Appendix 1

Example of Application of Framework in the Southern Benguela Ecosystem

While full applications of the discussed framework to the Southern Benguela, South Catalan Sea and North Sea have been previously described (see Loclkerbie et al. Lockerbie et al., 2017a; Lockerbie et al., 2016; Lockerbie et al., 2017b, respectively), an example of its application is given here.

A suite of eleven IndiSeas indicators, including six ecological indicators (mean fish length, mean lifespan, survey biomass, proportion of predators and trophic levels of both modelled and surveyed communities) and five fishing pressure indicators (inverse fishing pressure, landings, marine trophic index, trophic level of landings and the intrinsic vulnerability index), were utilised across all ecosystems. In the case of the Southern Benguela an additional four environmental indicators were selected which were considered to represent the most important environmental drivers in the ecosystem; sea surface temperature, chlorophyll concentration, upwelling and the position of the South Atlantic high pressure system.

Trends in all indicators were determined using linear regressions (time series plots can be seen in Figure A1), and each indicator received a score based on the significance and directions of detected trends; highly significant positive trend = 1, ecologically significant positive trend = 2, no significant trend = 3, ecologically significant negative trend = 4 and highly significant negative trend = 5. A score adjustment system was developed (Figure 2), following detailed sensitivity analysis (see Lockerbie et a., 2016), to modify scores to account for the impacts of both fishing pressure and environmental variability on ecological indicators. Fishing pressure indicators were combined, as described above, into an indicator of overall fishing pressure, and it is this indicator that was utilised to determine whether ecological indicator trends resulted from the observed trend in fishing pressure. Score adjustment was based on both the direction of the trend in fishing pressure, and to what extent fishing pressure could explain the observed trend in an ecological indicator. Following this initial score adjustment, it was necessary to determine whether the trends in environmental indicators would have influenced the observed ecological indicator trends. At this stage, due to the complex nature of ecosystems, it is not possible to determine whether the identified environmental change would be positive or negative for the ecosystem, as various species will respond differently. Therefore, this adjustment involved dividing the indicator score depending on the extent to which environmental variability was thought to have impacted the ecological indicators, acting to lessen the impacts of fishing on the indicator in question and signifying that fishing pressure was not the sole cause of the observed ecological indicator trend. Finally, scores were adjusted to account the possible redundancy of correlated indicators by applying different weightings to correlated and non-correlated indicators. This weighting acted to reduce the contribution of correlated indicators to the overall ecosystem score. It was necessary for this final adjustment to be ecosystem specific, as different indicators were correlated in different ecosystems.

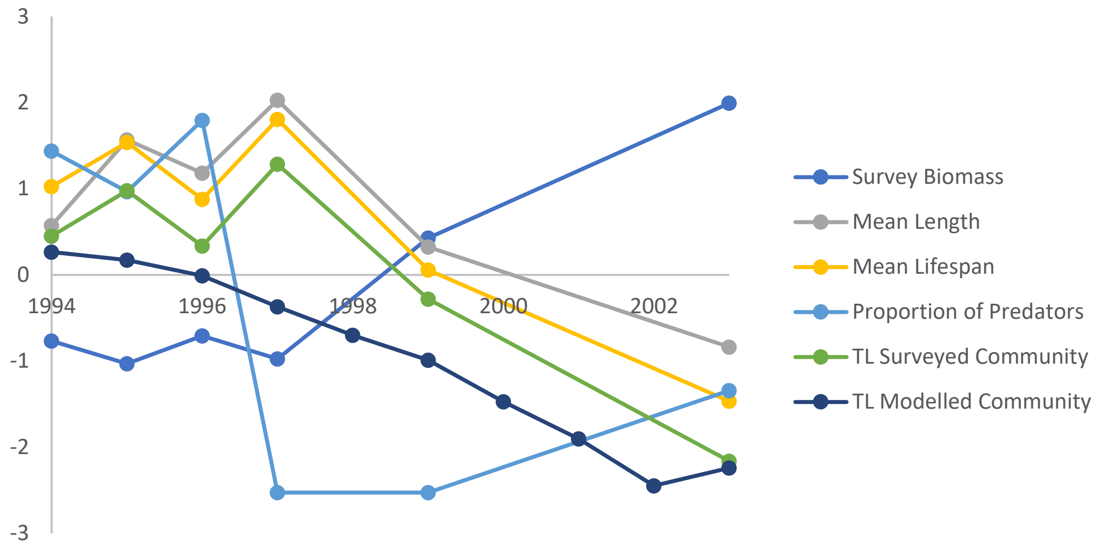

Figure A1: Time series plot of indicators values for Period 2 (1994-2003)

This process was applied to each of the three periods in turn, classifying the state of the ecosystem in each. Table A1 shows summarised results from the assessment of Period 2 (1994-2003) in the Southern Benguela. When applying the score adjustment to the framework it is necessary to provide details to ensure the correct interpretation of indicator trends. While IndiSeas indicators have been formulated so that a decreasing trend is considered to represent a negative change within an ecosystem, other factors may come into play. Therefore, at this stage the considerable importance of including expert knowledge was highlighted, with regional experts ensuring accurate understanding of ecological changes represented by the indicator trends. For example, in Period 2, when there was a decrease in fishing pressure, the negative scores observed in numerous indicators were unexpected (see Table A1). However, through use of expert knowledge alongside information gained from literature, it was possible to relate the highly significant negative trends observed in mean lifespan, proportion of predators and the trophic levels of both the modelled and surveyed communities to a short-lived but significant increase in small pelagic fish in the early 2000s (Roy et al., 2001). This increase in small pelagic species was significant enough to alter indicators trends over the entire period, with negative trends not representing a negative influence of fishing pressure on the ecosystem.

Table A1: Summary of outputs of decision tree framework for Period 2 (1994-2003) in the Southern Benguela. Scores are sequentially adjusted to account for the influences of fishing pressure and environmental variability. A weighted mean is used to account for potential redundancies and calculate a final score, classifying the ecosystem. See footnotes for details on how the observed fishing pressure and environmental indicator trends impact each indicator (Adjusted from Lockerbie et al. 2016).

	Period 2 (1994-2003)				
Indicator	Original Score	Trends in fishing pressure & did fishing pressure cause this trend?	New Score	Did the environment influence this trend?	Final Score
Mean Length	3	Decreasing - Partially[i]	2.25	Yes[v]	1.5
Mean Lifespan	5	Decreasing - No[ii]	5	Yes[v]	3.33
Biomass	1	Decreasing - Yes[iii]	0.5	Yes[vi]	0.33
Proportion of Predators	5	Decreasing - No[iv]	5	Partially[vii]	4
Trophic Level of Surveyed Community	5	Decreasing - No[iv]	5	Yes[viii]	3.33
Trophic Level of Modelled Community	5	Decreasing - No[iv]	5	Yes[viii]	3.33
Mean Score	4				2.64
Weighted Mean				**Ecosystem score:**	**2.56**

[i] Overall fishing pressure decreased, therefore increased mean fish length may be expected due to decreased pressure on the ecosystem. Lack of change in mean fish length likely resulted from increases in small pelagic fish during this period while predators have not yet started to recover (Roy et al., 2001).

[ii] Overall fishing pressure decreases, therefore a significant decrease in mean lifespan would not be expected due to decreased pressure at all trophic levels. The highly significant decrease observed here is likely a result of an increase in small pelagic fish that was observed during this period (Roy et al., 2001).

[iii] Overall fishing pressure decreased; therefore, increased biomass within the ecosystem would be expected because of reduced mortality.

[iv] Overall fishing pressure decreased, therefore decreased proportion of predators and trophic level of both the surveyed and modelled communities would not be expected. May be have resulted from the unusual and short-lived increase in small pelagics (Roy et al., 2001) while predatory fish populations had not yet shown a recovery.

[v] Observed offshore movement of the South Atlantic High Pressure System along with variability in upwelling (both increases and decreases are observed at different locations). This would influence nutrients and primary production as well as dispersal and recruitment impacting all levels of the ecosystem. This, along with variability in upwelling (see Lockerbie et al. [1] - Table 3) may have influenced mean length and lifespan of fish as certain environmental conditions favoured certain species. A shift towards conditions which favoured small pelagic species, and their subsequent increase in abundance, could explain the decrease in mean lifespan (Connolly et al., 2001; Gaylord and Gaines, 2000; Rochet and Trenkel, 2003).

[vi] Observed offshore movement of the South Atlantic High Pressure System along with variability in upwelling (both increases and decreases are observed at different locations). This would influence will influence primary productivity,

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