The importance of regular hydroacoustic biomass surveys off South Africa

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Hydro-acoustic surveys are the primary inputs for the management of South Africa's small pelagic fish resources. Regular surveys are, however, being hampered by vessel breakdowns and funding limitations. Alternative survey or biomass estimation methods should be investigated, some of which are briefly mentioned. Additionally, small to moderate cost savings may be possible from reductions in survey effort, particularly during high biomass periods.

Small pelagic fish in South African waters, anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* are managed through total allowable catches (TACs) and total allowable by-catches (TABs), while West Coast round herring *Etrumeus whiteheadi* is currently manged through a precautionary upper catch limit (PUCL). Fishery-independent bi-annual hydro-acoustic surveys have been conducted since1984 to estimate the biomass of adult fish at the onset of austral summer (October through December), and of recruits at the onset of winter (May through July) (DFFE 2025).

The survey results are key inputs for quantitative stock assessments and used in harvest control rules to recommend catch limits. Sardine TACs and TABs, initial anchovy TACs, and round herring PUCLs for the following year's fishing season are set in December each year based primarily on the results from the summer biomass surveys. Because the anchovy fishery mainly targets anchovy recruits, the final anchovy TACs and juvenile sardine TABs for the year are recommended upon the completion of the recruit survey in winter (i.e., midway during the fishing season).

The summer survey extends from Hondeklip Bay on the West Coast to Port Alfred on the South Coast with the possibility of surveying to Port St Johns if weather, time and/or resources permit (Figure 1a). The main area of the winter survey is the area between the Orange River and Cape Infanta (Figure 1b). This area was found to cover the main recruitment of anchovy in the 1980s, but these surveys have been extended as far as Port Alfred in many recent years when weather, time/resources allow, to ensure estimation of sardine and round herring recruitment on the South Coast. These surveys were usually conducted on board the research vessel *Africana* or *Algoa* (in the late 1990s/early 2000s), but have increasingly been conducted on board the fishing vessel *Compass Challenger* when the Africana was not available. Eleven out of 24 surveys since 2013 have been conducted on the Compass Challenger.

The South African small pelagic fishery is manged through an Operational Management Procedure (OMP), conditioned on low probabilities that the abundances of these resources drop below levels at which successful future recruitment might be compromised. In 2009, Barange and de Oliviera estimated that the cancellation of the recruit survey in any year would result in TACs for anchovy and sardine that were reduced by about 10%, and that the cancellation of both the recruit and biomass surveys would result in TACs that were about 30% lower. They argued this on the basis that to maintain reasonable levels of risk, the management procedure would have to compensate for the loss of fishery-independent data by reducing average catches. Coetzee et al. (2024) estimated that not conducting the annual biomass survey in 2004 would result in a loss to the fishing industry in the order of R500 million to R1 billion for the 2025 fishing season whereas the cost of conducting a survey is in the order of R8 million (1 to 3 % of the loss). These calculations assumed TACs that would be reduced by some 15 or 30%.

Additionally, pelagic surveys collect a wealth of other information on life history and biology (parasite infection rates, age and weight measurements, gonad maturity, genetic material), impacts of anthropogenic activities (pollution, heavy metals), and ecosystem interactions (studies on predator and prey of fish, diet samples), while also feeding into National Biodiversity Assessments and Spatial planning. Importantly, these surveys ensure sustainable harvesting of pelagic fish by allowing higher harvest rates in years with high abundance and conserving stocks in years with low or poor abundance or recruitment.

While many fisheries resources are managed on the basis of commercial catch data and assumptions that catch rates are proportional to stock size, this is not necessarily the case for small pelagic schooling fish, which tend to reduce their distribution range as their biomass declines (Barange et al. 2009). These small aggregations can then sustain high catch rates despite a drop in overall abundance. Additionally, to maximise fish quality and income, the South African pelagic fishing industry tends to target fish aggregations close inshore and within reach of processing facilities. Any catch rates arising from these catches results in a mismatch between fishing effort and the larger fish distribution (Figure 3 and 4).

The small pelagic fishing vessels also do not operate in isolation. Typically when one vessel finds a fishable aggregation, other vessels are alerted and hence the CPUE of vessels subsequently fishing the same aggregation as the vessel that initially found the aggregation are likely to be higher. While technological creep can be accounted for during CPUE standardization, the use of long-range sonars does make it much easier to find aggregated fish, even at low biomass. Finally, the operation of the small pelagic industry is rather complex with very few factories processing the catches of all right holders. Vessels are given daily “tallies”. This means that even if a vessel can catch more, they are only allowed to deliver a fixed amount (the “tally”) of fish to a factory. If they encounter larger schools, they either split the school during fishing, or arrange for a second vessel to pump the excess fish onboard – this is known locally as “bo-lyn”. This practice will further bias CPUE estimates.

Furthermore, catch rates in one season are poor predictors of biomass in the next season. This is because small pelagic fish typically have short lifespans and exhibit strong population responses to environmental variability, which result in large natural fluctuations in abundance over space and time (Figure 4). So even if a correlation between CPUE and biomass can be established, as was the case for anchovy CPUE between the months of April to June in the area north of Cape Columbine and the subsequent recruitment estimate a month or two later (Butterworth et al. 2020), this does not assist in setting TACs for the following year and is too late for setting TACs for the early part of the annual recruit run. Note too that no such correlations have been established for sardine recruitment or for adult biomass, which is needed for setting sardine and round herring TACs.

It is likely that future funding for conducting surveys will continue to be limited and that problems with the aged Africana will persist. At present, the largest part of the budget allocation for research vessels goes towards “ownership costs”, i.e., vessels need to be staffed, berthed and maintained even if they do not go to sea. The only additional cost when undertaking research surveys is that for fuel and vitals, which make up a small portion of the daily cost of owning and operating a research vessel. When using a fishing vessel to conduct the surveys, an additional expense burden is carried because the “ownership costs” of the research vessel still apply.

Alternative options that might be considered include: 1) Government sells or decommissions its research fleet, freeing up funds to charter independent vessels, 2) the setting aside of research TAC allocations that may be sold to the highest bidder to fund surveys, 3) Government/Fishery partnerships or co-funding models where right holders contribute directly to funding surveys, 4) Industry-funded surveys where the industry charters a suitable vessel and conducts the surveys (with government scientists participating), or 5) participation by all pelagic vessels in the surveys, provided they are fitted with scientific echosounders and where vessels recoup their expenses from “sample catches” taken during their participation. Each of these alternatives require in-depth discussion to weigh the likely pros and cons and are not dealt with in detail here.

A final alternative, likely to result in only small cost savings, is to adjust the survey effort. Survey effort includes a combination of survey coverage (the northern, eastern and offshore extent of the sampling domain) and the number of transects randomly positioned within each stratum, which in turn has implications for the inter-transect spacing and the degree of coverage (intensity). Survey coverage cannot be decreased as it is essential that each species’ full distributional range be surveyed if biomass estimates are to remain comparable from one year to the next. The current standard survey coverage for biomass surveys has been extended eastward on several occasions to check that a large proportion of the biomass is not located east of Port Alfred – this should ideally also be done for the area to the north of Hondeklip Bay, where round herring have at times been observed, particularly now that fishing pressure on this resource is increasing.

The average inter-transect spacing and degree of coverage (Aglen 1983), calculated as:

$$DOC = {}^{L}/_{\sqrt{A}}$$

where L represents the total length of all transects surveyed (km) and A is the area of the sampling domain (km^2) have improved considerably over the course of the timeseries (Figure 5) mainly because of the eastward expansion of anchovy and sardine and the need to survey these areas with higher intensity than was appropriate for the early years. These improvements were deemed particularly important for sardine, which has inherent patchiness and where the biomass is dominated by a small number of very dense aggregations. The spatial structure of sardine hotspots develops over short autocorrelation ranges (<10 nmi) and the distribution of sardine is extremely right skewed; hence biomass estimates depend strongly on the “hit” or “miss” of these high density areas. Several studies (Barange et al. 1997, 2005; Coetzee et al. 2010) showed that to encounter sufficient high density aggregations of sardine frequently, an inter-transect spacing of around 10 nmi was required. Current average transect spacing is still slightly above this level.

However, given the practical constraints of funding, it is worthwhile considering the implications of reduced sampling effort. This could for example be quantified using retrospective resampling of historical transect data, which will allow the change in biomass and precision of reduced survey effort to be evaluated explicitly. Results from a preliminary attempt at this are shown in Figures 6-8 (see Appendix A for methods). These results suggest that for the last decade of summer biomass surveys (2014 – 2024) a systematic reduction in survey effort from 1.0 to ~ 0.5 of the total survey transect length had limited impact on the median biomass estimates of all three species (Figure 6 , left panels), with the median biomass ratios remaining close to one for large effort reductions. The associated CVs, however, increased almost linearly as effort was reduced (Figure 6, right panels) rising to around 1.3 – 1.5 times higher than for the full survey coverage. The 10 – 90% quantiles in both plots widened progressively as effort decreased, indicating increasingly variable outcomes under greater effort reduction.

The worm plots show a high level of divergence amongst replicates for all three species, both at low biomass levels (2024, Figure 7) and high biomass (2014, Figure 8). Even small reductions in effort resulted in substantial variability in biomass and CVs and illustrated that the removal of only a few individual lines can strongly influence both the mean density and its variance. Although this needs further investigation, it is likely that the biomass and CVs will be less sensitive to effort reductions when biomass is higher, given that aggregations typically extend over larger areas than at low biomass and hence will be intercepted more than once. However, the trade-off between relatively small cost savings from a reduction in survey effort (i.e., saved fuel costs) vs loss in survey precision requires further discussion and evaluation. This is particularly important given that survey biomass estimates are used directly in the calculation of TAC recommendations and variability in biomass estimates at the scale seen in the annual worm plots will have huge implications for recommended catch limits.

References

Aglen, A. 1983. Random errors of acoustic fish abundance estimates in relation to the survey grid density applied. FAO Fish. Rep., 300: 293-298.

Barange, M., Coetzee, J., Takasuka, A., Hill, K., Gutierrez, M., Oozeki, Y., Lingen, C. v. d., et al. 2009. Habitat expansion and contraction in anchovy and sardine populations. Progress in Oceanography, 83: 251-260.

Barange, M., Coetzee, J. C., and Twatwa, N. M. 2005. Strategies of space occupation by anchovy and sardine in the southern Benguela: The role of stock size and intra-species competition. ICES Journal of Marine Science, 62: 645-654.

Barange, M., and De Oliveira, J. A. A. 1999. The value of acoustic surveys of anchovy and sardine: costs and benefits. In SA Shipping News and Fishing Industry Review - July/August 1999., pp. 42-44.

Barange, M., and Hampton, I. 1997. Spatial structure of co-occurring anchovy and sardine populations from acoustic data: implications for survey design. Fisheries Oceanography, 6: 94-108.

Butterworth DS, Ross-Gillespie A, Coetzee JC. 2020. Can CPUE inform on sardine and anchovy recruitment strength? FISHERIES/2020/JUL/SWG-PEL/59. 5pp.

Coetzee, J. C., Misund, O. A., and Oechslin, G. 2001. Variable spatial structure of schooling pelagic fish off Namibia: Implications for acoustic surveys. South African Journal of Marine Science: 99-109.

Coetzee JC, Butterworth DS, de Moor CL, Durholtz D. 2024. Summary cost implications of not conducting a November 2024 small pelagic biomass survey with comments on the financial benefits of having conducted the 2024 demersal surveys. Unpublished DFFE Pelagic Scientific Working Group document. FISHERIES/2024/OCT/SWG-PEL/53. 7 pp.

DFFE (Department of Forestry, Fisheries and the Environment). 2025. Status of the South African marine fishery resources 2025. Cape Town: DFFE

Jolly G and Hampton I. 1990. A Stratified Random Transect Design for Acoustic Surveys of Fish Stocks. Canadian Journal of Fisheries and Aquatic Sciences. 47(7):1282-1291.

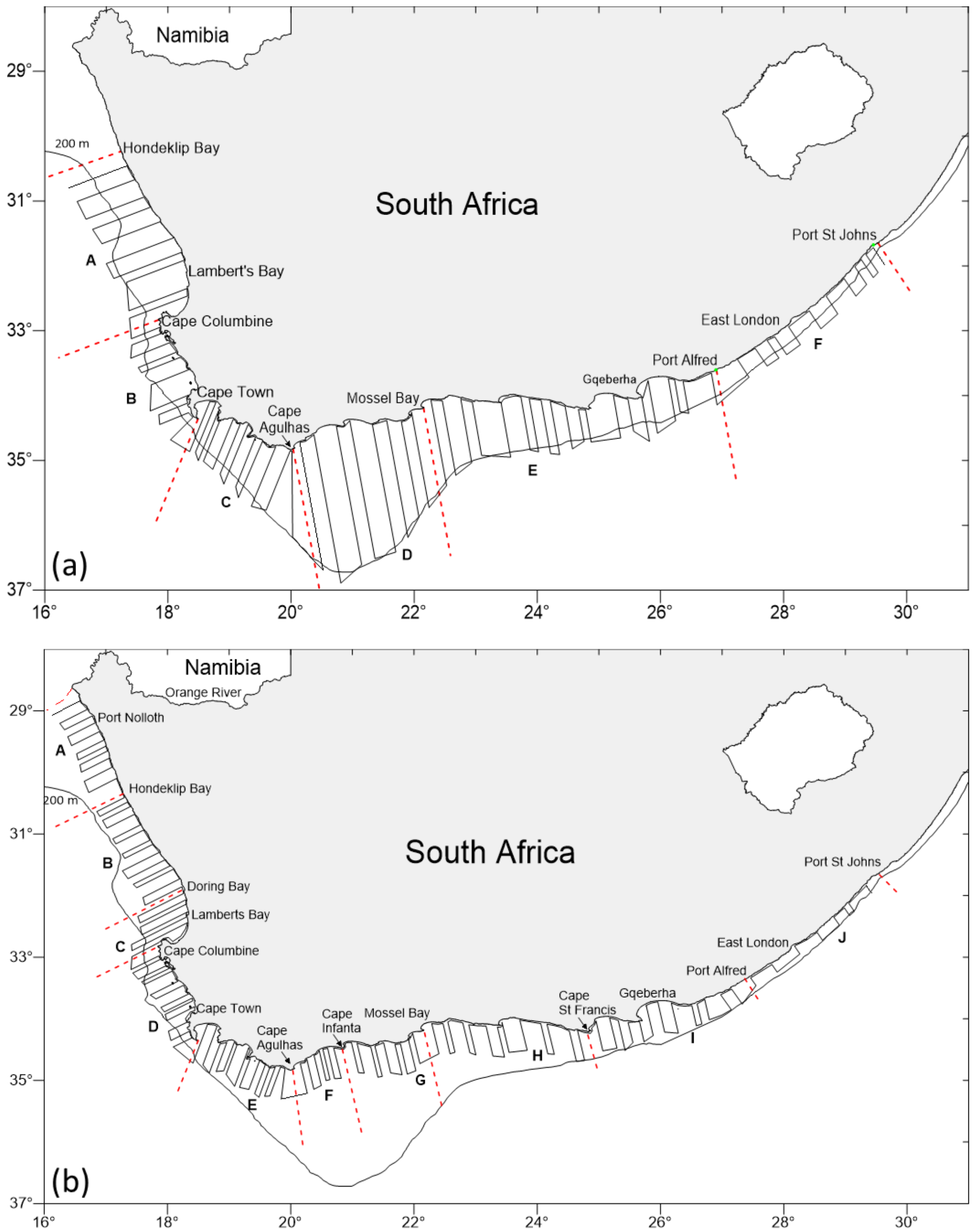

Figure 1. Typical random-stratified hydroacoustic survey design for summer biomass (a) and winter recruitment (b) surveys.

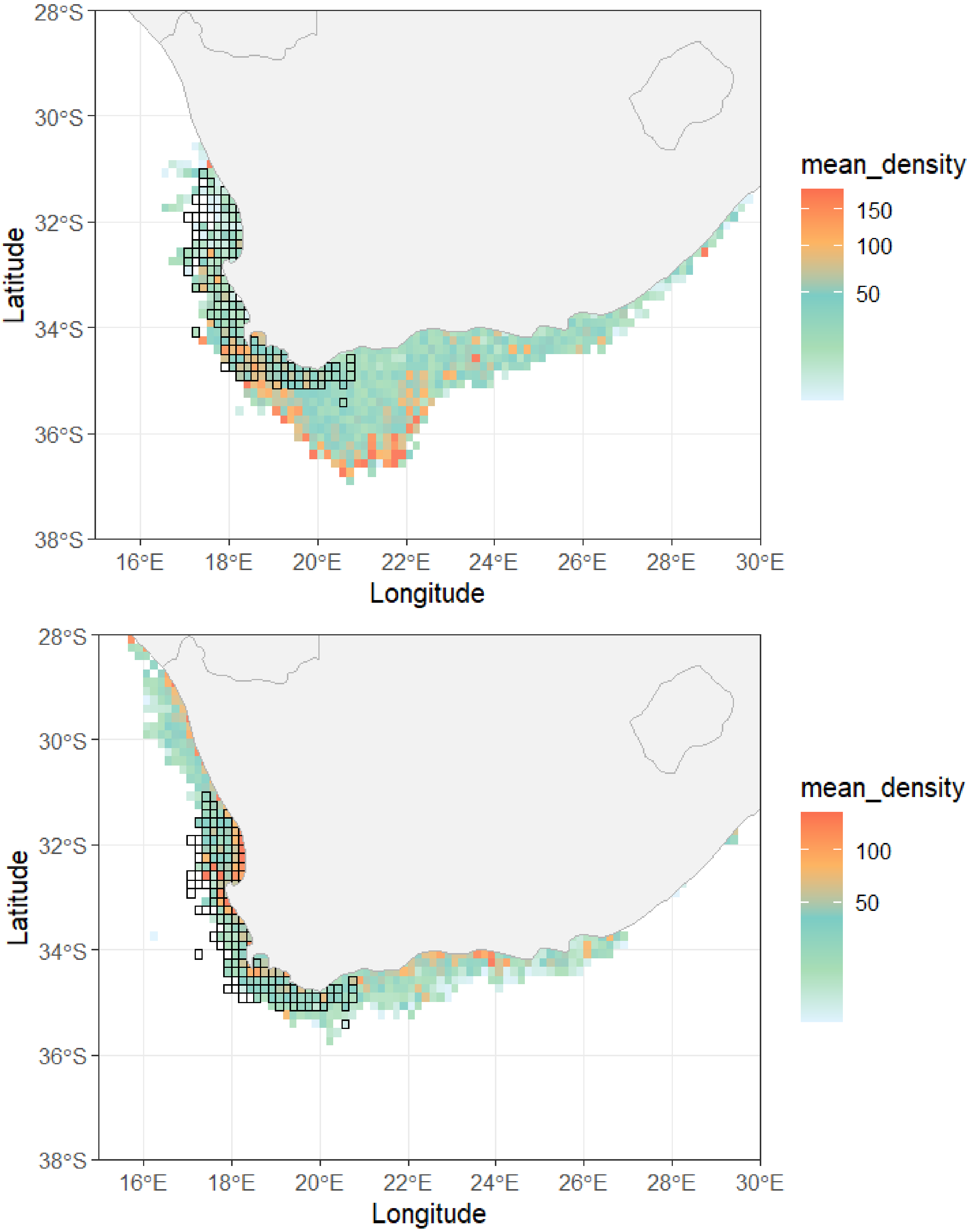

Figure 2. Composite anchovy density (average per 10´x10´ grid cell) over the entire timeseries for summer biomass (top) and winter recruit (bottom) surveys. Outlined grid cells indicate the position of directed anchovy catches since 1987.

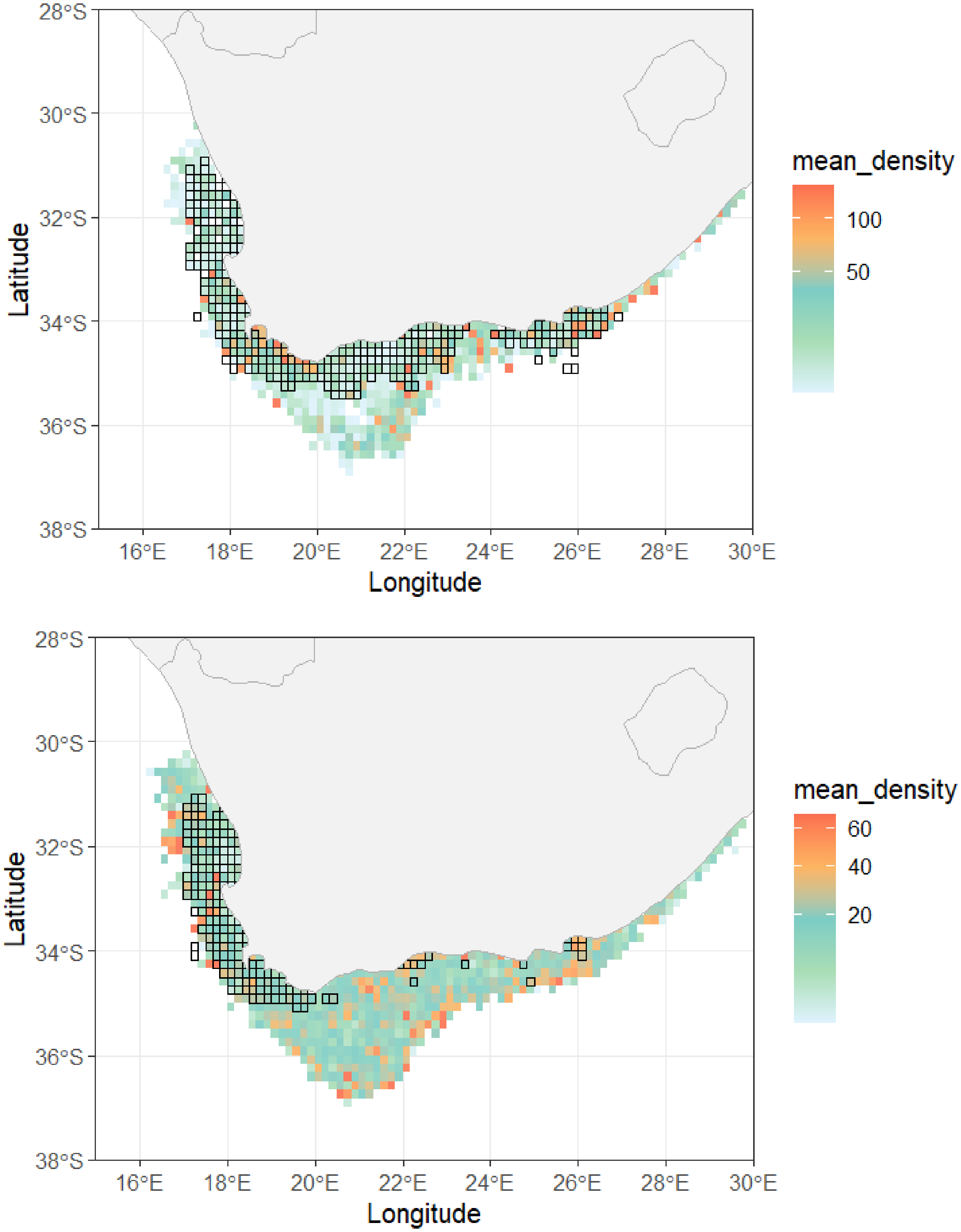

Figure 3. Composite sardine (top) and round herring (bottom) density (average per 10′x10′ grid cell) over the entire timeseries for summer biomass surveys. Outlined grid cells indicate the position of sardine and round herring catches since 1987.

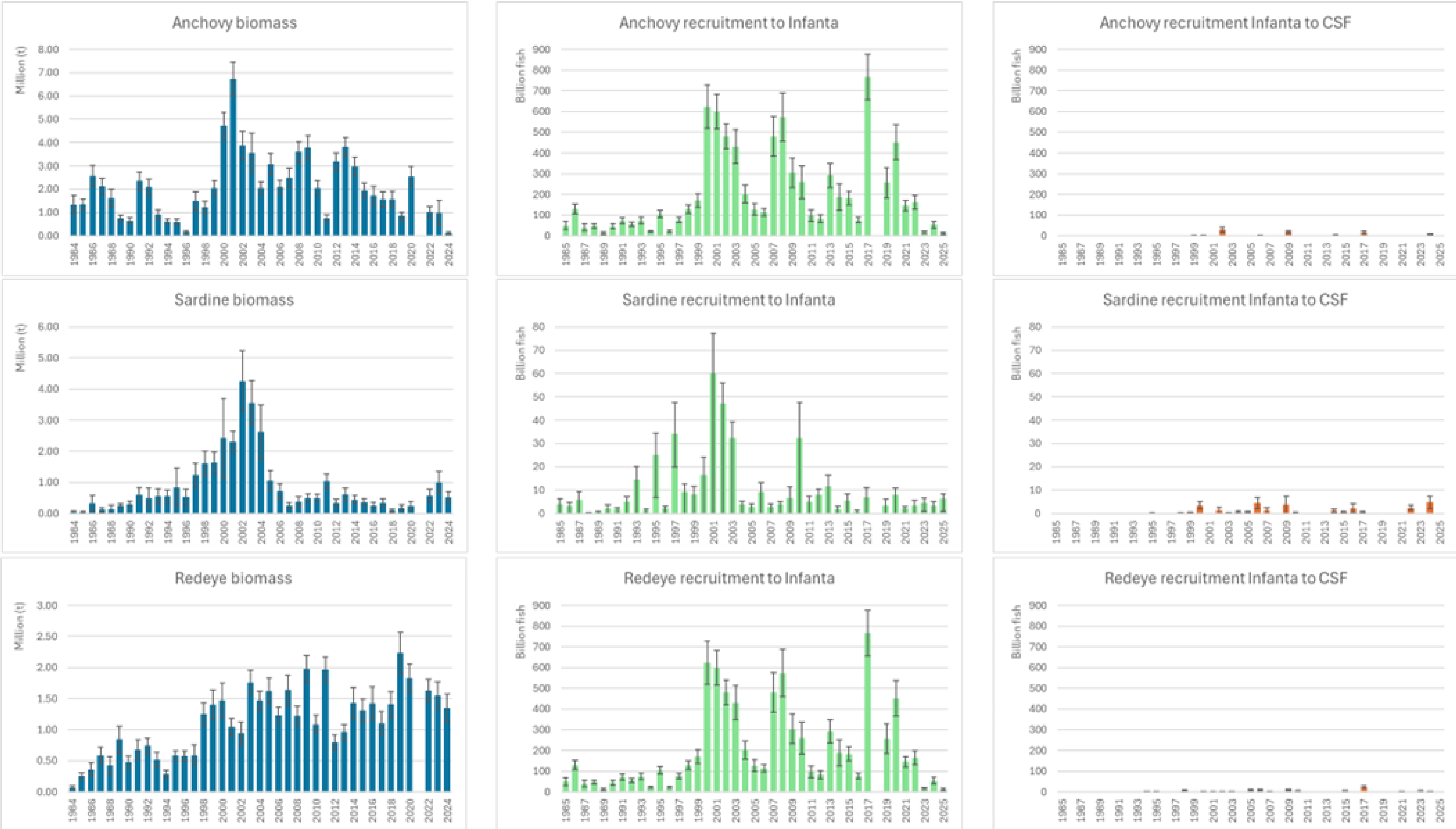

Figure 4. Summer biomass estimates (left panel, million t), winter recruit survey estimates up to Cape Infanta (middle panel, billion fish) and winter recruit survey estimates from Cape Infanta to Cape St Francis (right panel, billion fish) for anchovy (Top), sardine (middle row) and

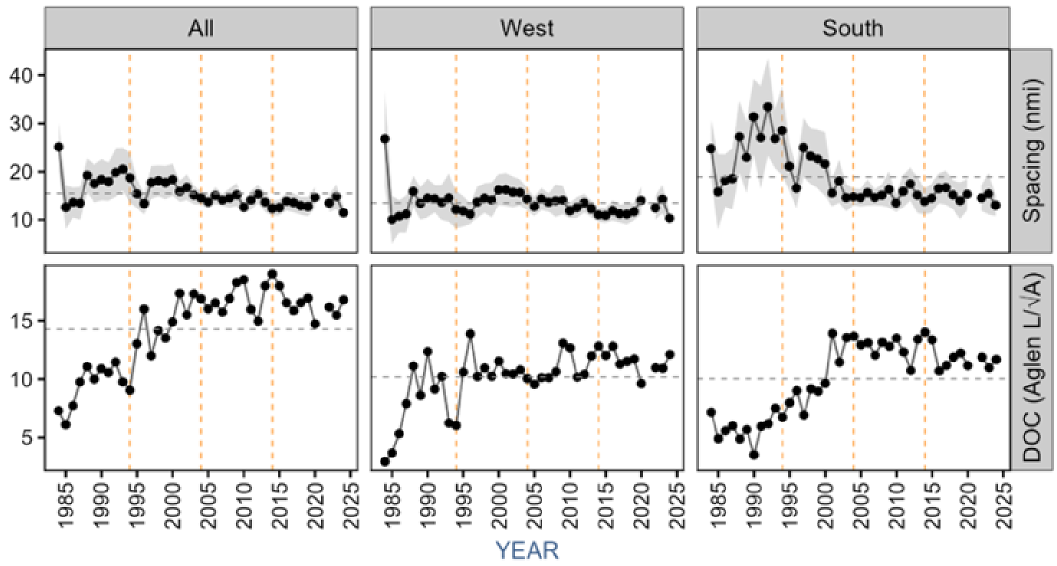

Figure 5. Temporal variation in inter-transect spacing (nmi) and survey intensity (DOC) for summer biomass surveys from 1984 to 2024 for the full survey domain (All, left), the West Coast (middle) and the South Coast (right). Shaded bands represent the 95% confidence intervals and the dashed grey horizontal lines represent the overall mean for each metric (Ignore vertical dashed lines).

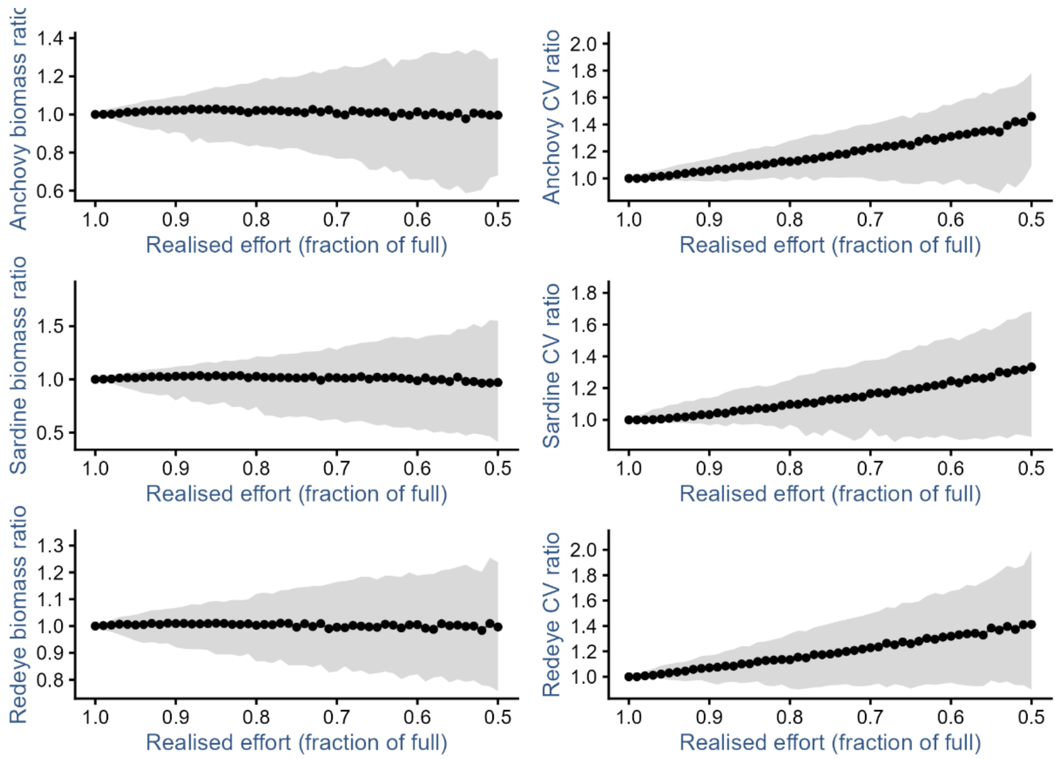

Figure 6. Sensitivity of biomass and CV to reductions in survey effort for anchovy (top), sardine (middle) and redeye (bottom). Black line is the median over 100 replicates and grey shading represents the 10–90% uncertainty interval.

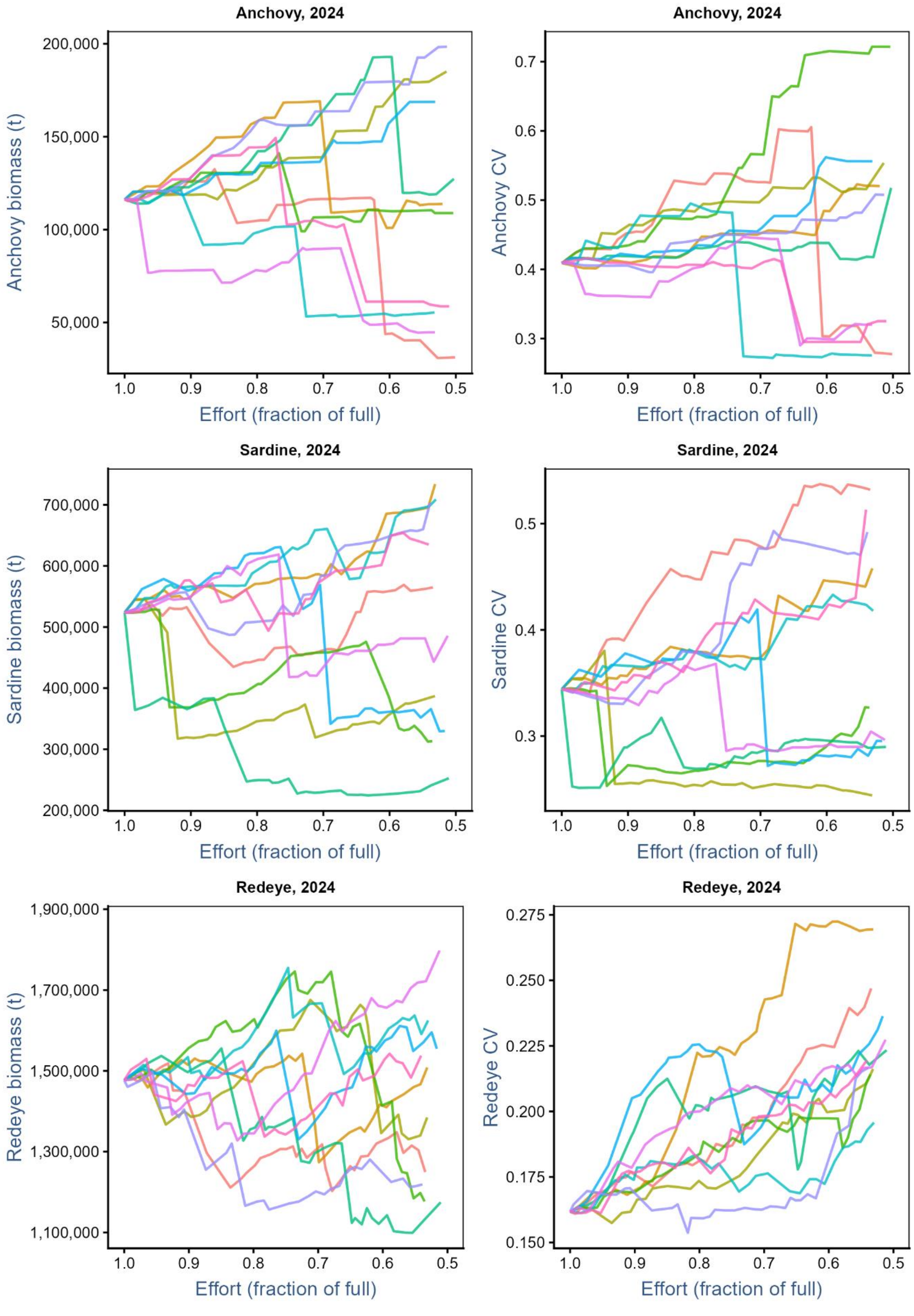

Figure 7. Worm plots showing sensitivity of biomass (left) and CV (right) to progressive reductions in survey effort for anchovy (top), sardine (middle) and redeye (bottom) during the 2024 biomass survey. The first 10 bootstrap iterations are shown.

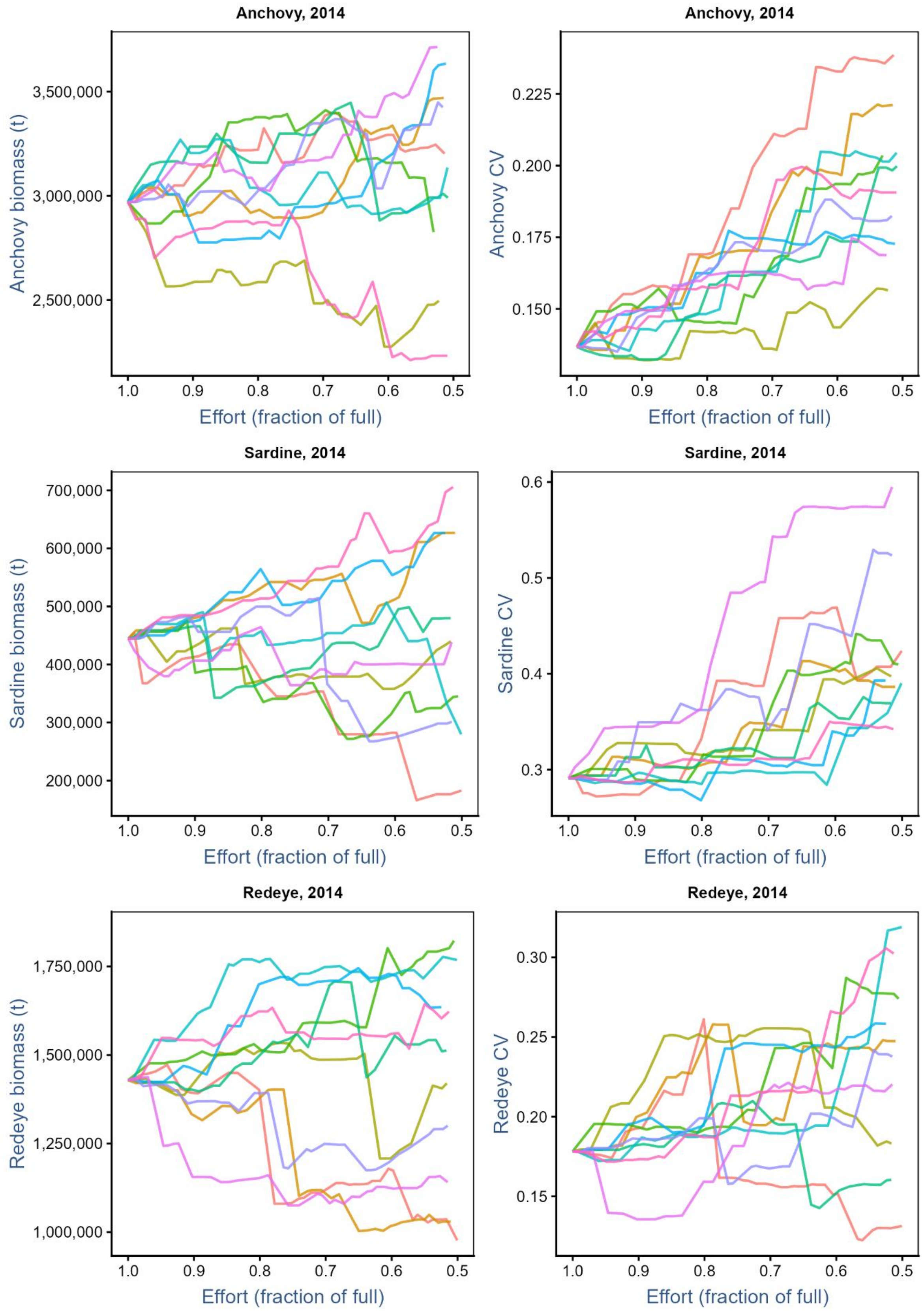

Figure 8. Worm plots showing sensitivity of biomass (left) and CV (right) to progressive reductions in survey effort for anchovy (top), sardine (middle) and redeye (bottom) during the 2014 biomass survey. The first 10 bootstrap iterations are shown.

Appendix A: Resampling method

This appendix outlines the resampling framework developed as a first attempt to evaluate the consequences of progressively reducing survey effort on biomass and variance estimates.

Biomass estimation framework

Hydroacoustic surveys follow a random-stratified transect design, with transects allocated to predefined strata (A to E, for summer surveys), based on past distribution patterns and guided by the most recent stratum estimates of variance. Each survey is designed with the aim of reducing the total survey CV for sardine, the species with the patchiest distribution. Following Jolly and Hampton (1990), each transect provides a species-specific estimate of mean density $\bar{\rho}_j$ (g m^{-2}) and has an associated transect length L_j (nmi) from which stratum level and survey biomass are estimated. Stratum-level mean density ($\bar{\rho}_k$) is calculated as the transect-length-weighted mean:

$$\bar{\rho}_k = \frac{\sum_j \bar{\rho}_j L_j}{L_k}$$

where $L_k = \sum_j L_j$ and the variance of the stratum mean density (s_k^2) is calculated as:

$$s_k^2 = \frac{n}{n-1} \frac{\sum_j \left[(\bar{\rho}_j - \bar{\rho}_k) L_j \right]^2}{L_k^2}$$

where *n* is the number of transects in the stratum.

Biomass per stratum B_k (t) is then $\bar{\rho}_k \times A_k$, where A_k is the area (km^2) and total survey biomass is $B_s = \sum_k B_k$. The corresponding variance is

$$s_s^2 = \sum_k s_k^2,$$

and the total transect length is $L_s = \sum_k L_k$. These values represent the full-effort ("reference") estimates for each survey.

Resampling strategy

To evaluate how reduced survey sampling effort affects biomass estimates and their precision, a systematic resampling approach was taken. Effort was reduced by progressively removing one transect at a time, while recalculating B_s and s_s^2 after each removal. This process was repeated 100 times per survey to generate distributions of B_s and s_s^2 at each realised effort level, where the realised effort level E_r represents the proportion of the total transect length L_s remaining $E_r = \frac{L_{rem}}{L_s}$ and decreases continuously with each transect removed from 1.0 to ~ 0.5. The bootstrap distribution distributions of B_s and s_s^2 at each realised effort level E_r across the 100 replicates was summarised using the median and the 10 – 90% interval. Only the last 10 summer surveys were considered, reflecting recent survey design and species distributions.

Resampling was at the level of the survey, rather than at stratum level because: 1) transect lengths and areas vary greatly across strata (e.g., long transects/large area in Stratum D, short transects/small area in Stratum E – see Figure 1a), 2) proportional effort reduction would distort the spatial distribution of sampling effort, and 3) removal of “short” and “long” transects is not equivalent in terms of effective intensity.

However, to avoid unrealistic spatial imbalances in the resulting design, the following constraints were imposed:

1) Minimum transect count constraint - strata had to retain at least 3 transects to ensure a meaningful estimate of variance.
2) Additional transects could be removed from a stratum only if its current sampling intensity $I_{cur} = \frac{L_{k,rem}}{\sqrt{A_k}}$ remained ≥ 0.5 of its full-survey intensity $I_{full} = \frac{L_{k,full}}{\sqrt{A_k}}$.
3) Among eligible strata, the removal probability was proportional to each stratum’s remaining intensity margin (i.e., the degree to which its current sampling intensity exceeded the minimum allowable value of 0.5) defined as $\frac{I_{cur}}{I_{ful}} - 0.5$. This effectively means that transects were removed more often from strata furthest above the minimum allowed intensity.
4) Once a stratum was selected, one transect was removed at random.

This strategy creates effort reductions that are operationally realistic, spatially feasible and consistent with the actual uneven distribution of survey effort amongst strata.

For reporting, the 100 bootstrap replicates for each survey were first transformed into biomass ratios and CV ratios relative to that survey’s full-effort estimate:

$$\text{Biomass ratio} = B_{samp}/B_s\,, \quad \text{CV ratio} = CV_{samp}/CV_s.$$

Effort values $(L_{s,rem}/L_s)$ were binned to the nearest 0.05 (i.e., 1.00, 0.95, 0.90, …, 0.50). For each bin, across surveys, all bootstrap replicates from all 10 surveys were pooled and the median and 10 – 90% interval calculated.