biomass indexes by feature and reporting zone, we estimated a (minimum) total biomass of 63,900 ton ± 14,700 (SE) for the six surveyed areas (Table 7). The highest biomass index was estimated for reporting area 3444 (20,205 ton), in which six separate features (probably stocks) were included. The lowest biomass index was estimated for area 3046 (4,300 ton), although usable acoustic data was only available for two of its features in only one of the five years (2005) considered in this work. Large differences were observed between features within and across reporting zones. The highest mean biomass index of 9,400 ton in feature 3444-SB contrasted with the lowest estimate of just 80 ton in features 3751-SA.

2.2. *Alfonsino*

Pooling alfonsino results across years and adding up results by fishing area allowed us to estimate a minimum biomass of 6,100 ton ± 1,830 (SE) for the 3 fishing areas and 7 features evaluated in 2007 and 2008. The highest biomass was estimated for fishing area 2787 (Table 8) that grouped 5 features, adding up to a minimum biomass of 4,800 ton ± 1,920 (SE)

Table 7: Surveyed area (A, km^2), estimated biomass index (B.I., ton) and coefficient of variation (CV) for orange roughy in the SWIO high seas by feature, reporting zone and year (2004-2007). Values are averaged by feature across years and added by fishing areas within and across years. Precision of estimates exceed convention about significant digits to assure numeric consistency among related quantities.

Fishing Area	Feature	2004			2005			2006			2007			2008			Average/Sum	
		A	B.I.	CV	A	B.I.	CV	A	B.I.	CV	A	B.I.	CV	A	B.I.	CV	B.I.	CV
3046	AN				38	3,319	0.21										3,319	0.21
	DV				8	1,012	0.29										1,012	0.29
	Sub-total				46	4,331	0.17										4,331	0.17
3544	BD	33	5,421	0.18	25	5,099	0.24				39	2,285	0.16	4	1,362	0.67	3,542	0.13
	HV	7	1,276	0.67	7	752	0.46										1,014	0.45
	SB	12	9,136	0.8	87	16,706	0.1	27	5,807	0.15	33	12,310	0.15	7	2,995	0.21	9,391	0.18
	SH				14	1,180	0.25										1,180	0.25
	WR													15	9,004	0.90	9,004	0.90
	DT													1	491	0.54	491	0.54
	Sub-total	52	15,833	0.47	133	23,737	0.09	27	5,807	0.15	72	14,595	0.13	26	13,852	0.59	24,622	0.46
3654	ER	4	8,577	0.69													8,577	0.69
3751	HA	10	6,126	0.55													6,126	0.55
	MM	9	5,349	0.25										2	912	0.44	3,131	0.22
	SA													1	77	0.63	77	0.63
	SC	13	6,679	0.53										2	369	0.47	3,524	0.50
	BB													5	1,362	0.37	1,362	0.37
	Sub-total	32	18,154	0.28										10	2,720	0.25	14,220	0.45
3947	DA				5	1,402	0.6							5	2,461	0.30	1,932	0.29
	SU													1	186	0.70	186	0.70
	ZE				33	9,994	0.36										9,994	0.36
	Sub-total				38	11396	0.32							6	2647	0.28	12,112	0.30
Total		88	42,564	0.253	217	39,464	0.11	27	5,807	0.15	72	14,595	0.129	41	19,219	0.43	63,862	0.23

Table 8: Surveyed area (A, km^2), estimated biomass index (B.I., ton) and coefficient of variation (CV) for Alfonsino in the Indian Ocean by feature, reporting zone and year (2007 & 2008). Precision of estimates exceed convention about significant digits to assure numeric consistency among related quantities.

Zone code	Feature code	2007			2008			Mean	
		A	B.I.	CV	A	B.I.	CV	B.I.	C.V.
3654	EURO				2.4	386	0.34	386	0.34
2787	ENNO	13.2	1666	0.81				1,666	0.81
	ENSO	3.9	78	0.62				78	0.62
	CRNE				1.1	349	0.64	349	0.64
	TB2E				1.9	1701	0.52	1,701	0.52
	TB2W				3.3	1032	0.99	1,032	0.99
	Sub-total	17.1	1744	0.77	6.3	3082	0.44	4,826	0.40
3357	FREO				4.1	1269	0.33	1,269	0.33
Total		17.1	1744	0.77	12.8	4737	0.30	6,095	0.32

3. Relative biomass estimates

Using corrected density as a measure of relative abundance has the advantage of being less sensitive to inter-annual changes in the extension of the surveyed area. Being the product between fish density and the proportion of the observed area effectively occupied by the stock, it also allows accounting for changes in concentration patterns. This approach, however, ignores and becomes highly sensitive to changes in surveying patterns, especially when these changes include an incomplete coverage of the study area as a response to an increasing knowledge of the target species distribution in the surveyed area (Niklitschek & Roa, unpublished data).

In the present data series, it results evident that in some years only a fraction of the potential fish distribution area was covered within each feature (Figure 4). Moreover, in some years, such as 2008, the logged data suggest that surveys targeted particular fish aggregations rather than a given geographical area where the stock might be present. In these cases, the absolute biomass index would tend to under-estimate the actual biomass in the area by underestimating the actual extension of the stock area. The relative biomass indexes, on the other hand, would tend to over-estimate the actual biomass density by over-estimating the actual proportion of the area occupied by the stock.

Although orange roughy acoustics surveys have been used as absolute estimates (especially given data limitations to produce trustable population dynamics models), we firmly recommend to consider SWIO estimates as relative ones. Although these acoustic assessments might still be valuable as minimum biomass estimates, we feel they have the potential to be valuable tools to assess inter-annual trends, after a sufficiently long data series becomes available. To achieve that goal, the number of surveys and features surveyed each year should be largely incremented, assuring a minimum of three surveys per feature and three features per fishing area. Fulfilling these sampling requirements would demand that all vessels involved in the fishery participate in future monitoring programs..

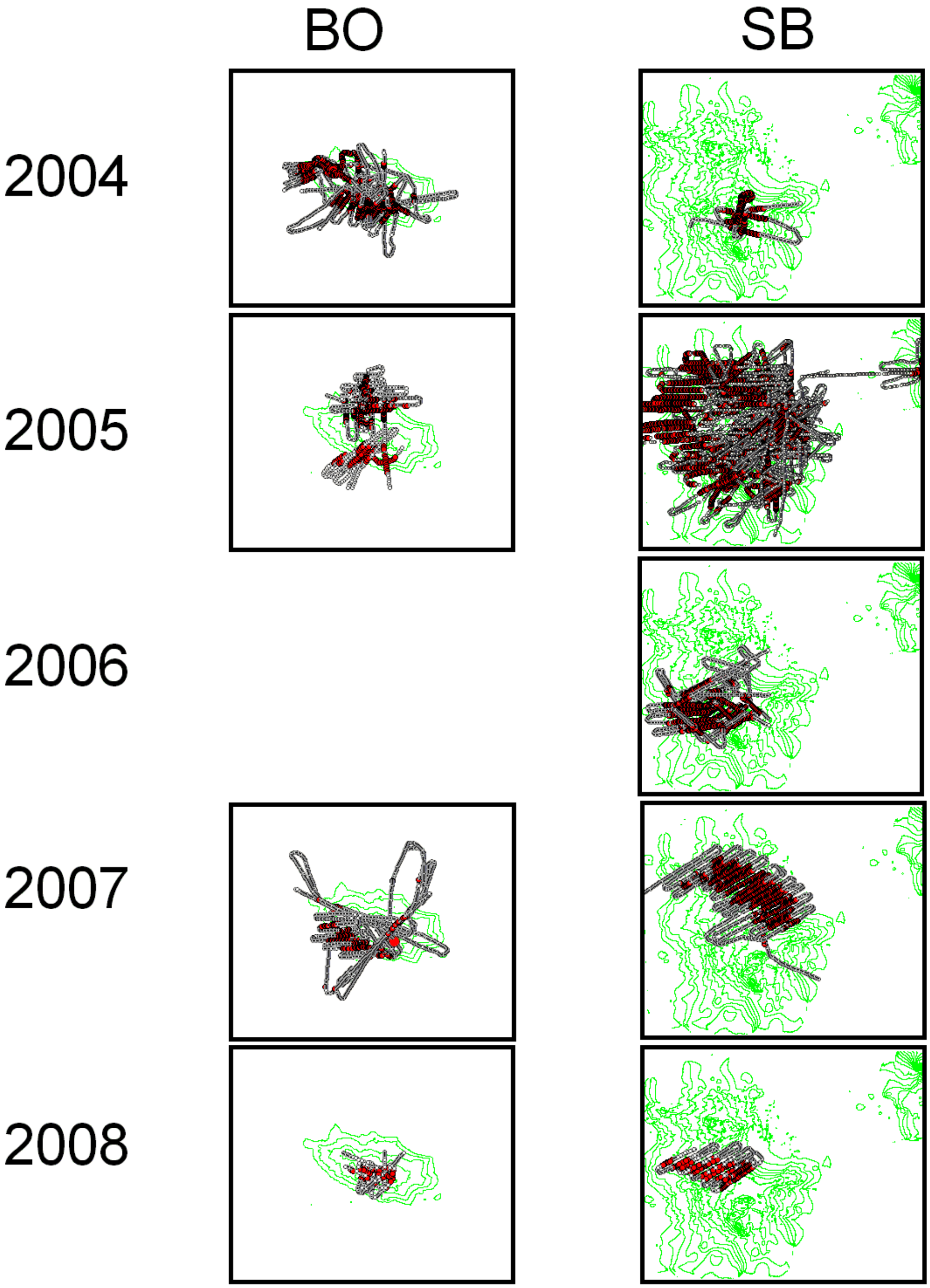

Figure 4: Surveying tracks in selected features from the 3544 fishing area: BO (left panel) and SB (right panel), by year. Orange roughy presence/absence denoted by red/grey colors.

3.1. Orange roughy

Only one of the six zones analyzed in this report, zone 3544, was surveyed each year from 2004 to 2008. Correct density estimates suggest a major reduction of circa 75% in orange roughy density between 2004 and 2005, followed by a consistent increase in relative abundance until 2008, when this index reached 82% of the 2004 value (Figure 5). A range between 50 and 200 ton/km^2 was estimated for most fishing areas, with a minimum of 35 ton/km^2 in fishing area 3046, and a maximum of 775 ton/km^2 in fishing area 3654. The estimate for the latter area was characterized by a very large uncertainty, equivalent to 69% of the estimate.

3.2. Alfonsino

Average corrected density ranged between 95 and 500 ton/km^2 (Figure 6). While no feature was assessed in both 2007 and 2008, pooling results within fishing area 2787 showed an apparent increment of circa 4-fold in corrected density (Figure 6). Such large increment is unlikely in a year and probably related to reported high variability of alfonsino stocks (Niklitschek et al. 2008).

In the current analysis we have used a relative abundance index (corrected density in ton/km2) that is largely based upon directly observed acoustic variables (S_A and presence/absence, pS) but also incorporates an additional non-observed variable (target strength) and biological parameters (length and weight) obtained from a likely selective sampling gear. Using a simpler index (such as $S_A \cdot pS$) would have the advantage of simplicity and parsimony, but would be harder to interpret by managers and stakeholder given its units would not have explicit biological meaning (e.g. m^2/mn^2).

We also claim that reported total biomass estimates are closer to a relative index than to an absolute one. Therefore, while expressing our results in terms of ton or ton/km^2 facilitates interpretation, it implies the risk to misunderstand these results, including the interpretation of them as the total biomass of alfonsino and orange roughy present in the study area. In fact, only 17 out of the 35 or more orange roughy known fishing grounds in the SWIO are included in this report, with no more than one snapshot analyzed for most features. Besides starting from incomplete and rather intermittent observations, we have very limited information about orange roughy distributional patterns, availability and dynamics in the study area. All these added to our still limited knowledge on orange roughy acoustic properties (target strength).

Having in account all the limitations described above, if we considered the total biomass index of 63,900 ton as a lower limit for the total absolute biomass, and the approximated 2,000 ton caught in the six reporting zones included in this study (G. Patchell, pers. comm..), it would be possible to calculate that the recent catch rate had been no greater than 3.1%. In fact, the actual catch rate had to be much lower than this quantity considering the present minimum biomass estimate represents only a fraction of the stock distribution area, while the cumulated catch is for the whole SWIO. Some bias in the opposite direction might exist if the actual mean TS values were larger than those we used. Such discrepancy might result from inadequacy in the TS-length relationship, as well as from bias in the size distribution assumed for the insonified aggregations (see below).

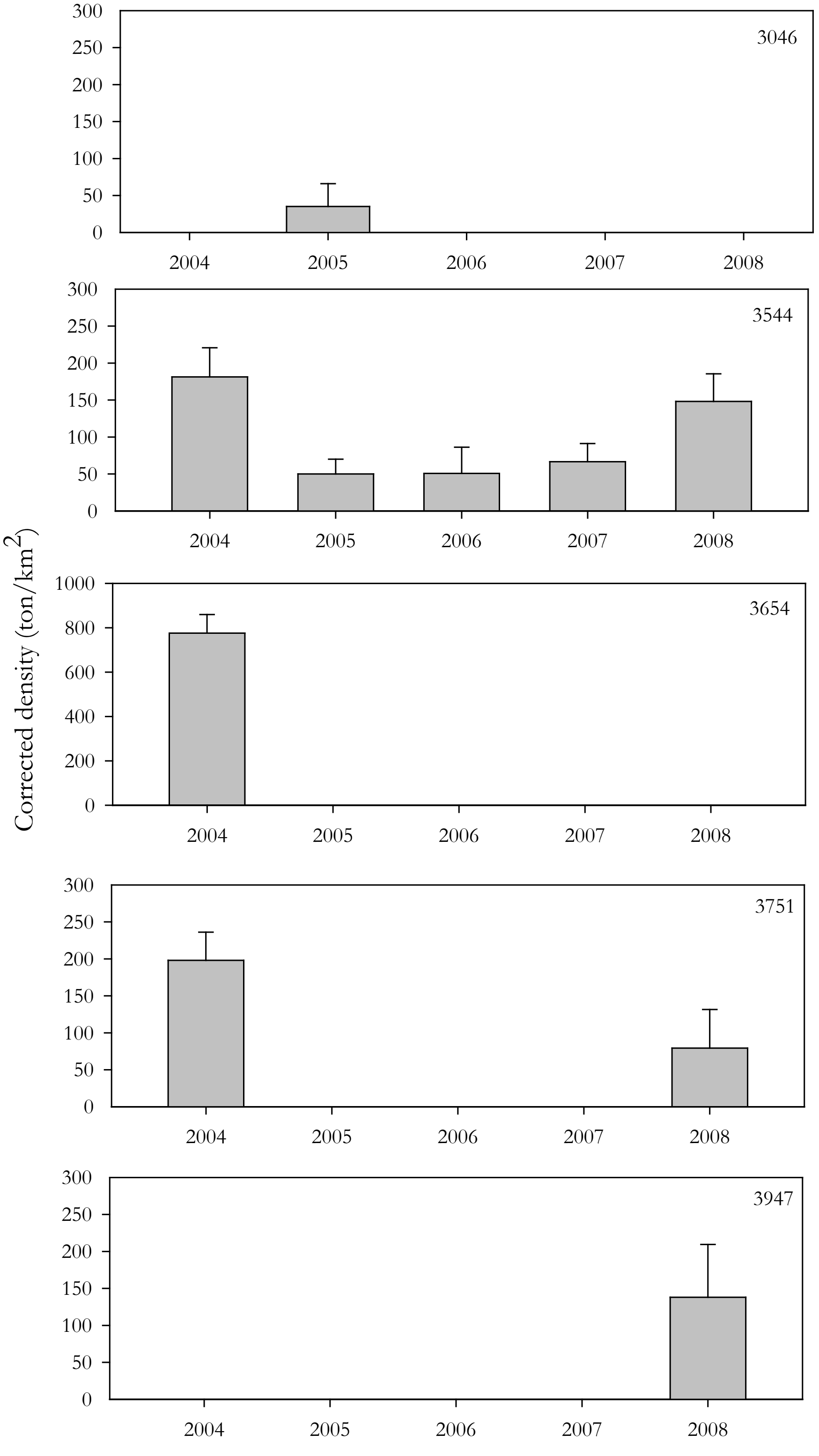

Figure 5: Corrected density of orange roughy by fishing area (as labeled in upper right corner), as a measure of relative abundance for five fishing areas in the SWIO for the 2004-2008 period. Note unequal y-scale for fishing area 3654.

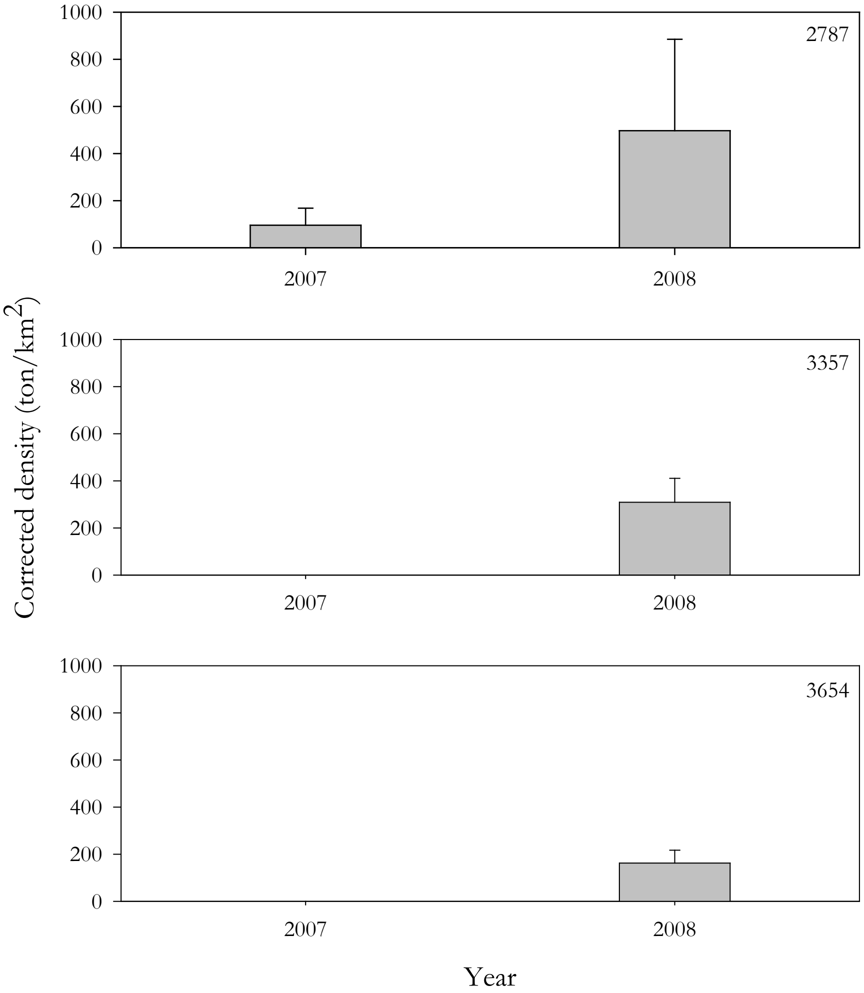

Figure 6: Corrected density of alfonsino by fishing area (as labeled in upper right corner), as a measure of relative abundance for five fishing areas in the Indian Ocean for years 2007 and 2008.

4. *Main sources of uncertainty and potential bias*

Orange roughy target strength is still matter of debate and several relationships and/or mean values have been suggested for this species around the world (Kloser et al. 1997, McClatchie & Ye 2000, Hampton & Soule 2002, Kloser & Horne 2003, Niklitschek et al. 2007a). Abundance and biomass estimates are highly sensitive to which relationship is used, with differences of up to 55% between the most extreme reported ones.

Potential bias in species composition and size distribution estimates are also relevant sources of error, given trawling difficulties associated to depth and topography. Previous studies suggest, nonetheless, low size-selectivity of bottom trawls for orange roughy. These findings probably linked to the absence of juveniles in the fishing grounds. Size selectivity for other targets (e.g. myctophids) is nonetheless a potentially relevant source of bias than needs further investigation (Kloser et al. 2002).

Orange roughy aggregations showed to be highly mobile within each ground, with some evidence of non-random circular patterns around the hills. This movement challenge survey design in order to avoid both double counting and double missing of the fish. In the present report a rather conservative approach was taken, averaging rather than adding up sampling strata within seamounts.

Dead zone was calculated to have annual mean heights between 2.4 and 16.9 m (Table 5), with some seamounts showing values as high as 47 m. While the standard approach assumes fish density in the dead zone to be equal to the one observed on top of it, the frequency and magnitude of commercial catches where no marks are present suggest a larger proportion of orange roughy could be hidden in this zone.

While attenuation due to transducer motion was ignored in the present analysis, a rather high amount of missing/corrupted pings affected data quality in some areas and years, such as fishing area 3751 in 2004, were 36-79% of pings were excluded from roughy echotraces. The fact that a significant amount of pings were missing or corrupted in some areas and years implies the acoustic signal was probably attenuated in many others (Stanton 1982). If new studies are considered to be done in the same area, continuous recording of vessel motion from a digital sensor, as well as placing the transducer in a drop keel or a shallow tow body would be highly recommended to improve data quality and to allow for bias correction.

IV. CONCLUSIONS AND RECOMMENDATIONS

- The quality and spatial coverage of the 2004-2008 orange roughy acoustic data obtained from the F/V *Will Watch* was sufficient for post-processing and statistical analysis and allowed to estimate a total biomass index of 63,900 ton, with a relatively low sampling error (23% CV).
- Although similar in quality, the spatial and temporal coverage of alfonsino data was much more limited than the orange roughy one, and restricted to only two years, 2007 and 2008, in just 3 fishing areas. From this data set, we estimated a total biomass index of 6,100 ton (35% CV).
- While we recommend using estimated biomass indexes as relative quantities, they could be also considered as minimum estimates for the absolute biomass of 6 orange roughy and 3 alfonsino fishing areas, which grouped 17 and 7 fishing grounds, respectively.
- Several biomass estimates at both zone and feature scales were extremely uncertain (>50% CV). Any use of them as local estimates would require extreme cautiousness.
- A significant improvement in precision and exactitude of biomass estimates would be expected after implementing the following recommendations:
    - Defining a minimum of 3 repeated surveys for each ground and year.
    - Assuring each of the repeated surveys cover and exceed the whole surveyed area were roughy is expected/observed to be present. Although fixed grids are not a requirement in our analytical approach, we strongly recommend to follow a pre-defined design (star, parallel or zig-zag transects).
    - Including a motion sensor & logger in all participating vessel(s) to record pitch & roll data continuously.
    - Randomly sampling and recording maturity stage and/or gonadic index for trawls obtained in each surveyed area.
    - Evaluating the effects of maturity stage upon biomass estimates.
- Since large inter-laboratory differences were detected in post-processing results when comparing mean S_A values obtained by two independent teams from a common data set (Chatham Rise Plume Survey 2004), this results might not be directly comparable to results obtained by other scientific teams elsewhere.

- Large although not always consistent effects resulted from applying different biomass estimation procedures. Overall, the maximum likelihood geo-statistical procedure (Roa-Ureta & Niklitschek 2007) used as a default in the present report tended to produce lower estimates than random sampling design-based methods commonly used in orange roughy assessments (Jolly & Hampton 1990).

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VI. APPENDIX I

1. *Effects from sampling assumptions and statistical approaches used to estimate abundance and biomass:*

Abundance and biomass estimation procedures for the 2004-2008 SWIO acoustic data series have been based upon the maximum likelihood geo-statistical approach (MLGS) developed by Roa-Ureta & Niklitschek (2007). This choice was made considering two major advantages of such statistical approach. First of all, being a model-based method, it does not depend upon a particular sampling design, which is particularly suitable for data that have been originated thorough surveys of opportunity with a variety of sampling designs, including the lack of them (random-walks). Second, the MLGS approach provides an explicit state-of-the-art treatment of spatial correlation, particularly relevant for highly aggregated resources. The MLGS approach differs, on the other hand, from estimation methods commonly used for acoustic deep-sea assessments realized in countries such as New Zealand and Australia. These countries are involved in the SWIO fisheries and have devoted important efforts to achieve a sustainable management of orange roughy and alfonsino in their jurisdictional waters. Thus, there is an obvious need to produce comparable estimates that might facilitate transferability of management criteria.

In order to assess the potential effects of estimation methods, we compared MLGS results against those obtained under two alternative approaches:

i. Random sampling design based upon transects (RST), where an unconditional S_A mean is computed from transect S_A means, weighed by transect length. Independence between transects and normally distributed errors are assumed.

ii. Random sampling design based upon elementary sampling units (RSEU), where a conditional S_A mean is computed from all positive sampling units (ESU) and then multiplied by the proportion of the survey area occupied by the stock, which is computed from all ESUs. Sampling units corresponded to 50 m adjacent sections, and were assumed independent from each other.

The RST analysis follows Jolly & Hampton (1990)'s method for semi-random transects and it is the most frequently used approach in orange roughy dedicated surveys elsewhere (Kloser et al. 2002, Hampton & Soule 2003, Niklitschek et al. 2003, Hampton et al. 2004, Soule et al. 2007, Hampton et al. 2008). Both the MLGS and the RSEU approaches differ from RST since the first two produce separate estimates i) for the conditional S_A mean, obtained from positive values only; and ii) for the stock presence ratio. In the present application, binomial error distributions were assumed for the stock presence ratio in both approaches, while log-gamma and normal error distributions were assumed for the conditional S_A corresponding to MLGS and RSEU, respectively. Survey area in the RST method is simply computed as the product between transect length and mean distance between transects. In the MLGS and RSEU methods this computation is not always possible (transects may not exist), and surface area is computed as the total number of 250 m^2 pixels covered by the survey.

1.1. *Orange roughy in SB seamount example*

We applied the three analysis methods to the SB seamount (2008 data set, Survey 1). The classical RST method produced 17% higher biomass estimates than the MLGS method (Table 9). Such difference was related to a 7% higher estimate for the mean S_A as well as to a 10% larger computed survey area. The RSEU method yielded biomass estimates which were very close to RST. Here the lower survey area computed by the RST method was compensated by a 7.5% increase in mean S_A (Table 9).

Regarding the difference in survey surface area, it is evident that computing the survey area as the product between transect length and mean distance implies a certain level of extrapolation, more o less important depending of the relative dimensions of the survey area. In a design-free (irregularly covered area) such approach results impractical and the most objective way to define the area is the simple joining of the acoustic track vertices. For the Sleeping Beauty application, scaling up the MLGS and RSEU survey areas to match the RST one reduced differences in biomass estimates to the S_A differences, this is RST estimate had been 7% higher than the MLGS one and 7% lower than the RSEU biomass estimate (Table 10).

Table 9: Analysis method effects upon biomass estimates in Sleeping Beauty seamount (Survey 1 2008). MLGS: maximum likelihood geostatistical approach (Roa-Ureta & Niklitschek 2007); RSEU: random sampling assumed from 50 m elementary sampling units; RST: random sampling assumed considering each transect as a sample. In both MLGS and RSEU unconditional S_A was computed as the product between the stock presence ratio and the conditional S_A mean (from positive values).

Analysis method	Surface Area	Stock presence ratio		Unconditional acoustic density (m^2/mn^2)		abundance (×10^6)		biomass (ton)		
		p	EE	S_A	EE	N	EE	B	EE	CV
MLGS	6.7	0.54	0.048	72.4	26.2	0.94	0.177	3018	638	0.21
RSEU	6.7	0.52	0.03	83.2	17.8	1.08	0.101	3470	477	0.14
RST	7.4	n.a.	n.a.	77.4	14.8	1.10	0.210	3523	759	0.19

Table 10: Analysis method effects upon biomass estimates in Sleeping Beauty seamount (Survey 1 2008). MLGS: maximum likelihood geostatistical approach (Roa-Ureta & Niklitschek 2007); RSEU: random sampling assumed from 50 m elementary sampling units; RST: random sampling assumed considering each transect as a sample. Surface area values for MLGS and RSEU scaled up to match RST method.

Analysis method	Surface Area	Stock presence ratio		Unconditional acoustic density (m^2/mn^2)		abundance (×10^6)		biomass (ton)		
		p	EE	S_A	EE	N	EE	B	EE	CV
MLGS	7.4	0.54	0.048	72.4	28.3	1.03	0.192	3294	698	0.19
RSEU	7.4	0.52	0.03	83.2	19.5	1.18	0.112	3787	521	0.09
RST	7.4	n.a.	n.a.	77.4	14.8	1.10	0.210	3523	759	0.19

1.2. *Comparative results from applying different analysis methods to the orange roughy SWIO 2008 data.*

In order to produce biomass estimates comparable to those obtained when spatial correlation is ignored, the RSEU method was applied to obtained alternative biomass estimates for the 10 areas surveyed in 2008 (Table 11 and Table 12). The effects of ignoring spatial correlation between samples (i.e. assuming a random sampling-design) differed between estimates for the area occupied by the stock (α) and for the mean acoustic density (S_A). In the first case, there was a mean reduction of 1% in the estimated stock area, while there was a ~19% increase in the estimated mean acoustic density. Therefore, estimated biomass under the random sampling design-based approach (Table 12) was 18% higher than the one obtained by the maximum likelihood geo-statistical approach. At this point is important to recall than our MLGS approach assumes a log-gamma error distribution compared to the normal error distribution normally assumed in the two random-sampling design approaches (RST and RSEU).

Table 11: Spatial distribution, acoustic density and relative abundance indexes estimated for alfonsino in the SWIO in 2008. Random sampling design-based analysis.

Zone	Observed Area (km²)	Stock presence ratio		Stock area (km²)		Acoustic density (m²/mn²)		Relative abundance Index (m²)	
		p	EE	α	EE	S_A	EE	φ	EE
BB	4.8	0.22	0.033	1.06	0.158	300	24	92	16
BO	3.7	0.64	0.04	2.37	0.148	178	32	123	23
DA	4.9	0.35	0.031	1.72	0.152	310	20	155	17
DT	1.1	0.28	0.053	0.3	0.057	321	44	28	7
MM	2.4	0.19	0.031	0.46	0.074	366	59	49	11
SA	0.7	0.14	0.063	0.1	0.044	128	19	4	2
SB	6.7	0.52	0.03	3.48	0.201	160	12	163	15
SC	2.1	0.15	0.032	0.32	0.065	245	29	23	5
SU	0.6	0.31	0.051	0.19	0.031	229	20	12	2
WR	14.8	0.19	0.012	2.77	0.173	199	17	161	17
AL	41.8	0.31	0.009	12.75	0.395	218	8	810	42

Table 12: Mean density, abundance and biomass estimates for alfonsino in the SWIO in 2008. Random sampling design-based analysis.

Zone	Mean density (ind/m^2)		abundance (×10^6)		biomass (ton)		
	D	EE	N	EE	B	EE	CV(%)
BB	0.54	0.043	0.57	0.097	2063	406	0.2
BO	0.36	0.064	0.85	0.161	2561	550	0.21
DA	0.53	0.034	0.91	0.1	3653	542	0.15
DT	0.54	0.073	0.16	0.037	667	170	0.26
MM	0.64	0.104	0.29	0.067	1129	281	0.25
SA	0.26	0.038	0.03	0.012	76	36	0.48
SB	0.31	0.023	1.08	0.102	3470	477	0.14
SC	0.44	0.052	0.14	0.033	503	129	0.26
SU	0.4	0.035	0.07	0.014	288	62	0.21
WR	0.33	0.028	0.92	0.096	3861	558	0.14
All	0.39	0.014	5.02	0.269	18271	1196	0.07

2. *Effects from post-processing procedures: Chatham Rise orange roughy plume survey 2004 example.*

To compare the effects of post-processing procedures, including different levels of human intervention in mark selection and drawing steps, we applied standard procedures used for the 2004-2008 SWIO series to the Chatham Rise Plume Survey (snapshots 8-12) conducted in 2004 by Fisheries Resource Surveys. Marks were selected using expert judgments although both the original survey (Hampton et al. 2004) report and a further standardization review produced by the same team (Hampton et al. 2008) were consulted. Mark delineation was done using Echoview's automatic school detection module SHAPES. Correction factors used were those reported by Hampton & Soule (2004). Biomass estimations were obtained using each of the three analysis methods described before: MLGS, RSEU and RST. As mentioned before, the RST method was equivalent to the one used by Hampton & Soule (2004) in their report.

A large difference was observed between original biomass estimates and the new estimates produced by us using any of the three methods. As expected form previous analysis, the lowest mean estimates were produced by MLGS, which yielded a mean biomass of 27,500 ton, a 41 % lower than the estimate reported by Hampton & Soule (2004) (

Table 13). A close agreement occurred between RSEU and RST methods, which produced mean biomass estimates which were 29-32 % lower than Hampton & Soule's (2004) ones. The most unexpected difference corresponded to the RST method, which was expected to yield identical results to Hampton & Soule (2004). Being everything else equal, such discrepancy suggests large effects from analyst judgment in terms of both shoal identification and shoal/bottom delineation.

Table 13: Survey area, unconditional mean S_A and Biomass estimates corresponding to the 2004 plume survey in the Chatham Rise area (snapshots 8-12). FRS: original estimates reported by Hampton & Soule (...); MLGS: maximum likelihood geo-statistical approach (Roa-Ureta & Niklitschek 2007); RSEU: random sampling from 50-m elementary sampling units; RST: random sampling from transects.

Snap-shot	Area (km^2)		Unconditional mean S_A (m^2/nm^2)				Biomass (TS=-51.4 dB) (ton)			
	FRS	UACH	FRS	MLGS	RSEU	RST	FRS	MLGS	RSEU	RST
7	62.0	62.9	222	106	127	161	56,803	27,499	33,006	41,708
8	61.4	57.1	264	201	175	194	67,011	47,407	41,217	45,765
9	70.8	66.7	131	78	99	94	38,234	21,516	27,331	25,903
10	37.8	35.9	231	160	201	177	36,043	23,734	29,807	26,252
11	40.6	40.2	201	104	159	144	33,774	17,228	26,407	23,916
Mean	55	53	210	130	152	154	46,373	27,477	31,554	32,709
(%)	100	-3.6	100	-38.2	-27.5	-26.6	100	-40.7	-32.0	-29.5

3. *Contrasting alfonsino estimates from the Indian and Pacific Oceans*

After contrasting alfonsino results from the Indian Ocean against alfonsino results in the SE Pacific Ocean (Juan Fernandez Archipelago) we observed similar acoustic and numerical (Table 154) densities between both areas, suggesting the relatively lower estimates obtained for the Indian Ocean are probably related to the smaller surface areas observed in the latter group of surveys. It also called our attention the higher stock presence ratios in the Indian Ocean (Table 15) which suggest survey patterns were more tightly related to the actual fish distribution or, as suggested before, they targeted fish shoals rather than stock areas.

Table 14: Spatial distribution, acoustic density and relative abundance indexes estimated for orange roughy in Juan Fernandez Archipelago in 2007. Maximum likelihood geo-statistical approach (Roa-Ureta & Niklitschek 2007).

Zone	Year	Survey Area (km²)	Stock presence ratio		Stock area (km²)		Acoustic density (m²/mn²)	
			p	EE	α	EE	S_A	EE
ENNO	2007	13.2	0.03	0.021	0.4	0.277	35,763	16,999
ENSO	2007	3.9	0.14	0.084	0.55	0.328	1,304	185
CRNE	2008	1.1	0.37	0.107	0.41	0.118	7,577	4,326
EURO	2008	2.4	0.17	0.05	0.41	0.12	7,072	1,153
FREO	2008	4.1	0.45	0.061	1.85	0.25	5,093	1,556
TB2E	2008	1.9	0.23	0.073	0.44	0.139	36,513	14,644
TB2W	2008	3.3	0.46	0.066	1.52	0.218	6,278	6,143
1	2007	383.3	0.076	0.011	29.2	4.23	2,222	174
1.1	2007	7.5	0.019	0.0158	0.1	0.12	7,473	4,797
2	2007	153.6	0.062	0.0089	9.5	1.37	10,307	2,141
6	2007	32.4	0.21	0.0206	6.8	0.67	3,726	1,815

Table 15: Mean density, abundance and biomass estimates for alfonsino in the Indian Ocean and Juan Fernandez Archipelago in the SE Pacific Ocean. Maximum likelihood geo-statistical approach (Roa-Ureta & Niklitschek 2007).

Zone	Year	Numerical density (ind/m2)		abundance (×106)		Biomass (ton)		
		d	EE	N	EE	B	EE	CV(%)
ENNO	2007	1.77	0.843	0.75	0.608	1666	1352	0.81
ENSO	2007	0.06	0.009	0.04	0.022	78	49	0.63
CRNE	2008	0.38	0.215	0.16	0.101	349	225	0.64
EURO	2008	0.56	0.091	0.23	0.078	386	132	0.34
FREO	2008	0.4	0.123	0.74	0.249	1269	425	0.33
TB2E	2008	1.81	0.726	0.77	0.396	1701	886	0.52
TB2W	2008	0.31	0.305	0.47	0.462	1032	1024	0.99
1	2007	0.6	0.047	17.5	2.87	7767	2735	0.35
1.1	2007	1.35	0.869	0.2	0.18	138	125	0.9
2	2007	1.61	0.333	15.2	3.82	13793	3656	0.27
6	2007	0.71	0.344	4.8	2.37	3213	1753	0.55