Appendix 1: Additional background for Scenarios

<u>Changes in weather patterns in the southern Cape</u>

While fishers often attribute the current and pervasive failures of kob catches on drivers like policy and regulation, lack of funds (capital) and the impacts of the inshore trawl fishery in the area, the underlying cause appears to be kob scarcity. These shortages are most likely due to a combination of anthropogenic climate change and fishery impacts (specifically historical over-exploitation) which place severe pressure on the southern Benguela, including the distributions of marine species (Blamey et al. 2015, Currie 2017, Currie et al. 2020). Discussions with fishers throughout the workshopping process highlight the importance of weather on their ability to proceed to sea. Fishers specifically note a change to long-established weather patterns, especially when considering wind and sea current (Ward 2018, Lyttle 2019). Gammage & Jarre (in review) show that although some drivers (like climate variability and change) are not always 'top of mind', it does not mean that the effect of those drivers is not felt and that they do not exist. The BBN outputs (see Gammage 2019, Gammage and Jarre 2020) highlight the importance of climate drivers in this fishery system.

Status of climate variability/change in South Africa and the southern Cape

South Africa's climate is regulated by the ocean on three sides of the country. The southern coast is warm-temperate with varying rainfall regimes that include summer, winter and bimodal peaks in rainfall (DEA 2013). For South Africa, the mean annual temperature in South Africa has risen at least 1.5 times more than the observed global average of 0.65˚C between 1960 and 2010. Although an overall increase in the frequency of extreme rainfall events has occurred over the same period (Ziervogel et al. 2014) with LTAS model outputs indicating a significant increase in future flood risk (DEA 2013); trends in rainfall indices show a decrease in the number of rain days which could indicate a drying trend (MacKellar et al. 2014). Recent research into rainfall and temperature trends in the southern Cape by Ward (2018) found no clear trends in time for changes in rainfall amounts, although high variability has been noted. However, farmers interviewed have indicated that while the amount of rain has not changed significantly, the rainfall patterns have changed over time. The coastal temperature in the area displays more variability than that interior temperatures. There were more prevalent outliers for warmer temperatures, particularly in austral winter. These observed trends are consistent with longer-term predictions for the Western Cape, where hotter, drier conditions are expected as climate change advances (MacKellar et al. 2014).

Climate and the marine environment

The South African coastline, one of the most naturally variable globally, is approximately 3000 km long and incorporates ecoregions ranging from cool-temperate on the west coast, warm-temperate on the south coast, to subtropical on the east coast (Mead et al. 2013). The continental shelf widens west of East London and east of Cape Point to form the roughly triangular Agulhas bank, which extends about 250 km (135 nm) off the coast of Cape Infanta (Gammage et al. 2017). Spatial and temporal changes in the Southern Benguela ecosystem are attributed to various natural and anthropogenic drivers in the system, such as biotic processes, changes in structural habitat, climate change and fishing (Blamey et al. 2015)

The research area and coupled fishing activities of fishers are found in the inshore of part of the Agulhas Bank. The hydrology of the Agulhas bank is primarily driven by the wind regime, the Agulhas current running along the shelf break, and seasonal overturn of shelf waters (Jarre et al. 2015). Analysis by Rouault et al. (2009) indicates a strengthening of the Agulhas current's flow over the past 25 years, which results in warmer offshore water. Rouault et al. (2010) confirmed offshore warming and inshore cooling, corroborating findings by Roy et al. (2007). However, Blamey et al. (2015) indicate a consistent warming trend across all seasons, with general warming most distinctive in the early southern hemisphere summer months. There is more disagreement between signals of different datasets for the Agulhas Bank than for the other subsystems of the Benguela (Jarre et al. 2015). The exact interplay and trends concerning sea temperature are difficult to determine for the greater Agulhas Bank (Lyttle 2018; Ward 2018).

Two distinct ecosystem regime shifts, the 1960s and mid-1990s/early 2000s have been identified and verified (Howard et al. 2007, Blamey et al. 2012), with Ward (2018) finding evidence of a potential third in the more recent analysis. Research into historical and prevailing wind regimes at the scale of the southern Cape has shown no significant and discernible trends at the small scale (nearshore) (Ward 2018), and thus accurate future predictions are problematic. However, Ward (2018) finds that offshore wind drivers show more evident trends of increased wind speeds overtime at the shelf scale. Lyttle (2019) show that this trend of increase in offshore winds influences swell, which results in increased in wave heights on the inshore scale of the southern Cape, although both these analyses are dependent on National Centre for Environmental Prediction (NCEP) wind data.

Changes in the fishery system

Fishers identified changes in the biophysical systems as one of the four KDFs in their system. As this system is currently operating in a state of resource scarcity (Gammage and Martins unpublished data, Duggan 2012, Gammage 2015, Currie 2017, Gammage et al. 2017, Martins et al. 2019), the focus of the biophysical KDF for the final scenario story will be placed on the current and potential future status of fishery resources in this area.

Status of fishery resources in the southern Cape: present day

Climate change and variability have direct and indirect impacts on marine resources. Direct impacts include changes in physiology (specifically growth and reproductive capacity), mortality, distribution and behaviour. Changes in productivity, structure, and composition of the marine ecosystems on which fish are dependent for food are indirect impacts. Fishing effort, biological interactions, and non-climatic environmental factors may also have similar effects (Brander 2010, Hollowed et al. 2013).

Changes in species abundance and distribution are mechanisms by which fisheries resources in an area can change over time. It has, to date, been difficult to determine linefish stock levels in South Africa accurately, but particularly at the scale at which the linefishery in the southern Cape operate (see Blamey et al. 2015). However, for this scenario exercise, we can assume some changes on the small-scale, based on larger-scale change provided by previous research in the southern Benguela and Agulhas bank to establish potential future systems states (notably Blamey et al. 2015). Thus, it is only necessary to ascertain what changes fish stocks may undergo in the broadest term for these scenarios. A synthesis of ecosystem change seen in the southern Benguela by Blamey et al. (2015) describe changes seen in the southern Benguela ecosystem, whilst Currie (2017) provides a comparison of historical baseline data from the demersal trawl fishery on the Agulhas bank to a data from a resurvey in three locations (Cape Infanta, Mossel Bay and Bird Island). Currie's research provides valuable insights into how fish assemblages in some species key to the linefishery in the area have changed regarding species abundance and distribution over the past 100 years and allow us to speculate on potential future trends (in the broadest terms).

Changes in the distribution of crucial fish species on the Agulhas bank

Changes in marine distributions for the southern Benguela are well-documented. However, most of the knowledge of the physical and ecosystem change stems from the west coast of South Africa, resulting in a poor understanding of the system dynamics on the Agulhas Bank, particularly at small, localized scales (Blamey et al. 2015, Watermeyer et al. 2016, Currie 2017). One of the most important distribution shifts seen in the southern Benguela is the southward and eastward shift in distribution from the west coast to the Agulhas bank of Sardine (*Sardinops sagax*) and Anchovy (*Engraulis encrasicolus)* (der Lingen et al. 2002, Fairweather et al. 2006). As sardine and anchovy are important prey fish, it is thought that this shift may have impacted other ecosystem parts, including the distribution or abundance of fish and squid. Watermeyer et al. (2016) found evidence of increased catch proportions of amongst others, squid (*Loligo reynaudii*); kingklip (*Genypterus capensis),* round herring (*Etrumeus whiteheadi*) and chub mackerel (*Scomber japonicus*) east of 20°E (east of Cape Agulhas) following the documented shifts in sardine and anchovy distribution. Other significant eastward distributional shifts noted include west coast rock lobster (*Jasus lalandii*) (Blamey et al. 2012) and the eastward range expansion of kelp (*Ecklonia maxima)* (Bolton et al. 2012).

Changes in abundance of key fish species on the Agulhas bank

The analysis by Currie (2017) includes changes in abundance for fish species found on the Agulhas Bank. Specifically, declines in the kob abundance seen in the area are severe. Whereas kob catches in trawls were dominant (up to 25% of the catch) in the 1903/1904 baseline, they were absent in the repeat surveys of 2015. This evidence supports other studies (Griffiths 1997, 2000) and fishers' accounts (Gammage 2015, Gammage et al. 2017, Martins et al. 2019). In addition, Currie (2017) shows a substantial decrease in the kob catches in the inshore trawl in the first half of the 20th century, likely indicative of early fishing pressure and resulted in removing a sizable proportion of the pre-disturbed populations of kob (Currie 2017). This, coupled with more significant pressure in the mid-1960s and early 1980s, has likely contributed to the severe depletion of stocks experienced in the present time. Other commercially exploitable species from the area which show declining abundance include silvers/carpenter, which was found to be 0.1% of historical abundance and white stumpnose, which was found to be at 0.1% of historical abundance (Currie 2017).

At the same time, the same comparative work carried out by Currie (2017) has noted an increase in abundance in, among others, gurnards (*Chelidonichthys spp.)* and horse mackerel (*Trachurus capensis)*. However, these species present little opportunity to the linefishery in its current format. Currie (2017)'s research was carried in the context of inshore trawl and did not necessarily overlap with the linefishery in the same area. The conflict between these fisheries is well-documented, and line fishers accuse inshore trawl of increasingly encroaching on their fishing grounds. Due to the interconnectedness of the habitats in the southern Cape/Agulhas bank ecosystem, we can assume that ecological niche replacement has taken place in the inshore part of the ecosystem.

Fishery resources in the southern Cape: potential futures

The most significant drivers of change in this marine ecosystem will likely be fishing pressure and the effects of large-scale, long-term climate variability and change. While the examples of distributions shift and changes in abundance highlighted above are by no means exhaustive, it illustrates the current state of system flux and underscores the problem of resource scarcity regularly highlighted by fishers. Regarding fishing pressure on inshore marine species, even though inshore trawl effort has significantly declined in recent years, the after-effects of long-term trawling may have resulted in irreversible damage to traditional stocks. Historical, long-term trawling on the Agulhas bank has likely led to a reduction in habitat complexity. Modified energy flow pathways would benefit specific taxa but negatively affect others. Taxa that have declined on the Agulhas bank are associated with reef habitats, while species displaying an increase in abundance prefer soft substrates or inhabit both hard and soft benthic substances (Currie 2017). The survey sites used by Currie (2017) have remained commercial trawling grounds since the initial historical surveys took place. Thus, reef-like habitats, consolidated substrates structure forming communities that may have been present historically, have likely been removed or degraded by trawling. This seems to have promoted a change from partially-reef associated assemblages to catch compositions dominated by taxa associated with unconsolidated benthic habitats. This support the belief that extensive trawl activity on the inshore trawl grounds bank has modified benthic habitats. If this is correct and the sediment structure has been modified by trawling, the benthic habitat and the fishing community dependent on it may be permanently altered and fail to recover even if fishing were stopped (Currie 2017).

However, it remains challenging to predict marine ecosystem and fisheries responses to climate change accurately. Complex species distribution relationships, variation in abundance, the impact of overfishing couples with other system stressors create knowledge gaps that are difficult to circumvent. As a result, effective modelling is limited by incomplete information on the functioning of biological resources and the physical changes in the oceans. Moreover, there is also much uncertainty about the future impacts of climate change, specifically at local scales such as the southern Cape (Ortega-Cisneros et al. 2017, 2018).

As described, several marine species have already shifted their geographic ranges. Regarding fish species' general response to warming, a (south) westward migration of warm temperate species such as Geelbek (or Cape salmon) (*Atractoscion aequidens*) could occur. The temperate regions may also contract, with south coast species potentially affected by increased upwelling, related temperature extremes, reduction in runoff, and habitat loss, resulting in a decrease in subtropical species diversity and abundance. Extreme rainfall and dry spells, together with sea-level rise, could result in the loss of nursery habitats. The positive impacts of increased rainfall could be offset by seasonal shifts that may confuse behavioral cues at critical life-history stages such as spawning and migration. For example, changes in freshwater flow, sea surface temperature, and turbidity may impact the squid fishery and endemic subtropical linefish such as white Steenbras (*Lithognathus lithognathus*).

For the Agulhas bank, if populations are pressured to move due to anthropogenic warming, some of these populations may be facing a dead end. If the bank were to experience a net-warming effect, cooler-water species could move towards and into the upwelling ecosystem of the west coast, where cool shelf and inshore waters might be maintained (Lamont et al. 2018). It is, however, likely that if the highly productive west-coast subsystem suits their habitat requirements, they already occur there. The southern edge of the Agulhas Bank together will serve to limit the possible poleward expansion of demersal and pelagic species and could signify a potential dead-end if changing environments force species to migrate southward (e.g. Currie 2017). However, warm temperate species which could migrate south (east)ward due to warming could fill the niche created by the loss of the colder water species, presenting line fishers with alternative commercially exploitable species which would not necessarily necessitate a drastic shift in fishery or strategy (Blamey et al. 2015).

In another scenario, the bottom waters of the Agulhas Bank may cool due to an increase in coastal upwelling (Lamont et al. 2018) and/or greater shelf-edge upwelling, which we would expect to be driven by variability of the Agulhas Current (Rouault et al. 2009, Beal and Elipot 2016). The likely impact would be on the cold eastern ridge; (Swart and Largier 1987, Lutjeharms et al. 2000) and inshore parts of the bank through increased coastal upwelling. Species wishing to avoid the colder waters may move further east towards the warmer bottom waters found near the slightly warmer inshore areas between Mossel Bay and Cape Agulhas. This area is narrow compared to the greater (but cooler) Agulhas Bank and suggests that these distribution changes could reduce the geographic spread of the population. Furthermore, the increase in upwelling would likely increase productivity in certain areas, which would cause further changes in the ecosystem. Along with the cooling trend, there would be potential for species such as yellowtail (*Seriola lalandii*) to migrate eastward into the fishing grounds of the southern Cape linefishery (Blamey et al. 2015), offering a potentially viable alternate linefish species to target.

Summary of scenarios derived from additional drivers

Figure A2.1 shows four possible scenarios based on current and potential changes in species distribution and abundance patterns on the Agulhas Bank. Climatic drivers have already been incorporated in that that fish stocks could respond to the warming/cooling of the Agulhas Bank. Conversely, warming or cooling seen in the Agulhas bank will likely be a function of larger-scale climate changes. Thus it becomes unnecessary to take specific climatic drivers into account for these scenarios.

Linefish (specifically kob and silvers) catches continue to decline, no commercially viable species take up the niche left by the decline in the main target species. Fishers keep targeting kob, silvers, sharks and other red (reef) fish when available. Fishers forced to diversify outside fishery to sustain livelihoods. No significant/observable cooling or warming trend on the Agulhas bank seen.

Current situation in the southern Cape linefishery continues as is - kob, silver and shark catches are landed when available. Although catches remain relatively low, fishers catch enough fish to 'get by' and whilst they engage in outside livelihood activities to supplement income; the 'die-hard' fishers do not permanently diversify out of the fishery. No significant/observable cooling or warming trend on the Agulhas bank seen.

Cooling on the Agulhas bank with increased upwelling sees eastward species distribution shift of species such as yellowtail, traditionally caught between Cape Point and Cape Infanta. The may also be an increase in offshore pelagic fish species. Should abundance of species such as Yellowtail be an hindrance to achieving a sustainable (line)fish derived income, fishers may be forced to diversify outside the linefishery by getting involved in the growing pelagic fishery in the area (crew on trawlers, employment at processing plants).

Warming in Agulhas bank triggers an south (west)ward migration of temperate fish species from the Garden Route and eastern Cape coastal waters to colder water. Warm temperate species (such as Cape salmon), migrate south(east) ward and fill niche left by loss of the temperate species. Line fishers are able to easily change their target species without major shifts in strategy and fishery structure.

Figure A2.1. Four future scenarios for the linefishery based on current and possible future species distribution and abundance changes in the Agulhas Bank. Warming and cooling trends in the Agulhas bank have been incorporated

LITERATURE CITED

Beal, L. M., and S. Elipot. 2016. Broadening not strengthening of the Agulhas Current since the early 1990s. *Nature* 540(7634):570–573.

Blamey, L. K., J. A. E. Howard, J. Agenbag, and A. Jarre. 2012. Regime-shifts in the southern Benguela shelf and inshore region. *Progress in Oceanography* 106:80–95.

Blamey, L. K., L. J. Shannon, J. J. Bolton, R. J. M. Crawford, F. Dufois, H. Evers-King, C. L. Griffiths, L. Hutchings, A. Jarre, M. Rouault, K. E. Watermeyer, and H. Winker. 2015. Ecosystem change in the southern Benguela and the underlying processes. *Journal of Marine Systems* 144:9–29.

Bolton, J. J., R. J. Anderson, A. J. Smit, and M. D. Rothman. 2012. South African kelp moving eastwards: the discovery of Ecklonia maxima (Osbeck) Papenfuss at De Hoop Nature Reserve on the south coast of South Africa. *African Journal of Marine Science* 34(1):147–151.

Brander, K. 2010. Impacts of climate change on fisheries. *Journal of Marine Systems* 79(3–4):389–402.

Currie, J. 2017. Historical baselines and a century of change in the demersal fish assemblages on South Africa's Agulhas Bank. University of Cape Town.

Currie, J. C., L. J. Atkinson, K. J. Sink, and C. G. Attwood. 2020. Long-Term Change of Demersal Fish Assemblages on the Inshore Agulhas Bank Between 1904 and 2015. *Frontiers in Marine Science* 7(May):1–16.

DEA. 2013. *Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate Change Implications for Marine Fisheries in South Africa.* Pretoria, South Africa.

Duggan, G. L. 2012. In the realm of the Kob Kings: Rethinking knowledges and dialogue in a small-scale fishery. University of Cape Town.

Fairweather, T. P., C. D. Van Der Lingen, A. J. Booth, L. Drapeau, and J. J. Van Der Westhuizen. 2006. Indicators of sustainable fishing for South African sardine Sardinops sagax and anchovy Engraulis encrasicolus. *African Journal of Marine Science* 28(3–4):661–680.

Gammage, L. 2015. Considering one's options when the fish leave. A case study of the traditional commercial handline fishery of the Southern Cape. University of Cape Town.

Gammage, L. C. 2019. Development of a scenario-based approach for responding to change in fishery systems: a case study in the small-scale fisheries of South Africa's southern Cape. University of Cape Town.

Gammage, L. C., A. Jarre, and C. Mather. 2017. A case study from the southern Cape linefishery 1: The difficulty of fishing in a changing world. *South African Journal of Science* 113(5/6).

Gammage, L., and A. Jarre. 2020. Using structured decision-making tools with marginalized fishers to promote system-based fisheries management approaches. *Frontiers in Marine Science* 7(447).

Gammage, L., and I. Martins. (n.d.). South African In-country GULLS analysis.

Griffiths, M. H. 1997. The application of per-recruit models to Argyrosomus inodorus, an important South African sciaenid fish. *Fisheries Research* 30:103–115.

Griffiths, M. H. 2000. Long-term trends in catch and effort of commercial linefish off South Africa's Cape Province: snapshots of the 20th century. *South African Journal Of Marine Science* 22(January):81–109.

Hollowed, A. B., M. Barange, R. J. Beamish, K. Brander, K. Cochrane, K. Drinkwater, M. G. G. Foreman, J. A. Hare, J. Holt, S. Ito, S. Kim, J. R. King, H. Loeng, B. R. Mackenzie, F. J. Mueter, A. Okey, M. A. Peck, V. I. Radchenko, J. C. Rice, M. J. Schirripa, A. Yatsu, and Y. Yamanaka. 2013. Projected impacts of climate change on marine fish and fisheries. *ICES Journal of Marine Science* 70(5):1023–1037.

Howard, J. A. E., A. C. Jarre, A. E. Clark, and C. L. Moloney. 2007. Application of the sequential t-test algorithm for analyzing regime shifts to the southern Benguela ecosystem. *African Journal of Marine Science* 29:437–451.

Jarre, A., L. Hutchings, S. P. Kirkman, A. Kreiner, P. Tchipalanga, P. Kainge, U. Uanivi, A. K. der Plas, L. K. Blamey, J. Coetzee, T. Lamont, T. Samaai, H. M. Verheye, D. G. Yemane, B. Axelsen, M. Ostrowski, E. K. Stenevik, and H. Loeng. 2015. Synthesis: Climate effects on biodiversity, abundance and distribution of marine organisms in the Benguela. *Fisheries Oceanography* 24 (Suppl(S1):122–149.

Lamont, T., M. García-Reyes, S. J. Bograd, C. D. van der Lingen, and W. J. Sydeman. 2018. Upwelling indices for comparative ecosystem studies: Variability in the Benguela Upwelling System. *Journal of Marine Systems* 188:3–16.

der Lingen, C. D., J. C. Coetzee, and L. Hutchings. 2002. Temporal shifts in the spatial distribution of anchovy spawners and their eggs in the Southern Benguela: Implications for recruitment. *GLOBEC Report*:46–48.

Lutjeharms, J. R. E., J. Cooper, and M. Roberts. 2000. Upwelling at the inshore edge of the Agulhas Current. *Continental Shelf Research* 20(7):737–761.

Lyttle, C. 2019. The variability and change in sea state as relevant to the small-scale handline fishery of the Southern Cape, South Africa. University of Cape Town.

MacKellar, N., M. New, and C. Jack. 2014. Climate trends in South Africa Observed and modelled trends in rainfall and temperature for South Africa : 1960 – 2010. *South African Journal of Sciences* 110(7):1–13.

Martins, I. M., L. C. Gammage, A. Jarre, and M. Gasalla. 2019. Different but similar? Exploring vulnerability to climate change in Brazilian and South African small-scale fishing communities. *Human Ecology* 47:515–526.

Mead, A., M. H. Griffiths, G. M. Branch, C. D. McQuaid, L. K. Blamey, J. Bolton, R. J. Anderson, F. Dufois, M. Rouault, P. W. Froneman, A. K. Whitfield, L. R. Harris, R. Nel, D. Pillay, and J. B. Adams. 2013. Human-mediated drivers of change — impacts on coastal ecosystems and marine biota of South Africa. *African Journal of Marine Science* 35(3):403–425.

Ortega-Cisneros, K., K. Cochrane, and E. A. Fulton. 2017. An Atlantis model of the southern Benguela upwelling system: Validation, sensitivity analysis and insights into ecosystem functioning. *Ecological Modelling* 355:49–63.

Ortega-Cisneros, K., K. L. Cochrane, E. A. Fulton, R. Gorton, and E. Popova. 2018. Evaluating the effects of climate change in the southern Benguela upwelling system using the Atlantis modelling framework. *Fisheries Oceanography* 27(5):489–503.

Rouault, M., P. Penven, and B. Pohl. 2009. Warming in the Agulhas Current system since the 1980's. *Geophysical Research Letters* 36(June):2–6.

Rouault, M., B. Pohl, and P. Penven. 2010. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. *African Journal of Marine Science* 32(2):237–246.

Roy, C., C. D. Van Der Lingen, J. C. Coetzee, and J. R. E. Lutjeharms. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy Engraulis encrasicolus spawners in the southern Benguela. *African Journal of Marine Science* 29(3):309–319.

Swart, V. P., and J. L. Largier. 1987. Thermal structure of Agulhas bank water. *South African Journal of Marine Science* 5(1):243–252.

Ward, C. 2018. Climate Variability in social-ecological systems of the southern Cape: Integrating farming and fishing perspectives. University of Cape Town.

Watermeyer, K. E., L. Hutchings, A. Jarre, and L. J. Shannon. 2016. Patterns of distribution and spatial indicators of ecosystem change based on key species in the southern Benguela. *PLoS ONE* 11(7):1–22.

Ziervogel, G., M. New, V. E. A. Garderen, G. Midgley, A. Taylor, R. Hamann, S. Stuart-hill, E. van Garderen, G. Midgley, A. Taylor, R. Hamann, S. Stuart-hill, J. Myers, and M. Warburton. 2014. Climate change impacts and adaptation in South Africa. *WIREs Climate Change* 5(September/October):605–620.