# Evaluating the implementation efficacy of an ecosystem approach to fisheries in the South African anchovy fishery

by

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## Abstract

A knowledge-based tool was developed to assess the efficacy of the ecosystem approach to fisheries in the South African anchovy fishery. South Africa has agreed to implement an ecosystem approach to fisheries (EAF) management. The EAF management comprises of three dimensions; ecological well-being, human well-being and ability to achieve. The focus for this study was on the ecological well-being dimension. Meetings were held with experts to revise objectives stemming from issues in the anchovy fishery documented earlier and indicators linking to these objectives. A hierarchical tree was constructed using these indicators and objectives. The objectives were divided into pressure and state. The indicators were transformed using piecewise linear transformation on to a common scale from -1 to 1. Thresholds were also decided to assess when the EAF implementation was considered to be 'good' (1), 'ok' (0) and 'bad' (-1). Weighted means were applied through the hierarchy. The overall resulting output, the truth value, was then used to assess how well the ecological dimension of the anchovy fishery had been doing over time. This showed the implementation efficacy of an EAF within the ecological dimension had been doing badly in 1987-1996, and since 1997 the ecological dimension of the EAF has been doing better. Sensitivity tests on the weights also showed that the knowledge based tool was robust to changes in weights. This allowed for experts to have slight differences in opinion over the way the weights should be distributed, but without these differences in opinion affecting the overall truth value. Sensitivity tests on the thresholds of one of the indicators showed that the outcome of the indicator is sensitive to changes in the thresholds. However, when looking at the overall truth values or the objectives, the changes to the thresholds did not affect the resulting objective values or the overall truth value that much. Although the indicator values change with changes in the thresholds, looking at the whole knowledge based tool it is fairly robust to moderate changes in thresholds.

## 1. Introduction

The small pelagic fishery in South Africa is an important fishery as it is the largest in terms of catch size, and second largest in terms of value. This fishery uses purse-seines and targets mainly sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*, with important bycatch species consisting of Cape horse mackerel *Trachurus trachurus capensis* and juvenile sardine. Red eye round herring *Etrumeus whiteheadii* is also targeted but not as a main focus (Shannon *et al.,* 2006). Juvenile sardine are also caught in the anchovy-directed fishery because the two species school together (Cochrane *et al.,* 1998). The anchovy-directed fishery is a recruitment fishery, whereas the sardine-directed fishery targets adults (Oliveira *et al.,* 2010)**.** Sardines are used mainly for canning, whereas anchovy and red eye round herring are used for reduction into fishmeal and fish-oil. An overview of the history of the fishery from its onset in the 1940s to present is given in Jarre *et al.* (2013).

Anchovy occur all along the coast of South Africa in the southern Benguela ecosystem, and typically in the upper layers of the ocean on the continental shelf. The first collapse of the sardine fishery occurred in the mid-1960s, this led to the mesh size being reduced allowing for anchovy to be targeted. During the 1970s and 1980s anchovy formed the major target of the small pelagic fishery (Hutchings *et al.,* 2012, also see Figure 1). However, by the mid-1990s, anchovy biomass and recruitment were low (Miller and Field, 2002). In contrast, sardine biomass was increasing again following conservative fisheries management since the mid-1980s aimed at rebuilding the stock, as well as a favourable environment (Shannon *et al.,* 2004, Hutchings *et al.,* 2012). Both species showed record high abundance in the early 2000s and anchovy is dominant in the catches now (Hutchings *et al.,* 2012).

The South African small pelagic fishing industry provides important employment, approximately 4,500 personnel (Cochrane *et al.,* 1997; Shannon *et al.,* 2006); therefore this fishery has a high economic and social importance. Due to this, management plans need to be adaptive to avoid overfishing, and to ensure the targeted stock and its ecosystem are healthy. The health of the principal target stocks is currently ensured through an Operational Management Procedure (OMP) which sets the framework for annual total

allowable catches (TACs) based on surveys. Ecosystem considerations in this framework are, however, in their infancy.

## 1.1. Forage Fish and their Importance

Forage fish, such as anchovy within the southern Benguela ecosystem, are a key part of many ecosystems; they are the primary food source for a variety of marine mammals, seabirds and fish predators (Pikitch *et al.,* 2012). Forage fish feed on zooplankton and phytoplankton, and provide an important link in marine food webs to the predators on the higher trophic levels. In upwelling systems such as the southern Benguela, the position of the food web occupied by the small pelagics is very low in species richness, known as the 'wasp-waist' configuration. Due to the small number of species occupying this position, change in the different species abundance can have an influence on the whole ecosystem though top-down control of their prey, or bottom-up control of their predators, whether this change is through environmental changes or fishing pressure (Cury *et al.,* 2000, Smith and Jarre, 2011). Anchovy population dynamics is driven by both the environment and fishing, which can also interact. As an example, it is believed the Peruvian anchoveta, *Engraulis ringens,* collapsed in the early 1970s due to a combination of high fishing pressure and an El Niño event that occurred (Pauly *et al.,* 2002). Because of the importance of forage fish in their ecosystem, it is vital to apply an ecosystem approach to fisheries (EAF) to the management of the small pelagic fishery in South Africa.

There is often alternation between anchovy and sardine dominance in ecosystems, referred to as 'regime shifts' (Schwartzlose *et al.,* 1999) or species dominance shifts (Cury and Shannon, 2004). Such long-term, ecosystem scale shifts can be caused through changes in abiotic factors driving changes in the planktonic food such as species composition or structure of community, favouring either anchovy or sardine (van der Lingen *et al.,* 2006). Sardine feed on small mesozooplankton, including small calanoid copepods, crustacean eggs, nauplii and anchovy eggs. Anchovy feed on the upper size range of the mesozooplankton and some macrozooplankton. Dietary variation is due to the differing morphology in the gill rakers and feeding behaviours attributed to each species (van der

Lingen *et al.,* 2006). The difference in diet allows anchovy to take advantage during times where large copepods dominate, and sardine to dominate under a range of different zooplankton compositions (van der Lingen, 2002). Change in dominance may require adaptive fisheries management (Fairweather *et al.,* 2006a). The change in dominance also makes optimising both the anchovy and sardine fisheries at the same time difficult, currently trade-offs are assessed while developing an OMP (Cochrane, 2001).

The life history of anchovy is very similar to the sardine life history. Anchovy spawn over the Agulhas bank, these eggs and larvae are then carried in the current to the west coast. As juveniles, they then make the journey back down to the Agulhas bank to spawn. During their migration to the spawning ground, during autumn and winter, they feed on phytoplankton, and grow in length (Hutchings *et al.,* 2012).

## 1.2. Ecosystem Approach to Fisheries Management

The implementation of an EAF approach focuses on three dimensions; ecological wellbeing, human wellbeing and ability to achieve (FAO 2003). An Ecological Risk Assessment (ERA) workshop was conducted for the small pelagics fishery, as reported in Nel *et al.* (2007). The ERA includes the problems within the fisheries as raised by the stake holders. It includes objectives with relevant indicators, which can then be used in the EAF approach. The ecological wellbeing dimension highlights the need to consider dependent predators during the management process; i.e. to include a management objective aimed at leaving enough individuals of exploited fish populations in the ocean as food for their predators. Integrating the human dimension allows for the consideration of the needs of fishers and other members of coastal communities, but also aims to account for national objectives (FAO, 2003; Paterson *et al.,* 2010). The 'Ability to achieve' dimension includes objectives pertaining to governance, and also objectives that cannot be addressed directly by fisheries management but need to be taken into account by it, such as the impact of climate change which is environmental (FAO, 2003; Nel *et al.,* 2007).

The small pelagics ERA defined some issues specific to the anchovy directed fishery, which included issues in the ecological wellbeing dimension. The species specific issues were

bycatch of juvenile sardine and redeye round herring, signs of reduced productivity in anchovy and signs of distributional shifts in spawning patterns. The general ecosystem issues were the impact on top predators and the 'impact of removal of forage fish on species which are bound by land-based breeding colonies' such as seabirds (Nel *et al.,* 2007).

An ecosystem approach to fisheries (EAF) is required due to the current state of the oceans globally. Recently, many global fisheries have been in a state of ecological, biological, social and economic crisis. Most countries have reports of the serious decline of fish stocks in their regions, with some of their stocks being 'overfished' or 'approaching overfished condition'. Some of the best known include reports of collapsed large fish stocks such as the Newfoundland cod (*Gadus morhua)* or Peruvian anchoveta. The ecological crisis can come from fisheries targeting mainly one species, as well as other ecosystem requirements not being considered. Fishing is also considered to have an impact on the trophic interactions within the ecosystem. By taking out large amount of one species, it can cause changes in species interaction and abundance in a trophic level within a specific ecosystem (e.g. Cochrane, 2000).

The EAF approach has become a necessity because the method of managing fisheries based on single species assessment (target resource-oriented management, TROM) was neither appropriate ecologically nor effective. The anchovy-directed fishery is currently managed through an OMP, in which total allowable catches (TAC) are allocated annually (de Moor *et al*., 2011). Bycatch of sardine and horse mackerel are concerns in the anchovy-directed fishery and are managed by setting limits for both; total allowable bycatch (TAB) for sardine and a precautionary upper catch limit (PUCL) for horse mackerel. The ecological objective of an EAF approach to management is 'sustainable use of the whole system, not just the target species' (FAO, 2003). EAF takes into account uncertainties about biotic and abiotic factors. Incorporating all of the three dimensions of EAF, biotic and abiotic factors allow for improvement of the basis of existing management frameworks, also the overarching goal to achieve sustainable development as a whole (Garcia and Cochrane, 2005).

The highly variable nature of the small pelagic fish abundance is well-documented. In South Africa, the sardine fishery used to dominate the catch (see Figure 1), until the sardine fishery collapsed in mid-1960s. After this, anchovy dominated the catch until the mid-1990s where the biomass and recruitment were low. Since the late 1990s, the recruitment and total biomass has been high (see Figure 2). The anchovy biomass has been doing relatively well since the 2000s, this is probably because the anchovy catch is lower than the TAC (see Figure 3). Any management plan needs to be robust to deal with this uncertainty. This pertains both to the interannual variability due to variable recruitment, as well as decadal-scale variability, such as species dominance changes. Management plans are sometimes made without the long term effect being taken into consideration, or without knowledge of the status of the stocks, or the interactions. Also, some of the management decisions do not represent all of the interested groups (Cochrane *et al.,* 1998). Unclear fisheries objectives makes managing the fisheries difficult (Cury *et al.,* 2005) therefore it is important to ensure the objectives of the fishery are clear and understandable (e.g. Degnbol and Jarre, 2004).

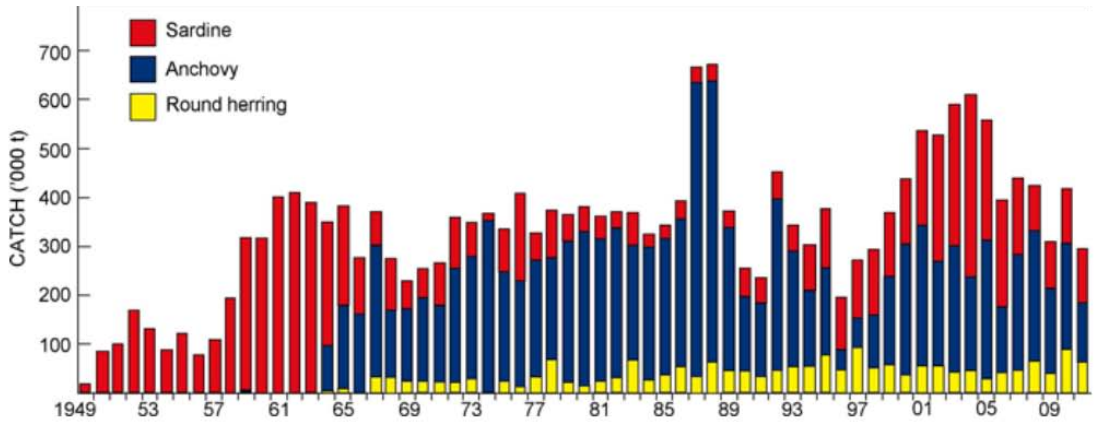


**Figure 1: Annual catches of sardine, anchovy and round herring taken by South Africa's pelagic fishery, 1949-2011. Figure taken from DAFF (2012).**

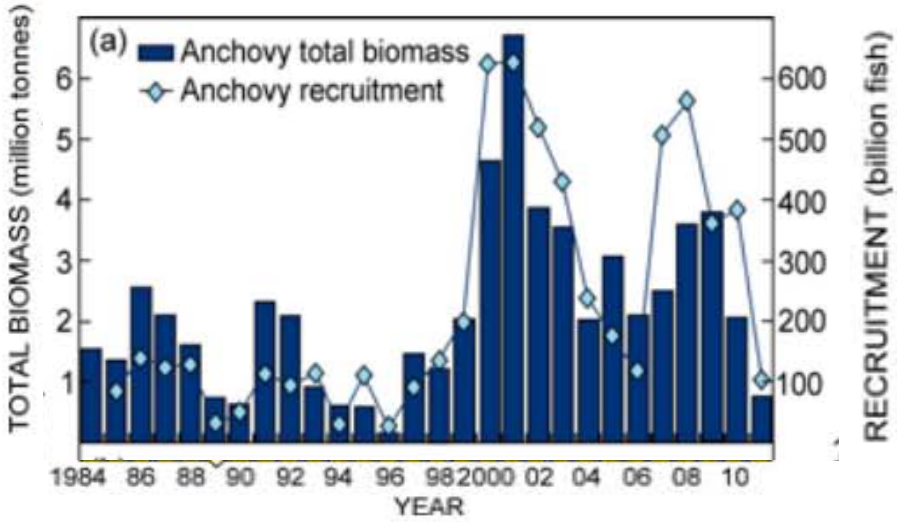


**Figure 2: Time series of acoustically estimated recruitment strength and total biomass of anchovy, 1984-2011. Figure taken from DAFF (2012).**

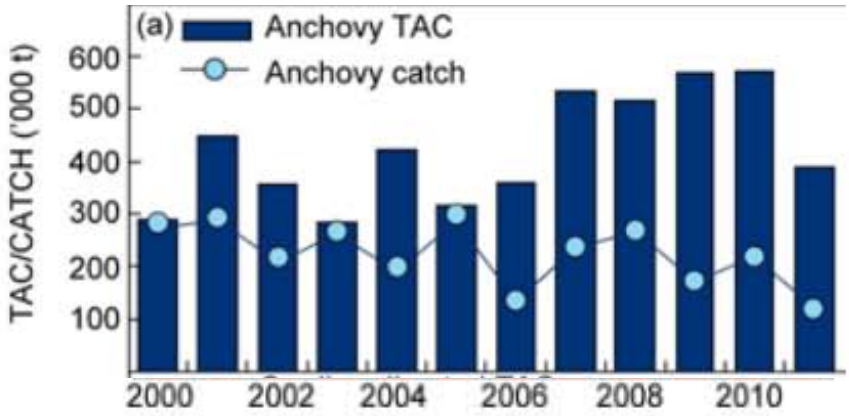


**Figure 3: Total allowable catches (TACs) for anchovy, 2000-2011. Figure taken from DAFF (2012).**

South Africa has agreed to implement an EAF approach which requires knowledge on the fisheries system and a way to measure the effect of management strategies (Shannon *et al.,* 2010). Expert ('knowledge-based') systems have shown to be an effective way to evaluate status and measure progress over time (Paterson and Petersen, 2010). An expert

system makes the management decision transparent, repeatable and communicable (Jarre *et al.,* 2008; Paterson *et al.,* 2010; Paterson and Petersen, 2010).

## 1.3. Indicators

Indicators play an important role in the implementation of an EAF (Shannon *et al.,* 2010), as they link objectives with management strategies (Degnbol, 2005). An indicator is an *'a priori'* defined system characteristic that can provide feedback on progress towards management goals and objectives (Slocombe, 1999). There are different types of indicators; driving force(s) pressure, state, impact, and response, known as the DPSIR framework which is widely used (Smeets and Weterings, 1999). Of these, pressure, state and response indicators are used most frequently. The indicators in the ecological well-being dimension of an EAF need to be able to collectively represent the ecosystem as a whole and not a select section, focusing on only a few species, typically target or bycatch species (FAO, 2003; Jennings, 2005). Key species need to be considered, and a wide range of indicators are needed to ensure an overview of the health of the ecosystem as a whole, although parsimony should be applied in their selection to avoid unnecessary overlap (FAO, 1999). For fisheries on forage species, it will be necessary to identify indicators pertaining to target species, bycatch and dependent predators as a minimum. The indicators and their corresponding objectives are arranged into a hierarchical tree which makes it easier to handle the multitude of issues conceptually and to present them to a wider audience (Garcia and Cochrane, 2005; Paterson *et al.,* 2007).

The indicators for the South African sardine-directed fishery have already been decided and discussed with experts (McGregor, PhD in prep). Management objectives stemmed from the ERA (Nel *et al.,* 2007) and were subsequently refined in meetings with experts (Paterson *et al.,* 2007; Jarre *et al.,* 2009; McGregor, PhD in prep). Indicators were defined for specific objectives, thresholds defined and weights agreed (McGregor, PhD in prep). To be able to assess the ecological well-being of the small pelagic fishery as a whole, objectives for the anchovy-directed fishery need to be added to the existing set for the sardine fishery. It is not possible to assess how well the small pelagic fishery is doing by only looking at the well-being of one part of the fishery. This project aims to fill that gap.

## 1.4. Expert Systems

Expert systems, also called knowledge-based tools, are models synthesising different 'expert' knowledge on a particular subject requiring an evaluation or decision (Jarre *et al.,* 2008). In the case of fisheries, experts can include many different groups of people, including scientists, managers, fishers and conservation practitioners.

There are different types of systems used as knowledge-based decision tools, including rule-based Boolean and fuzzy logic implementations. A fuzzy logic approach was developed for a proof of concept to evaluate the implementation of EAF in the sardine fishery (Paterson *et al.,* 2007), as well as for a tool that tracks the response of research and management to EAF issues (Paterson and Petersen, 2010). Rule-based Boolean logic has been applied to predict anchovy recruitment strength (Miller and Field, 2002). When these two methods were compared by Jarre *et al.* (2008), neither method outperformed the other, although they both had their own advantages. The rule-based approach used plain language, which is advantageous when the decision incorporates experts from a wide range of backgrounds. However, the numerical evaluation in the fuzzy logic model allows processing of larger amounts of information with ease (Jarre *et al.,* 2008). The authors also highlighted the advantage of visual representation of the results in any expert system software.

For the evaluation of the implementation efficacy of an EAF in the South African anchovy fishery, a number of indicators will be combined through an objective hierarchy, using the expert system approach.

## 1.5. Aim of this project

The overall aim of this project is to develop a knowledge-based tool to assess implementation efficacy of an EAF in the anchovy fishery. This knowledge-based tool can

then be used to complement a newly developed expert system for the South African sardine fishery (McGregor, PhD in prep), and will allow for a complete evaluation of the South African small pelagic fishery. This will fill the current gap in the assessment of the small pelagic fishery in an EAF context.

## 2. Material and Methods

Expert systems are models for synthesis and communication and can be used to aid decisions. The modelling process consists of design, coding, sensitivity analysis of model results to assumptions and key parameters, and interpretation of results (Starfield & Jarre, 2011). This study follows this process (see Figure 4).

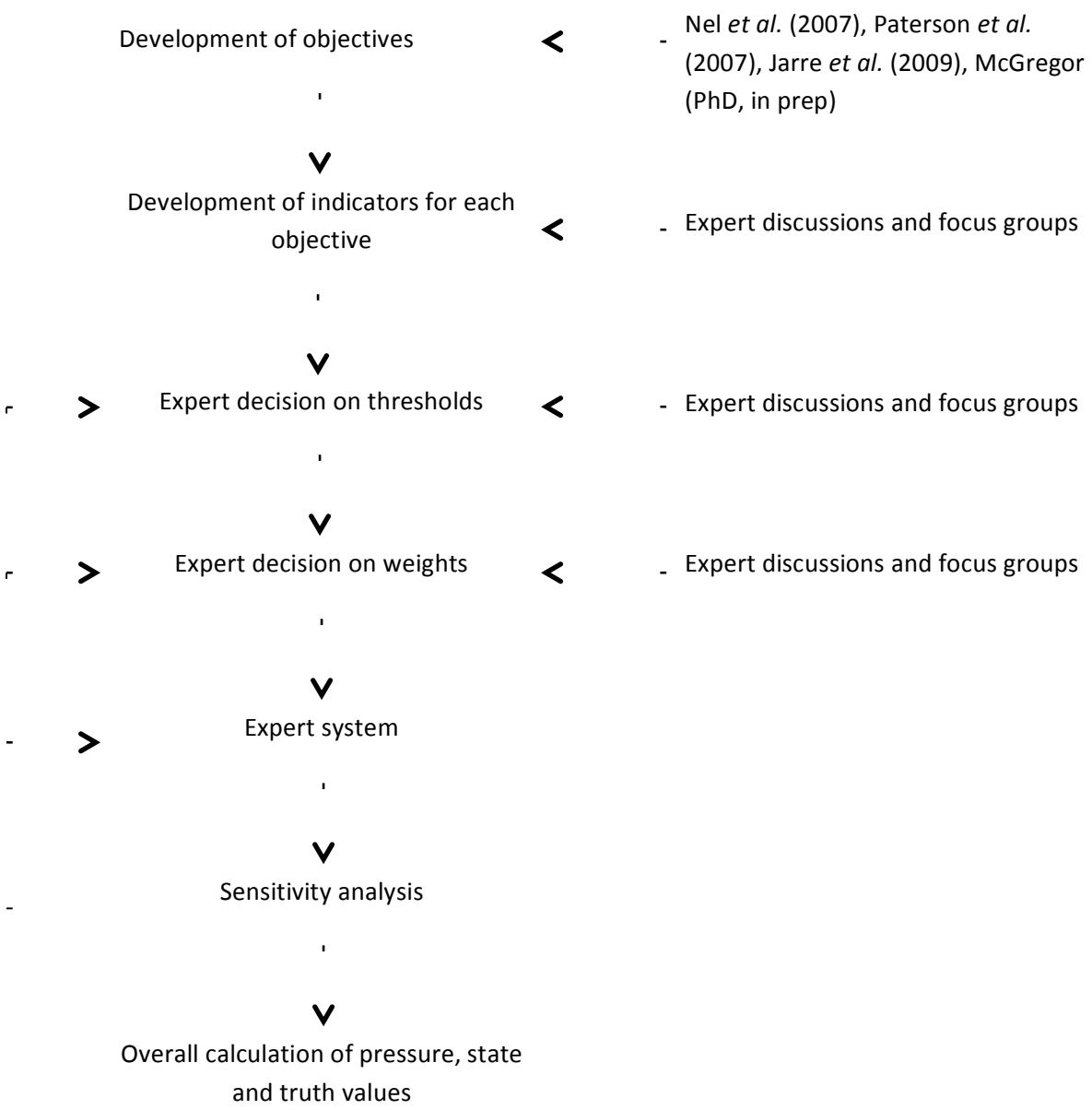


**Figure 4: Flow diagram of the methodology process, adapted from McGoodwin and Wright (2004).**

## 2.1. Design

The objectives and indicators form a hierarchy, with a single broad objective, that is broken up into more specific objectives, each of which has an indicator. The design part of the process was to decide on the objective hierarchy, indicators and thresholds for the indicators that would be used to show when the ecological dimension of the EAF

implementation is 'good', 'ok' or 'bad' for each specific objective, in terms of the indicator thresholds. These were decided by talking to experts (see Table 1), either as direct interviews or focus groups, and asking them to identify when the indicator was considered to be good, ok or bad. These thresholds then allowed for transformation to a common scale enabling comparison. The transformation was a piecewise linear transformation, 'fuzzy transformation' in fuzzy logic jargon and followed the methodology outlined in Paterson *et al.* (2007), where good was set to 1, ok was set to 0 and bad was set to -1 (see Figure 5) . Any missing data also provides an output of 0.

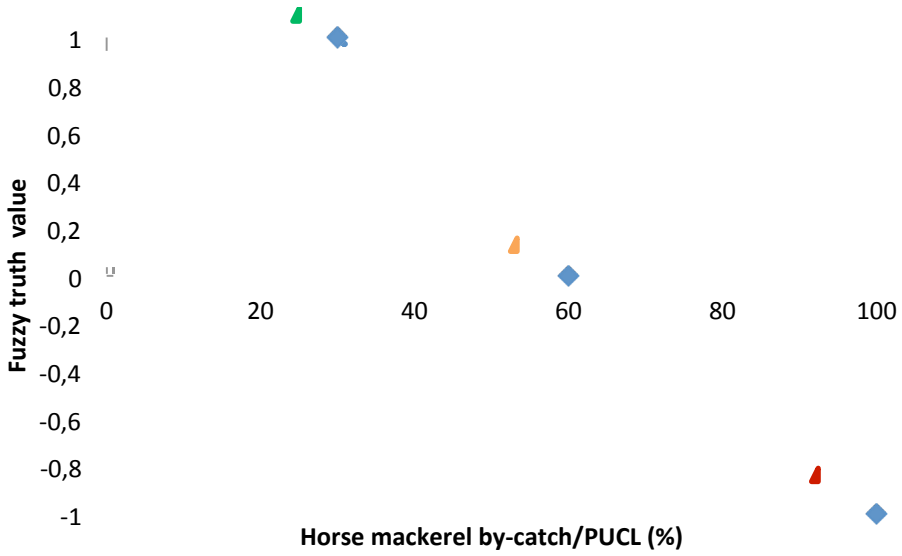


**Figure 5: The horse mackerel bycatch/PUCL indicator thresholds converted to the fuzzy truth value. The point with the green circle is where the value is 100% true, the point with the orange circle is where the value is ok and the point with the red circle is where the value is 100% false**

**Table 1: List of the names of experts consulted during the study and their area of expertise**

| Name | Expertise |
|---|---|
| Janet Coetzee | Chair of Small Pelagic Scientific Working Group (DAFF) |
| Dr Carl van der Lingen | Chair of EAF Scientific Working Group (DAFF/DEA) |
| Prof Larry Hutchings | Ex-Chair of EAF Scientific Working Group (DAFF/DEA) |
| Tracey Fairweather | EAF expert (DAFF) |
| Dr Robert Crawford | Seabird and EAF expert, (DEA) |
| Kate Robinson | PhD candidate, seabird expert (UCT) |
| Emily McGregor | PhD candidate, EAF expert (UCT) |
| Prof Astrid Jarre | SA Research Chair in Marine Ecology and Fisheries (UCT) |
| Dr. Hilkka Ndjaula | Small pelagics expert, (UCT) |

## 2.2. Implementation

The coding process involved creating a time series for all of the indicators, the data for this time series was made kindly available by DAFF (C. van der Lingen and J. Coetzee) and Dr H. Ndjaula (UCT) and E. McGregor (UCT). A knowledge-based tool was then developed in MS Excel. Weights were assigned to each indicator and at each level of the hierarchy. In the case where one indicator leads directly to an objective, the weighting would be 100%. In the case where multiple indicators lead into an objective, it had to be decided if they would be weighted equally, or if one would have more weighting than the others. Some indicators or objectives may be given more weighting if experts feel they are more important, where as some indicators may get a lower weighting if the underlying process was deemed less important or the data were of lower quality.

## 2.3. Sensitivity Analysis

A sensitivity analysis was conducted to see if the change in weights affects the overall output value of the expert system, in fuzzy logic jargon (e.g. Paterson *et al*., 2007)

called the 'truth value'. A sensitivity analysis was also conducted on any thresholds that were debated, to see how sensitive the indicators and the truth value were to the change in thresholds.

# 3. Results

## 3.1. Expert system design: objective hierarchy and indicators

A hierarchal tree was developed using the indicators that experts decided upon (see Figure 6).

### 3.1.1. Pressure objectives and indicators

The pressure objectives were split into two more specific objectives: optimise anchovy mortality and eliminate spatially disproportionate fishing.

**Optimise exploitation rate**

Optimise anchovy mortality leads into a more specific objective of optimise exploitation rate. For this objective there are two indicators; exploitation rate and fishing mortality, which is catch/recruitment biomass. As the anchovy-directed fishery is a recruitment fishery it is important to include a recruitment exploitation rate, known as fishing mortality, as well as the exploitation rate.

**Exploitation rate**

Exploitation rate is defined as 'the proportion of total mortality caused by fishing which is a measure of fishing intensity' (Fairweather *et al.,* 2006a). Based on the problems with aging anchovy (de Moor *et al.,* 2013), and the resulting uncertainty of estimating total

mortality using growth parameters, it was decided to calculate exploitation rate using the fishing mortality, F, and natural mortality, Z, values. These were taken from the current anchovy assessment (de Moor and Butterworth, 2012) as this was the most accurate source available. The indicator for this objective is exploitation rate.

**Recruitment Exploitation Rate**

As anchovy is a recruitment fishery it was decided to include an additional exploitation rate related to the recruitment biomass of the anchovy. The indicator is fishing mortality, which was calculated by the following equation:

$$Fishing\ mortality = \frac{Catch\ (t)}{Recruitment\ biomass\ (t)}$$

**Spatially disproportionate fishing**

Contrary to the expert system for the small pelagic fishery directed at sardine (McGregor, PhD in prep), spatially disproportionate fishing was not included as an indicator for the anchovy fishery. For sardine, this was a big problem as the bulk of the sardine biomass was historically found on the west coast, however since 1997 there has been an eastward displacement (Coetzee *et al.,* 2008). This causes concerns because the sardine could be fished too heavily on the west coast (Coetzee *et al.,* 2008; McGregor, PhD in prep). For anchovy, the south eastward shift has not interrupted the migratory life cycle of anchovy which are still thought to be a single stock with no particular spatial structure. Should this assumption change in the future, spatially explicit objectives and indicators would need to be defined.

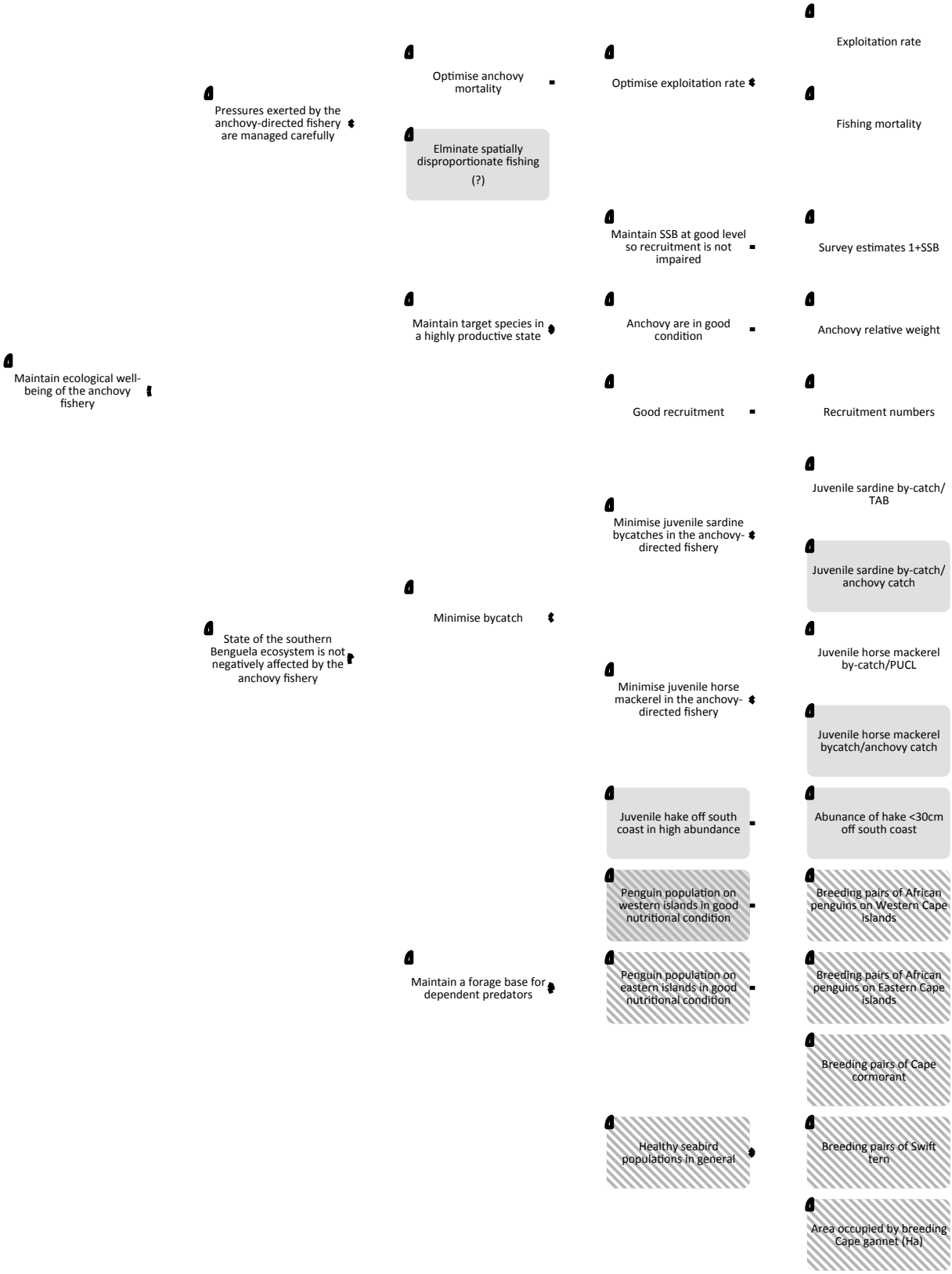


**Figure 6: Hierarchical tree of the objectives and the corresponding indicators for assessing efficacy of implementation of a EAF in the South African anchovy fishery. Shaded boxes pertain to indicators not included in the final system. Bird hierarchy and indicators, the hashed boxed, were kindly provided by E. McGregor (PhD in prep).**

### 3.1.2. State objectives and indicators

The state objectives were split into three more specific objectives: maintain target species in a highly productive state, minimise bycatch, and maintain a forage base for dependent predators.

#### 3.1.2.1. Maintain target species in a highly productive state

This objective is further split into three objectives: maintain SSB (spawning stock biomass) at good level so recruitment is not impaired, maintain anchovy in good condition and maintain good recruitment.

**Maintain SSB at good level so recruitment is not impaired**

Spawner biomass gives an indication of how well the stock is doing and the availability of anchovy that can be exploited. If the spawner biomass gets too low, it is possible for the fishery to collapse. In the 1990s there were a few years with a series of low biomass that resulted in very low recruitment and low anchovy abundance (Miller and Field, 2002), so the TAC was also reduced. Therefore it is important to have as an indicator to monitor for any potential issues (Fairweather *et al.,* 2006a).

The indicator for this objective is survey estimates of spawning stock biomass (SSB), in this case $1^{+}$SSB. It assumes that anchovy mature at age 1, and denotes that all age classes excluding juveniles (age 0) are combined into the estimate of the spawning stock biomass. Since the $1^{+}$SSB predicted by the assessment model was very closely related to the spawner biomass estimated from the survey (de Moor and Butterworth, 2012), the survey estimates were used directly. These were kindly made available by J. Coetzee (DAFF).

**Maintain anchovy in good condition**

There are three candidate indicators commonly used to measure the condition; condition factor, relative condition factor and relative weight. Relative weight has recently

been used most often, and gives an indication of the environmental conditions (Blackwell *et al.,* 2000), and was used as the indicator for this objective. It is calculated using the following equation:

$$Relative\ weight\ (W_r) = \frac{W}{W_S}\ x\ 100$$

where $W_S$ is the standard weight for fish of the same length, and W is the individual fish weight (Blackwell *et al.,* 2000), see also Ndjaula *et al.* (2013) for methodology. These unpublished data were kindly made available by H. Ndjaula (UCT). These values were then averaged over the year for a value which can be used as the indicator for the time series.

Anchovy relative weight comes from two data sets; field station data and survey data. Field station data mainly surveys juveniles and in the winter whereas survey data samples adults and juveniles, and in winter and summer. This can then add bias as juveniles are generally in a worse condition, and there could be a seasonal bias. While this is not ideal as it adds bias to the time series, it represents the best data available at the time and time series is therefore being used.

**Good Recruitment**

Anchovy recruitment numbers are highly variable, therefore this indicator will flag when there is a series of bad years, to highlight possible problems for the anchovy population and its predators. To allow for a productive ecosystem as well as a successful, stable fishery, the recruitment needs to be high each year. During the mid-1990s, there was a period of years with low anchovy biomass (see Figure 2), if this occurs again, the indicator will flag the low recruitment numbers. The indicator for this objective is recruitment numbers, which come from the May recruitment surveys (courtesy of J. Coetzee, DAFF).

**3.1.2.2. Minimise bycatch**

It is necessary to avoid bycatch in the anchovy-directed fishery. The three principal species of small pelagic bycatch, juvenile sardine, juvenile horse mackerel and juvenile

redeye round herring, were looked at. This objective is further split into two more specific objectives: minimise juvenile sardine bycatch in the anchovy-directed fishery and minimise juvenile horse mackerel bycatch in the anchovy-directed fishery. The redeye round herring was not included as an objective as it is not currently an issue.

**Juvenile Sardine bycatch/total allowable bycatch**

The sardine-directed fishery is not a recruitment fishery, and if too many of the sardine recruits are caught this will negatively impact the sardine population, and consequently the more valuable sardine-directed fishery. Juvenile anchovy and sardine often school together, resulting in juvenile sardine as bycatch in the anchovy-directed fishery (Fairweather *et al.,* 2006b).

Three potential candidate indicators were explored: total bycatch of sardine in relation to the total allowable bycatch (TAB), total bycatch of sardine in relation to the total anchovy catch, and total bycatch of sardine landed. It was decided against using the latter two. The total bycatch of sardine landed was not informative on its own as it was not possible to compare the bycatch to the TAB. The bycatch relative to the anchovy catch points at the cleanliness of the anchovy-directed catches, but are impacted by the degree of schooling together as well as targeting considerations by the fleet.

The indicator used is the total juvenile sardine bycatch taken in the anchovy-directed fishery in relation to the TAB for sardine, using the equation:

$$Percentage\ of\ bycatch\ threshold\ caught = \frac{Total\ bycatch\ of\ sardine\ (t)}{TAB\ (t)} \times 100$$

**Juvenile Horse Mackerel bycatch/precautionary upper catch limit**

Adult horse mackerel are fished by midwater trawlers on the south coast, but the species uses the productive west coast as nursery and feeding grounds for the juveniles. Juvenile horse mackerel can be mixed with anchovy, but too high a bycatch will adversely

impact the fishery of adult horse mackerel (Durholtz, 2012). Bycatch of juvenile horse mackerel has been managed by a PUCL since 2000, which seems to be effective as the bycatch, in tons, is often less than the PUCL. The PUCL has been set at 5000t since 2000, however there have been a few years where the TAC of anchovy could not be caught because the horse mackerel PUCL was reached, such as in 2002 and 2011. During these years, the fishery did not close for a long period, adaptive spatial management via temporary area closures was applied.

There were three different indicators suggested to be used: total bycatch of horse mackerel in relation to the PUCL, total bycatch of horse mackerel in relation to the total anchovy catch, and total bycatch of horse mackerel landed. Experts decided against use of the latter two. The total juvenile bycatch of horse mackerel in relation to the anchovy catch had too many unknown factors influencing it. The total bycatch of horse mackerel landed was not informative on its own, because no link exists between recruitment strength and catches of mixed schools by the purse-seine fleet.

The indicator for this is the total juvenile horse mackerel bycatch in relation to the PUCL for horse mackerel, using the equation:

$$Percentage\ of\ bycatch\ threshold\ caught = \frac{Total\ bycatch\ of\ horse\ mackerel\ (t)}{PUCL\ (t)} \times 100$$

More recently the PUCL has been changed so the total of the past three years should not be greater than 18000t, therefore the year's PUCL is dependent on the past two years' bycatch (Durholtz, 2012). Therefore, this indicator may need to be modified in the future to adapt to the change in PUCL.

**Juvenile red-eye round herring bycatch**

The bycatch of juvenile red-eye round herring is currently not an issue. There is currently a PUCL set at 100,000t which has not been reached therefore there is not a lot of pressure on the red-eye round herring. Red-eye round herring also have a strong diurnal

vertical migration, therefore they are too deep for seabirds to predate upon them (Dibattista *et al.,* 2012). They are eaten instead by hake. The bycatch of juvenile red-eye round herring should be included in the objectives so the necessity to develop an indicator is regularly revisited.

#### 3.1.2.3. Maintain a forage base for dependent predators

This objective was looked at by McGregor (PhD in prep). This study did another pass to see if it was possible to make any objectives anchovy-specific. Seabirds, predatory fish and mammals were considered, but mammals were ruled out as they are not anchovy specific. Only seabirds and predatory fish were considered further. Some seabirds are highly dependent on small pelagics, and some fish, such as hake are at least partially dependent (Shannon *et al.,* 2003). This objective is further split into three objectives: penguin population on western islands in good nutritional condition, healthy seabird populations in general and juvenile hake off south coast in high abundance. The penguin population on the eastern islands was not considered, unlike in McGregor (PhD in prep) as there is currently no fishing of anchovy in that area.

**African Penguins**

The number of breeding pairs of penguins as an indicator was considered by McGregor (PhD in prep) as an indicator of the well-being of the penguin populations in regards to their principal food; sardine and anchovy. This study looked to see if it was possible to separate times when anchovy was more important to the penguins' diet than sardine.

In the Western Cape, African penguins (*Spheniscus demersus*) generally breed between February – September, as this is when juvenile anchovy and sardine, and adult sardine are still in the area (Crawford *et al.,* 2006). Penguins are able to forage hundreds of kilometres when it is not breeding season, where they forage on a number of different species, including sardine and anchovy. Although anchovy is important to their diet at this time, it is not the only species they consume. However, during the breeding season, the

penguins have to stay close to the colony when they are foraging as they have to return to the island to regurgitate their food to feed their chicks; they only forage in a range of 20-55km (Crawford *et al.,* 2008; Sherley *et al.,* 2013). It is during this time that the anchovy recruits are migrating from the nursery grounds back to the spawning grounds, a route which takes anchovy past the penguin colonies on the west coast. Therefore, while rearing their chicks, anchovy make up a high proportion of the penguins' diet. It was found that when anchovy contributed less than 80% to the adult diet, chick survival was poor (Sherley *et al.,* 2013). This suggests the need for an anchovy related indicator to be included as an indicator for breeding success of penguins.

There were four candidate indicators: chick growth, chick condition, fledgling success and percentage of anchovy in the adults' diet.

The data for chick growth have been sporadic in the past, but have been collected since 2008 at both Robben and Dassen Islands on the west coast. Data for chick condition have been collected on Robben Island in 2004 and 2008-2013, and are also available from Dassen Island since 2008.

These two data series are not yet sufficient to assemble time series; they do not go back far enough to be able to determine long term changes in the data related to the ecosystem regime shift in the early 2000s (Howard *et al.,* 2007).

Diet samples from breeding penguins are taken during breeding season, therefore it could be possible to use this data as an indicator by looking at the percentage (in weight) of anchovy in the sample. A comparison of the percentage of anchovy in the diet and fledgling success has been assessed and a relationship between them was found (Sherley *et al.,* 2013). However, there was not enough data available so it was decided to use breeding pairs of African penguins as the indicator, the same as McGregor (PhD, in prep).

McGregor (PhD in prep) also considered the health of the African penguins on the eastern islands as a separate objective, however, when this was discussed with experts, it was decided to not be included in this study. The vast majority of the anchovy catch is currently taken on the west coast so it was felt this was not currently a problem, however, if this should change then it will have to be re-visited and an indicator needs to be developed.

**Cape Cormorant**

Cape cormorants (*Phalacrocorax capensis*) consume small pelagics, and it has been shown that when the abundance of anchovy was low, their reproduction was also low. The decline of the population of Cape cormorants has been attributed to multiple factors including avian cholera, predation by Cape fur seals and great white pelicans, and a shift in the distribution of pelagic fish stocks (Hamann *et al.,* 2012). However, Cape cormorants do not appear to be dependent on anchovy alone and are therefore not revisited in this study. The indicator, breeding pairs of Cape cormorants, is the same indicator used in the sardine expert system (McGregor, PhD in prep).

**Swift Tern**

Swift terns (*Thalasseus bergii*) prey on small pelagics, however unlike other sea birds, they carry the fish whole in their beaks to give to their chicks; other sea birds swallow the fish and regurgitate it to their chicks (Dr R. Crawford, DEA, pers. comm.). Therefore, the size of the fish is important with swift terns as it needs to be small enough to fit in their beak. Also, swift terns are not able to dive very deep, therefore where the fish are in the water column is also vital; they can only capture prey if it is in the top metre of the water column (Crawford, 2009).

When breeding, swift terns are restricted to a small feeding area, but they are nomadic in choosing their breeding site; they can breed at one island one year and a different island the next year (Crawford, 2003). Due to this behaviour they can potentially adapt to prey distribution on an annual basis (Crawford, 2009).

Swift terns are dependent on the biomass of both anchovy and sardine (Crawford, 2003). However, since it is currently not possible to separate the two species, and due to their ability to change breeding site, the indicator for the population abundance of swift tern, the numbers of breeding pairs, which was used in McGregor (PhD in prep) was not revisited in this study.

**Cape Gannets**

Cape Gannets (*Morus capensis*) have been shown to eat a variety of food, including anchovy, sardine, saury (*Scomberesox saurus*) and fishery discards (Mullers and Navarro, 2010), however, sardine is their preferred prey and has been associated with improved chick growth, due to the high lipid concentration present in sardines (Distiller *et al.,* 2012). An indicator specific to gannet health should be considered for the small pelagic fishery as there appears to be a link between the difficulty the fishery has catching their quotas and the gannets' ability to find prey, which probably lead to the population decreasing (Distiller *et al.,* 2012). However, since the focus of this project is on the anchovy-directed fishery, it was decided that gannets should not be re done in this study as they seem more dependent on sardine than on anchovy. The indicator used, area occupied by gannets, is the same indicator used in the sardine expert system (McGregor, PhD in prep).

**Abundance of juvenile hake (<30cm) on the South coast**

Anchovy are an important prey for hake (*Merluccius capensis* and *M. paradoxus)*. Although hake are known as generalist feeders (Payne *et al.,* 1987), it is thought that the increased availability of anchovy since the early 2000s could be beneficial to juvenile hake, particularly on the south coast**.** Anchovy is a dominant food item for juvenile hake, also on the south coast, until they are greater than 35cm and their diet starts to change (Durholtz *et al.,* in press).

The indicator for this objective was the abundance of hake <30cm on the south coast. A time series of juvenile hake abundance on the south coast, kindly made available by T. Fairweather (DAFF), and the anchovy spawner biomass east of Cape Agulhas (DAFF unpublished data, courtesy J. Coetzee) were compared. The total hake (t) was inversely correlated with the anchovy (t) (see Figure 7), implying top down effects through predation rather than bottom up effects. Based on this result, the objective was eliminated.

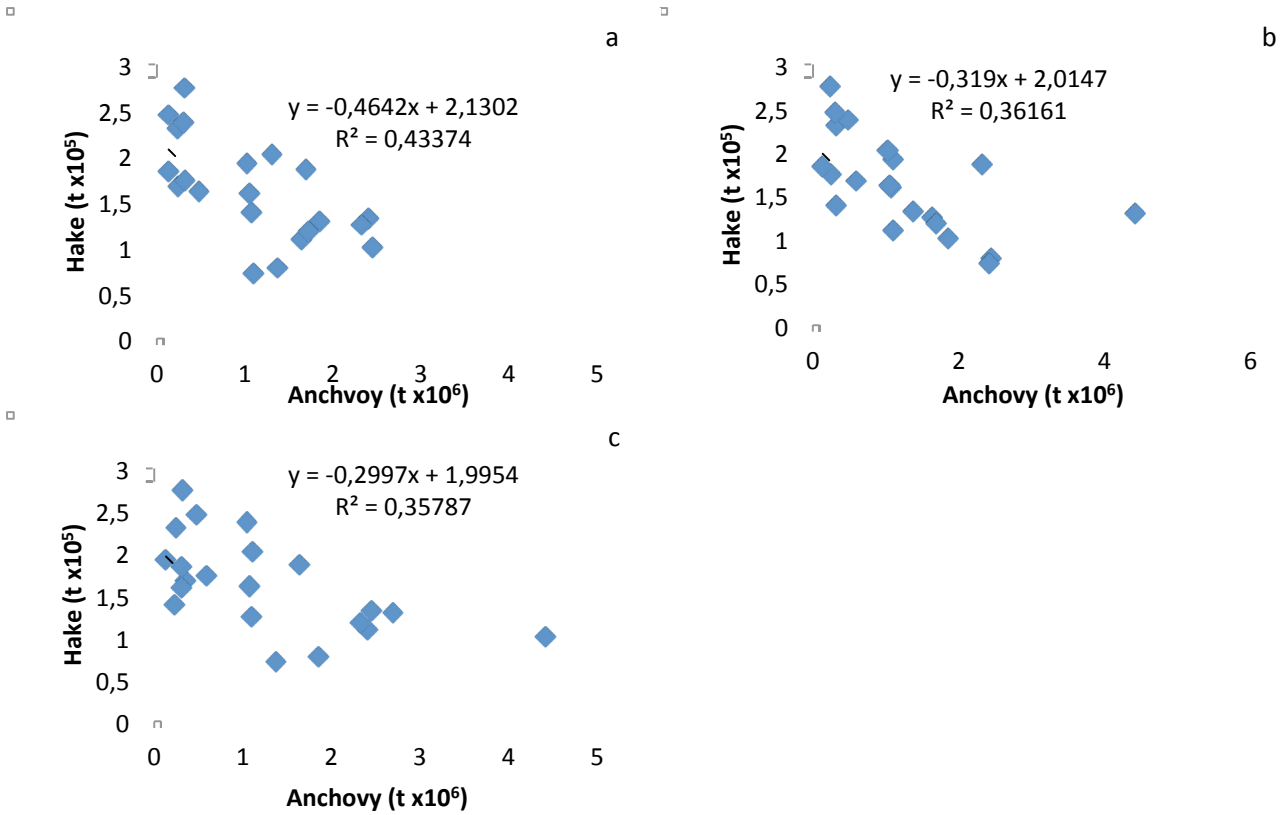


**Figure 7: (a) total hake biomass vs anchovy biomass on the east of Cape Agulhas with a 1year lag (b) total hake biomass vs anchovy biomass on the east of Cape Agulhas with a 2year lag (c) total hake biomass vs anchovy biomass on the east of Cape Agulhas with a 3year lag.**

### 3.2. Thresholds

After the indicators were selected, a time series for each was produced (see Figures 8 and 9). The time series then had thresholds overlaid for a comparison over the years. The thresholds (see Table 2) were all decided by experts.

The thresholds for the recruitment numbers were based on the thresholds used in Miller and Field (2002). They used back-calculated recruitment whereas this study uses survey recruitment, therefore the thresholds needed to be adapted. The average difference between back-calculated and survey recruitment was 55%, so the thresholds were multiplied by 0.55.

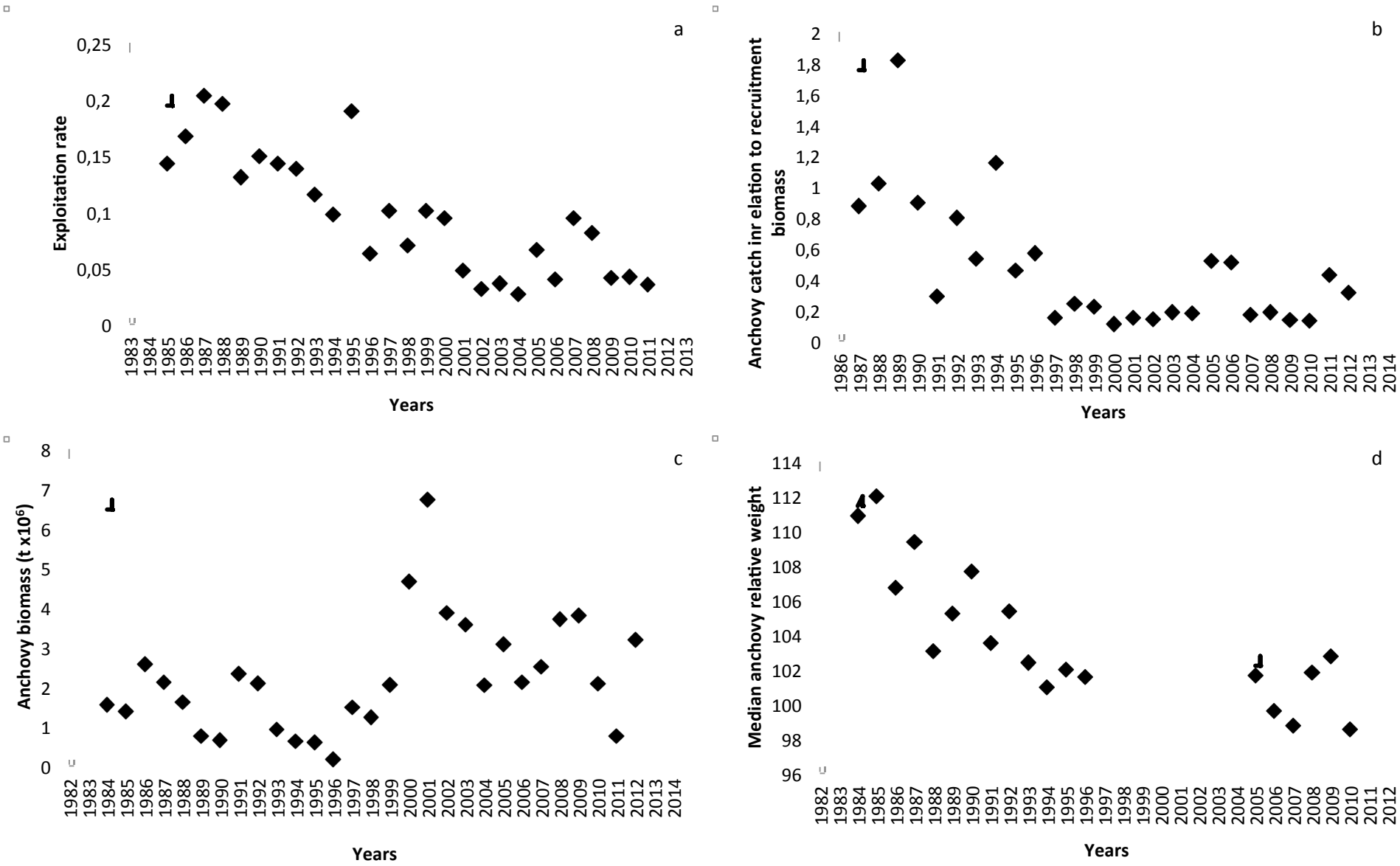


**Figure 8: Time series of indicators used in this project (a) Exploitation rate (b) catch/recruitment biomass (c) survey predicted SSB (d) Anchovy relative weight. a-b Data kindly made available by DAFF (Dr C. van der Lingen and J. Coetzee) d. Data made kindly available by Dr H. Ndjaula (UCT).**

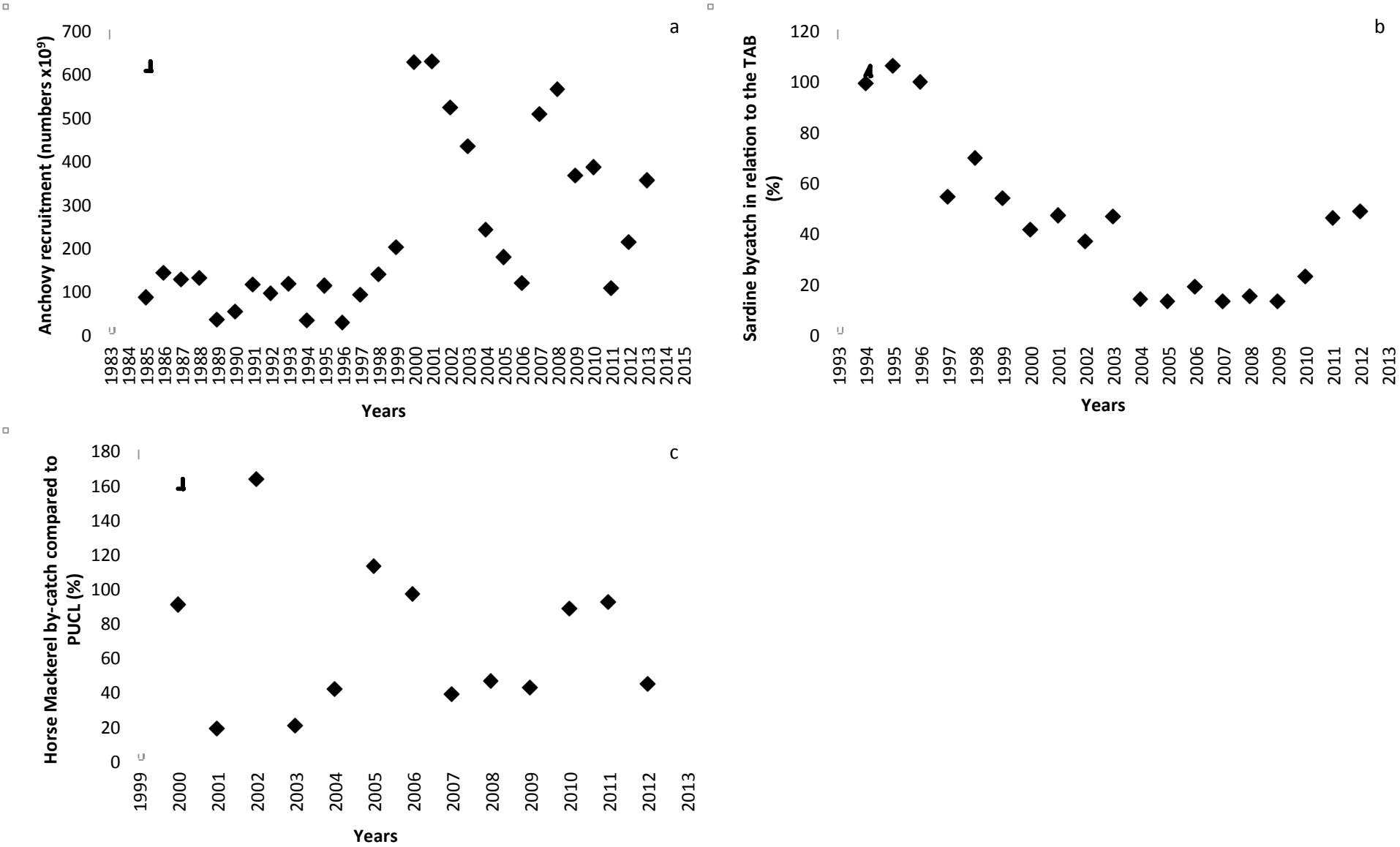


**Figure 9: Time series of indicators used in this project (a) Anchovy recruitment numbers (b) sardine by-catch/TAB (c) Horse mackerel by-catch/PUCL. Data made kindly available by DAFF (Dr C. van der Lingen and J. Coetzee)**

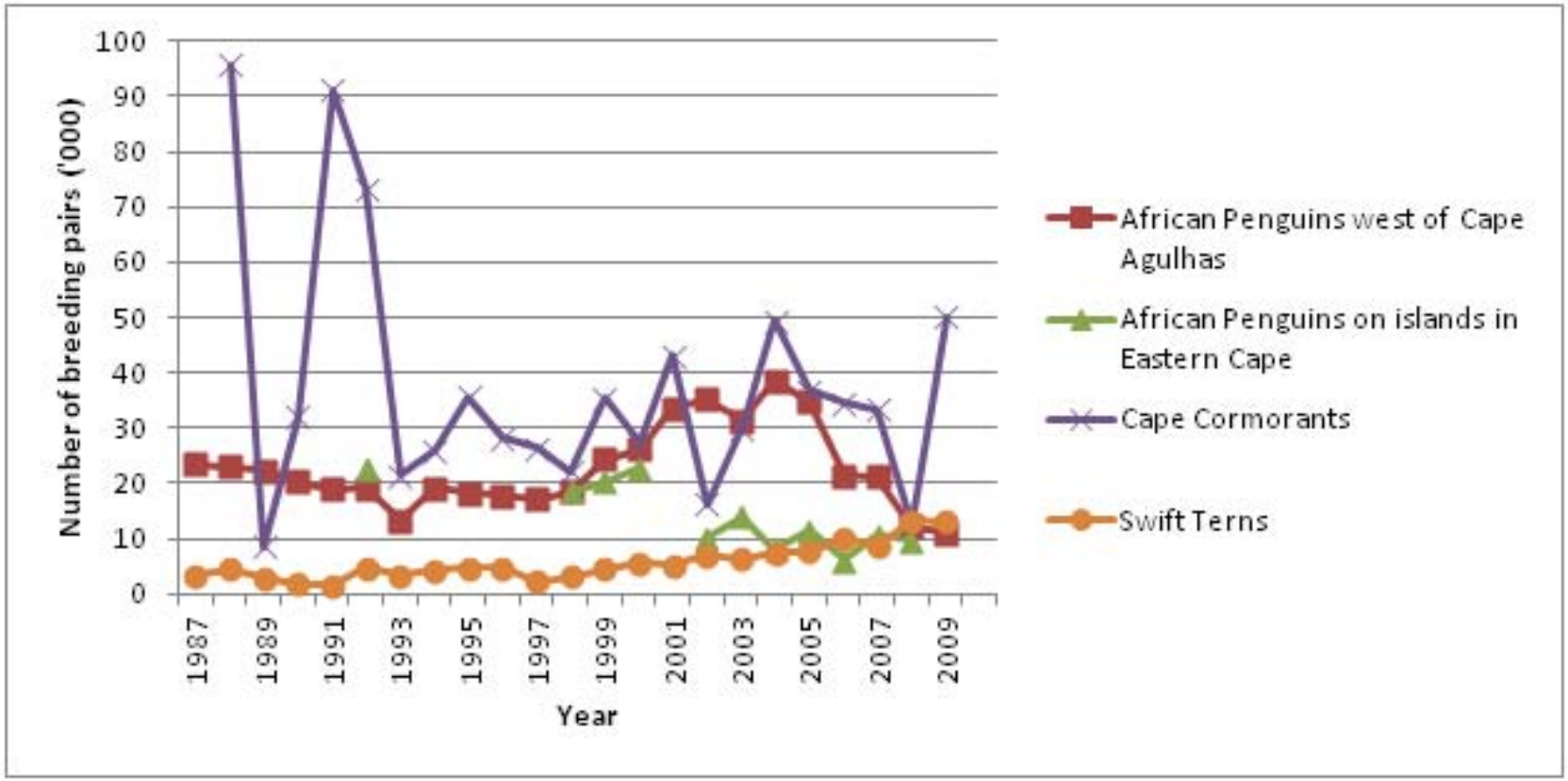


**Figure 10: Composite figure of selected seabird indicator time series showing the number of breeding pairs ('000) of: (i) African Penguins found west of Cape Agulhas, South Africa. (ii) African Penguins on islands in the Eastern Cape, South Africa. (iii) Cape Cormorants at six breeding localities within the Western Cape, South Africa and (iv) Swift Terns at all breeding localities in South Africa. (Courtesy of McGregor (PhD in prep)).**

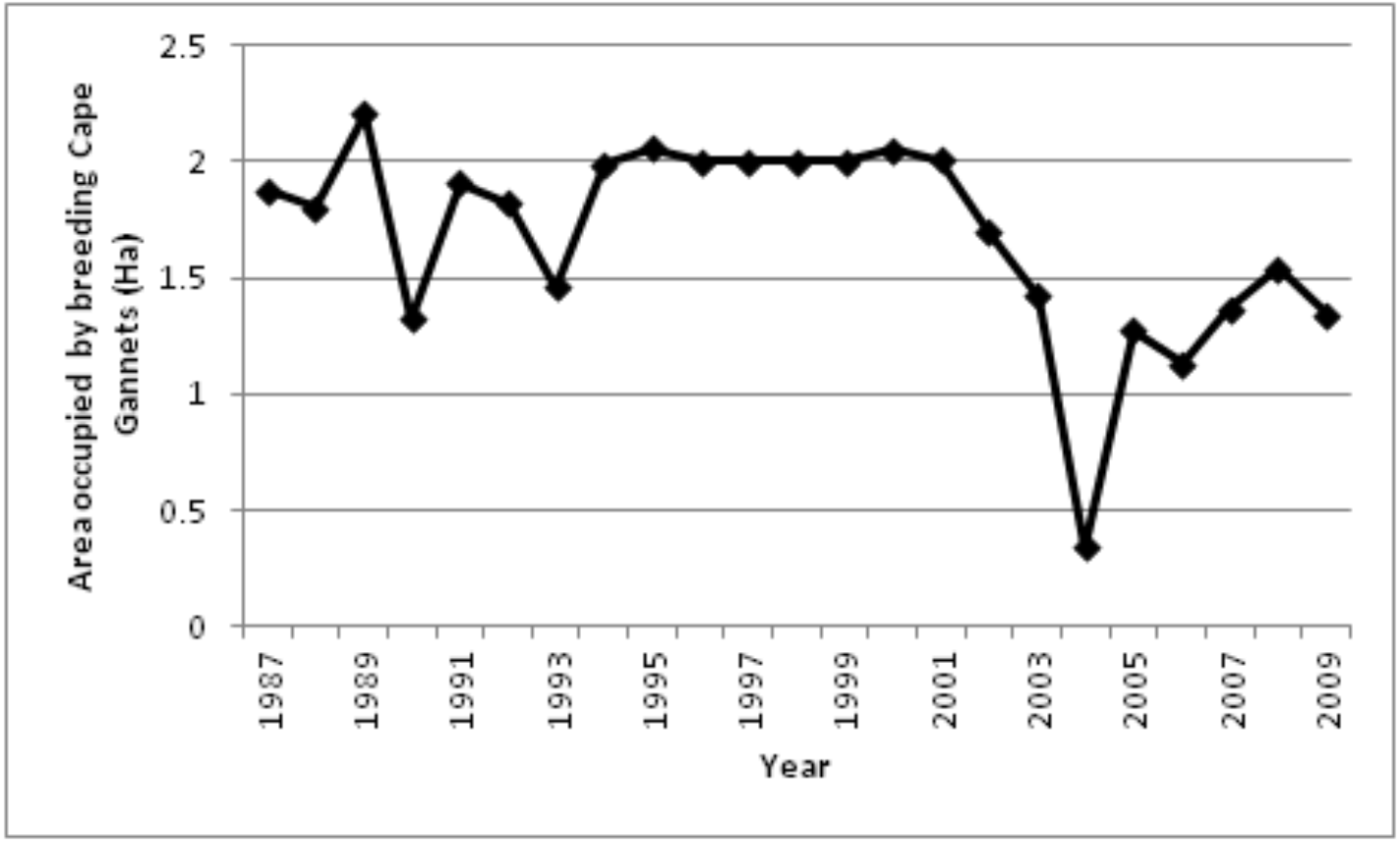


**Figure 11: The area in hectares occupied by Cape Gannets in the Western Cape, South Africa. (Courtesy of McGregor (PhD in prep)).**

**Table 2: The thresholds for when an indicator is considered to be 'good' (1), 'ok' (0) and 'bad' (-1) and units for the indictors.**

| Indicator | Thresholds | | | Units | Remarks |
|---|---|---|---|---|---|
| | **1** | **0** | **-1** | | |
| Exploitation Rate | 0.05 | 0.1 | 0.15 | Dimensionless | |
| Catch/Recruitment Biomass | 0.3 | 0.45 | 0.6 | Dimensionless | >1 indicates more fish caught than seen in survey |
| 1+SSB | 1.5 | 0.6 | 0.4 | Million Tonnes (Mt) | |
| Anchovy Relative Weight | 112 | 103 | 95 | Dimensionless | Parallel to procedure used for the sardine expert system (Ndjaula *et al.,*2013, McGregor, PhD in prep) |
| Recruitment Numbers | 137.5 | 99 | 55 | $x10^9$ | Adapted from thresholds used in Miller and Field (2002). |
| Juvenile sardine TAB/bycatch | 20 | 40 | 50 | % | TAB is set using a model, the model assumes the TAB is not met and is intentionally set high |
| Horse mackerel PUCL/bycatch | 30 | 60 | 100 | % | Horse mackerel is not a big cause for concern but the fishery should not be catching more than the PUCL |
| Breeding pairs of African penguins on western islands | 45 | 30 | 15 | Thousands of pairs | Taken from McGregor (PhD in prep) |
| Breeding pairs of Cape Cormorant | 80 | 60 | 40 | Thousands of pairs | Taken from McGregor (PhD in prep) |
| Breeding pairs of Swift Tern | 10 | 5 | 1 | Thousands of pairs | Taken from McGregor (PhD in prep) |
| Area occupied by breeding Cape Gannet | 2 | 1.75 | 1.5 | Hectares (ha) | Taken from McGregor (PhD in prep) |

### 3.3. Weights

Each level of the hierarchy was weighted so the weights equalled 100%. Where there was only one objective the objective was weighted 100%; where there were multiple objectives the weighting of each was discussed with experts. Table 3 shows the weights decided by the experts for the hierarchy levels with multiple objectives.

At the top level of the hierarchy, the pressure objectives were weighted 60% and the state indicators were weighted 40%. This was because the pressure indicators are more responsive to fisheries management measures, so should receive a higher weighting than state objectives, which are strongly influenced by drivers outside the reach of fisheries management (environment and food web internal dynamics). Given the importance of anchovy as forage fish in the southern Benguela, however, it was decided that the state objectives should receive a relatively high weighting nevertheless. Spatially disproportionate fishing is a big issue for sardine, which is a pressure objective, therefore this was weighted higher (McGregor, PhD in prep). One of the main issues for the anchovy-directed fishery is bycatch of juvenile sardine, therefore experts wanted the state to be weighted higher than in the sardine-directed fishery.

Experts decided that the catch/recruitment biomass indicator should be weighted 70%, while the exploitation rate indicator should be weighted 30%. This was because they felt it was more important to have the emphasis on the recruits rather than the adults, as anchovy is primarily a recruitment fishery.

The state objective leads into three other objectives; maintain target species in a highly productive state, maintain a forage base for dependent predators and minimise bycatch. The experts decided the weighting should be 40%, 20%, 40% respectively, although there was a discussion about whether they should all be weighted equally instead. The objective to maintain a forage base for dependent predators was weighted less in this particular study, as the indicators are, by and large, not specific to anchovy. The other two objectives were given equal weighting as the experts felt these were of equal importance. The maintain target species in a highly productive state objective is important as it will raise awareness to potential issues with the stock and the EAF implementation of the anchovy

fishery. The minimise bycatch objective is important to monitor any issues that could impact the sardine fishery given that the sardine fishery is a lot more valuable.

**Table 3: Weights for the objectives**

| | Weights |
|---|---|
| **Pressure** | **60** |
| Exploitation rate | 30 |
| Catch/recruitment | 70 |
| **State** | **40** |
| **Maintain target species in highly productive state** | **40** |
| SSB | 40 |
| Good condition | 20 |
| Good recruitment | 40 |
| **Maintain a forage base for dependent predators** | **20** |
| Penguins on the western islands | 50 |
| Seabirds in general | 50 |
| - Cape cormorant | 33 |
| - Cape gannet | 33 |
| - Swift tern | 33 |
| **Minimise bycatch** | **40** |
| Juvenile sardine bycatch | 70 |
| Horse mackerel bycatch | 30 |

The objective to maintain target species in a highly productive state leads into three other objectives; maintain SSB at good level so recruitment is not impaired, maintain anchovy in good condition and maintain good recruitment. The weighting was decided to be 40%, 20%, 40% respectively. The objective of maintaining anchovy in good condition was decided to be weighted less because the data was made up from two different data sets, making it less reliable. The objectives maintain SSB at good level so recruitment is not

impaired and maintain good recruitment were weighted higher as anchovy is a recruitment fishery so this indicator will raise awareness to recruitment issues.

The objective to minimise bycatch leads into three other objectives; minimise juvenile sardine bycatch in the anchovy-directed fishery, minimise juvenile horse mackerel bycatch in the anchovy-directed fishery and minimise juvenile red eye round herring bycatch in the anchovy-directed fishery. The objective of minimising juvenile red eye round herring is currently not being looked as it is not a concern, but is being included in the hierarchical tree to potentially be included at a later time, therefore this objective is not included in the weighting. The weighting decided for the remaining objectives were 30% for the objective to minimise the juvenile horse mackerel bycatch and 70% for the objective to minimise juvenile sardine bycatch. The juvenile sardine bycatch objective was weighted more because a high number of juvenile sardine bycatch has been shown to negatively impact the sardine fishery, and the sardine fishery is of a higher value. It is assumed that a high number of juvenile horse mackerel bycatch does not negatively impact the fishery as much as in the sardine fishery, and horse mackerel is not as valuable.

The seabird objectives were mostly weighted the same as in the sardine-directed expert system (McGregor PhD, in prep). As the objective of the health of the penguins on the western islands was not included in this study, the objective of penguins on the eastern islands and seabirds in general were equally weighted at 50%.

**Model Output**

The time series arising from the combination of the pressure values (see Figure 12) shows that earlier in the time series, the pressure was considered to be high, in 1987 and 1988 the value returned was -1. In the early 1990s the pressure was also high, but not doing as badly compared with the late 1980s; there was a switch from predominately bad to good. The peak in 1991 is due to the ratio catch/recruitment biomass doing well, and that indicator having a higher weighting. The pressure from the late 1990s onwards shows the ecological dimension of the EAF to be doing well, except for in 2005 and 2006, where the

pressure was considered to be ok. The catch/recruitment biomass indicator was negative in those years, and due to the weighting lowered the pressure output.

The time series for the state values (see Figure 13) shows the ecological dimension of the EAF was not doing that well during the 1990s, with the ecological dimension doing particularly badly in 1996. In the 1990s there was a lack of anchovy which would have reflected through the indicators and ultimately the state value. The 2000s show that the overall state objective was considered to be ok.

The time series for the overall truth values (see Figure 14) shows a similar pattern to the pressure time series, due to its higher weight relative to the overall state objective, and their overall (qualitatively) similar trajectory. The ecological dimension of the EAF is considered to be 'ok' to 'bad' in the late 1980s – mid 1990s, however there is still a peak where the ecological dimension was doing ok in 1991. From 1997, the ecological dimension of the EAF implementation efficacy for anchovy has generally been doing well apart from years in 2005, 2006 and 2011 where the pressure values dipped to ok.

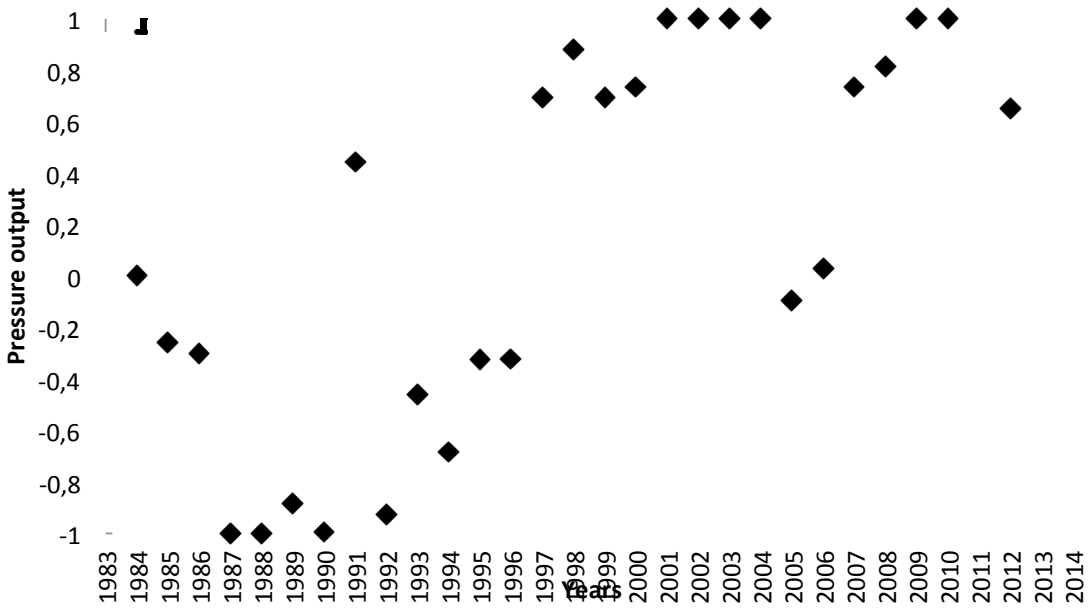


**Figure 12: Pressure values for the anchovy fishery over the period of 1984-2012.**

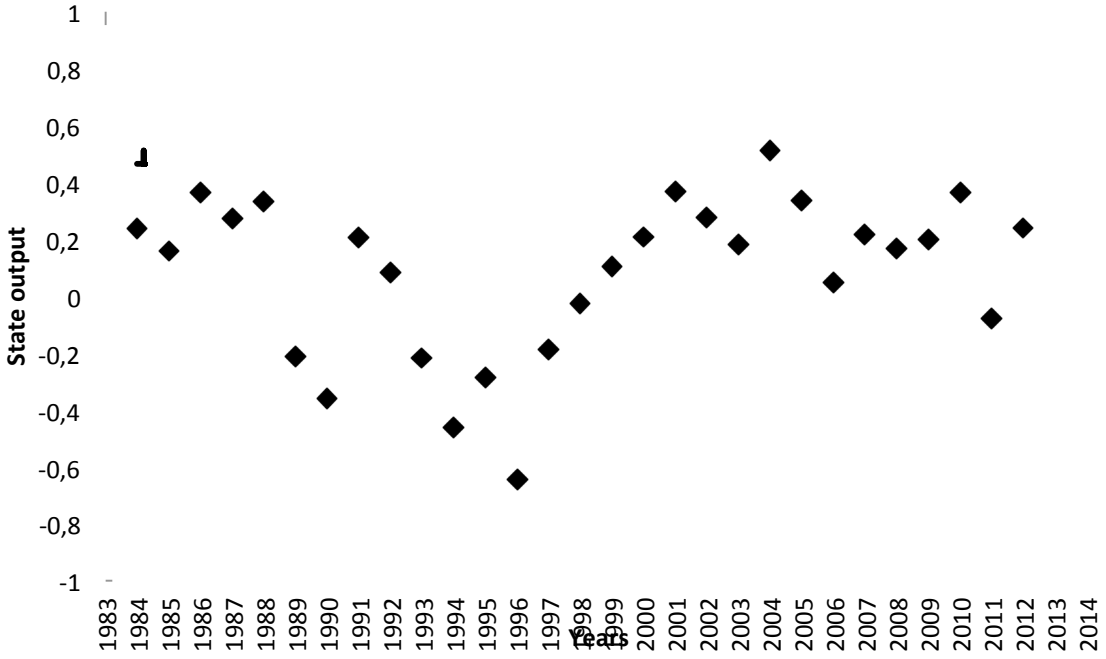


**Figure 13: State values for the anchovy fishery over the period of 1984-2012.**

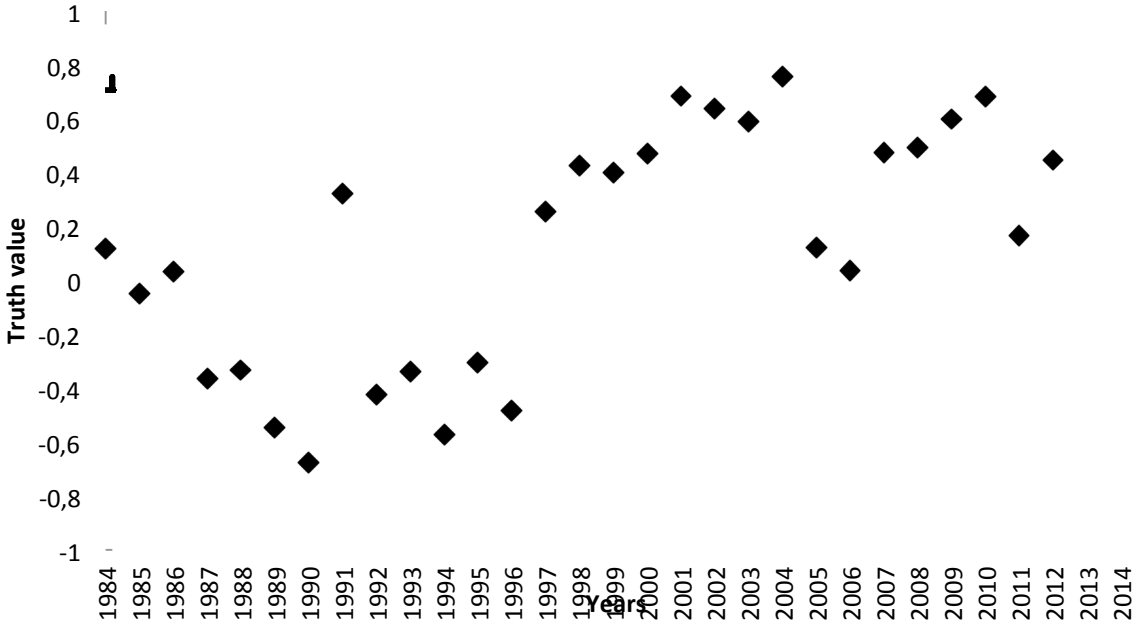


**Figure 14: Overall truth values for the anchovy fishery over the period of 1984-2012.**

### 3.3.1. Sensitivity analysis to changes in weights and thresholds

The comprehensive sensitivity analysis performed by McGregor (PhD in prep) for the sardine-directed expert system showed sensitivity to only a few thresholds or weights. Based on these results, this study only explores the sensitivity of the overall results to changes in a few weights and thresholds, which were specifically debated among the experts. The thresholds for SSB were debated and therefore a sensitivity analysis was under taken on these thresholds.

The influence of alternative weights at the top of the hierarchy (pressure versus state) and the general level of the state indicators were explored. A sensitivity analysis showed that weighting the pressure objectives 60% and the state objectives 40% showed a slight difference when compared graphically to when the pressure and state objectives were weighted equally (see Figure 15). The equal weighting gives a more conservative output.

There was a discussion about how the objectives to maintain target species in a highly productive state, to maintain a forage base for dependent predators and to minimise bycatch should be weighted. It was agreed it should be weighted 40%, 20%, 40% respectively, but there was a discussion if it should be weighted equally. A sensitivity analysis showed that when compared graphically there was only a slight difference in the outcome of the state value (see Figure 16). The equally weighted state value is higher in 2007-2010 as the weight of the bycatch objective increases from 20% to 33%. In these years, the bycatch indicators reflect those objectives to be doing well, and with the higher weighting, allows for the state value to be higher.

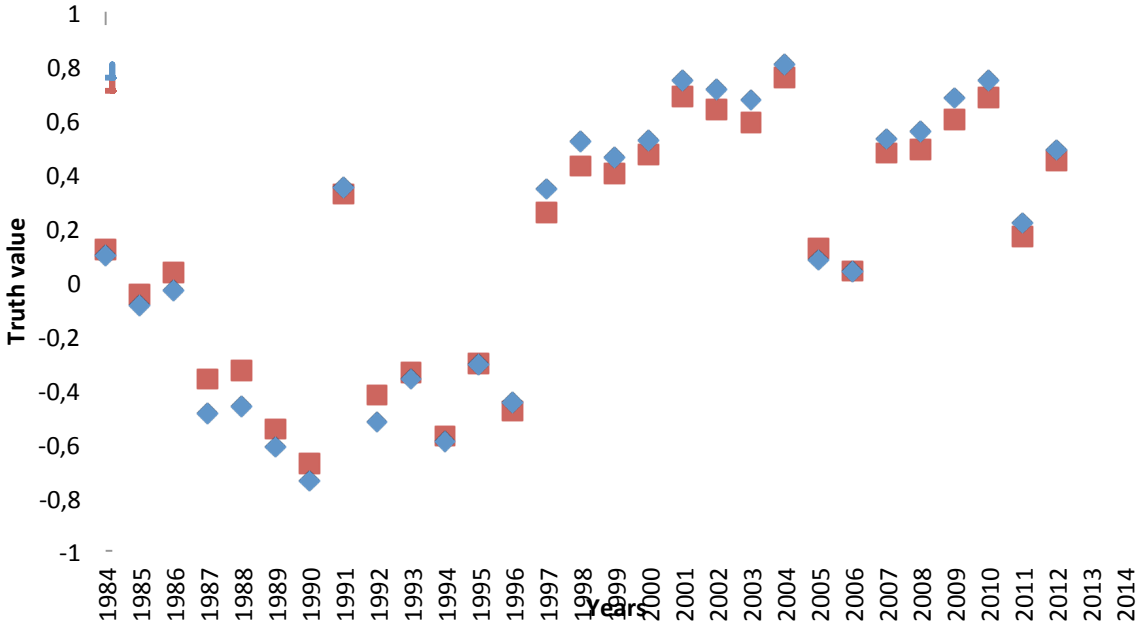


**Figure 15: Sensitivity analysis on the pressure and state weightings. The blue line is pressure weighted 60% and state weighted 40%, the red line is pressure and state equally weighted.**

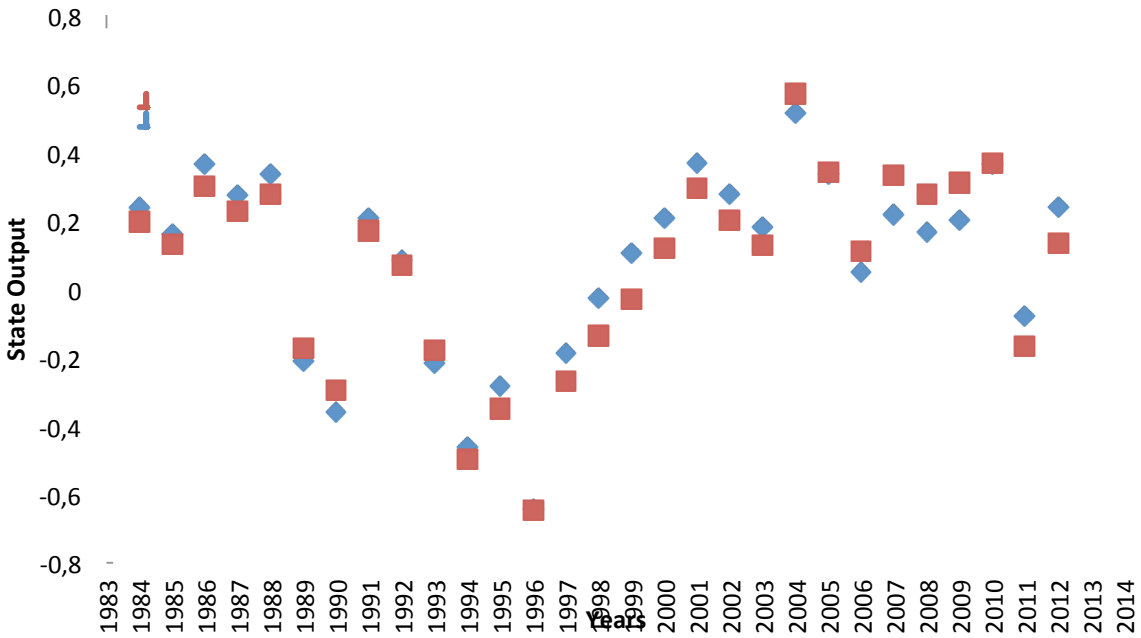


**Figure 16: Sensitivity analysis on the target species, seabirds and bycatch weightings. The blue line is target species and seabirds weighted equally at 40%, and bycatch at 20%. The red line is all three objectives weighted equally at 33%.**

A sensitivity analysis was performed on the thresholds of the indicator 1+SSB, using thresholds that were suggested in discussions. The bad threshold was changed from 0.4Mt to 0.138Mt, which is 10% of the average of anchovy (t) from 1984-1999, which is the current risk threshold from the assessment. The ok threshold was changed from 0.6Mt to 0.95Mt, which is the middle value between the good and bad thresholds. The good threshold was changed from 1.5Mt to 2Mt, and the ok threshold was kept at 0.95Mt, otherwise the ok area would have been too large. The sensitivity of the value of the indicator was assessed, as well as the impact it has on the overall truth value, and the objective to maintain target species in a highly productive state. Figure 17 shows that changing the bad threshold had no effect on the indicator values, whereas changing the ok and good thresholds did change the output. In 1989, 1990, 1994, 1995 and 2011 the change in thresholds changes the output, because changing the thresholds for these numbers changes them from ok to bad. Despite this, Figure 18 shows that the overall truth value was not affected by the changes in thresholds for the $1^{+}$SSB. However, there are a lot of indicators leading into the truth value so the change in thresholds may have got 'lost' in the overall value. The values for the objective to maintain target species in a highly productive state was then looked at to see if the change in threshold for the $1^{+}$SSB indicator affected the objective, as there are fewer indicators leading into that objective. Figure 19 shows that changing the bad threshold did sometimes cause the state value to differ, but only in a few years and it made the values more conservative. Changing the ok and good thresholds does not seem to change the state values. Figure 20 shows that changing the bad threshold made no changes to the objective value. Changing the ok and good thresholds changed the objectives values slightly. In 1989 and 1990 there was more of a difference with the changes, because changing the ok and good thresholds changes those years from ok to bad. For most of the years, the change in thresholds does not change the objective values that much.

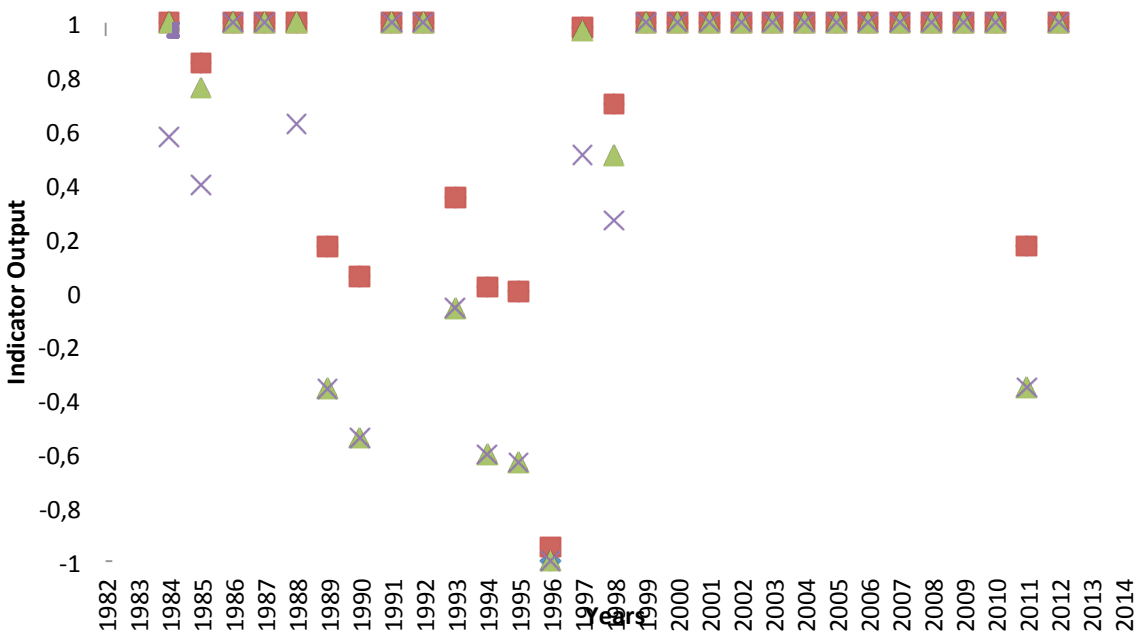


**Figure 17: Sensitivity analysis on the thresholds of the indicator $1^{+}$SSB to see how it affected the indicator value. The blue line is the 'control' using the threshold values as defined in Table 2 (but is hidden behind the red line), the red line is with the 'bad' threshold changed to 0.138Mt, the green line is with the 'ok' threshold changed to 0.95Mt and the purple line is with the 'ok' threshold at 0.95Mt and the 'good' threshold changed to 2Mt.**

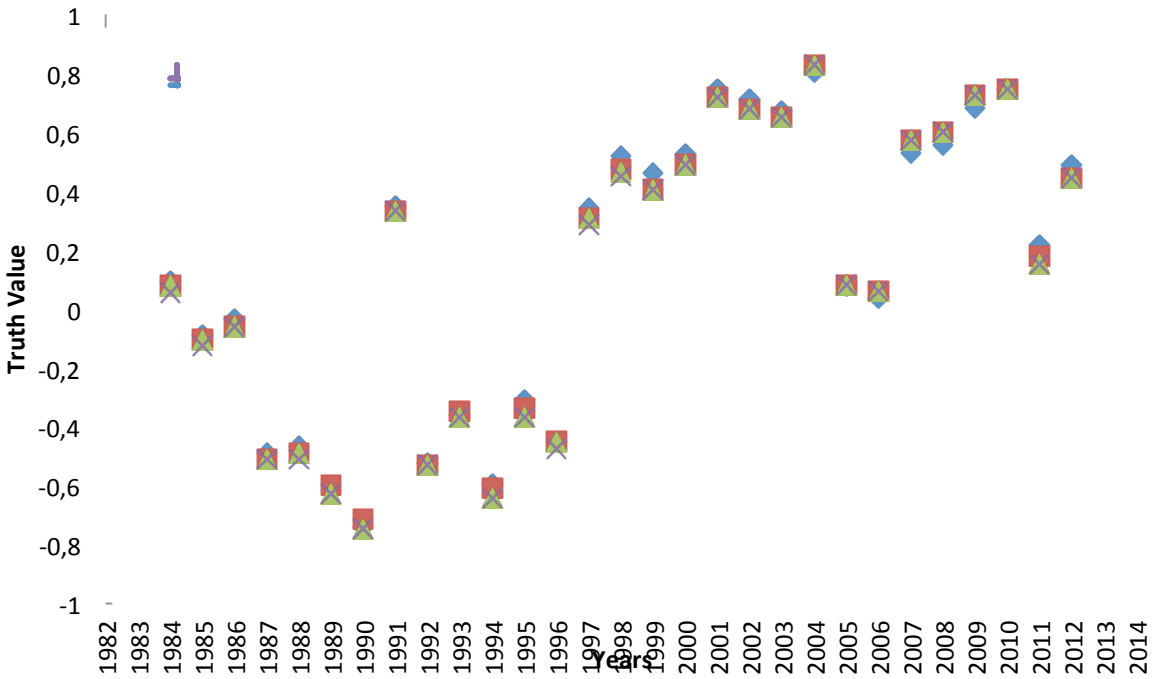


**Figure 18: Sensitivity analysis on the thresholds of the indicator $1^{+}$SSB showing how sensitive the truth values are to changes. The blue line is the control, the red line is with the 'bad' threshold changed to 0.138Mt, the green line is the 'ok' threshold changed to 0.95Mt and the purple line is the 'ok' threshold at 0.95Mt and the 'good' threshold at 2Mt.**

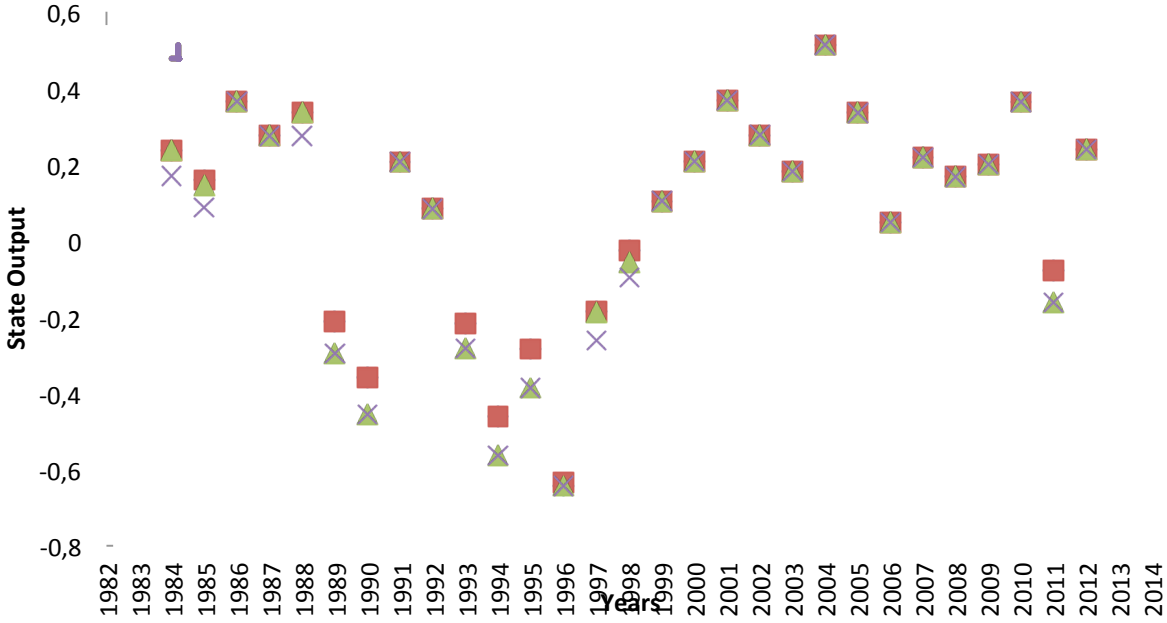


**Figure 19: Sensitivity analysis on the thresholds of the indicator 1$^{+}$SSB showing how sensitive the state values are to changes. The blue line is the control, the red line is with the 'bad' threshold changed to 0.138Mt, the green line is the 'ok' threshold changed to 0.95Mt and the purple line is the 'ok' threshold at 0.95Mt and the 'good' threshold at 2Mt.**

**Figure 20: Sensitivity analysis on the thresholds of the indicator 1$^{+}$SSB showing how sensitive the objective 'maintain target species productivity in a highly productive state' values are to changes. The blue line is the control, the red line is with the 'bad' threshold changed to 0.138Mt, the green line is the 'ok' threshold changed to 0.95Mt and the purple line is the 'ok' threshold at 0.95Mt and the 'good' threshold at 2Mt.**

As bycatch is known to be a problem within the anchovy-directed fishery, the thresholds of the two bycatch indicators were modified to explore the sensitivity of the state and overall truth values to uncertainties in these thresholds. The sardine bycatch indicator (% of the TAB caught, as detailed in Chapter 3.1.2) only has values from 1994, and the horse mackerel bycatch indicator (% of the PUCL caught, as defined in Chapter 3.1.2) only has values from 2000, for this reason, years before 1994 are not included in the graph. The thresholds for the sardine bycatch indicator were modified as follows; the good threshold was changed from 20% to 10%, the ok threshold was changed from 40% to 20% and the bad threshold was changed from 50% to 30%. Note that the latter two represent more conservative evaluations of sardine bycatch: as an example, originally, 25% of the TAB caught would have returned a positive value (indicator reflecting desirable conditions), whereas in the modified setting, it returns a negative value (reflecting undesirable conditions). The thresholds for the horse mackerel bycatch indicator were also changed; the good threshold was changed from 30% to 25%, the ok thresholds from 60% to 50%, and the bad threshold from 100% to 75%. In this sensitivity test, the sardine bycatch thresholds were made more conservative in line with the very high concern about sardine bycatch in the anchovy directed fishery.

Figure 21 shows that changing the bycatch thresholds for both of the indicators only resulted in a qualitative change (positive to negative result) in a single year, and larger discrepancies were only observed in four years (2000, 2002, 2006 and 2011). The state value is insensitive to the change in thresholds for the indicator for horse mackerel bycatch, which is due to the smaller changes in threshold, but also to the lower weight that this indicator receives in the evaluation procedure (30%). Changing the thresholds for the sardine bycatch indicator made the state value output a bit more conservative, again a reflection of the relatively larger changes and the higher weight of this indicator in the evaluation (70%). However, Figure 22 shows that the changes in the state output do not feed through to the evaluation of the overall truth value.

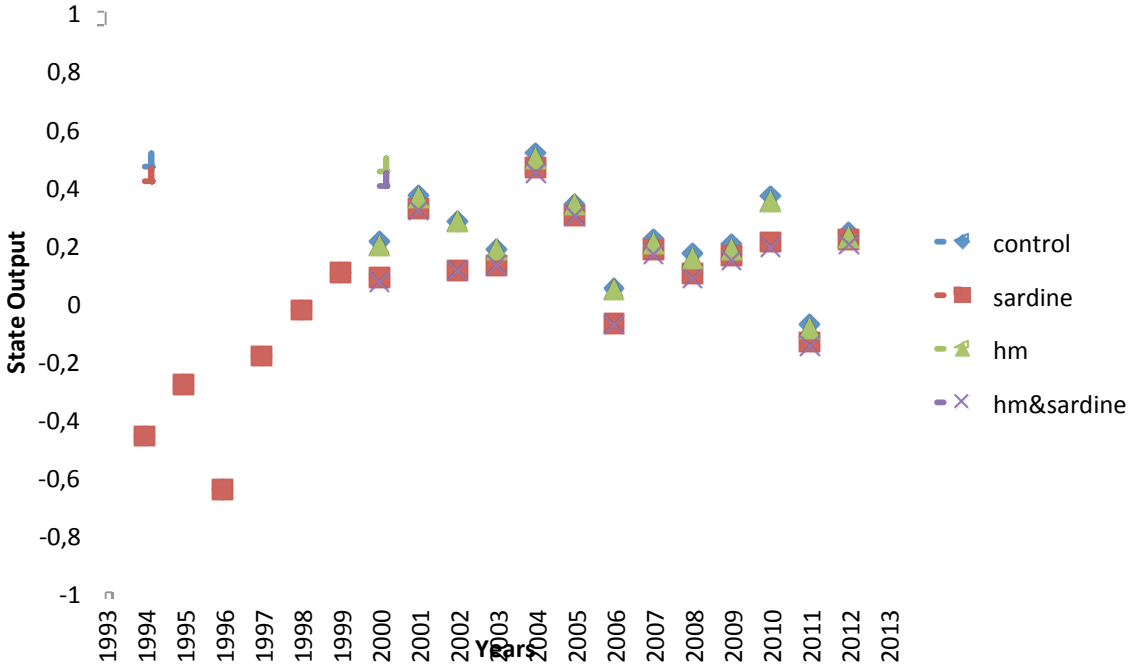


**Figure 21: Sensitivity analysis on the indicator thresholds for the sardine and horse mackerel bycatch indicators evaluating how sensitive the state values are to changes for each indicator and both indicators combined. The blue line is the control, the red line is with the sardine thresholds changed to good – 10%, ok – 20% and bad – 30% and horse mackerel thresholds unchanged, the green line is the horse mackerel thresholds changed to good – 25%, ok – 50%, bad – 75% and the sardine thresholds unchanged, the purple line is both the sardine and horse mackerel thresholds changed.**

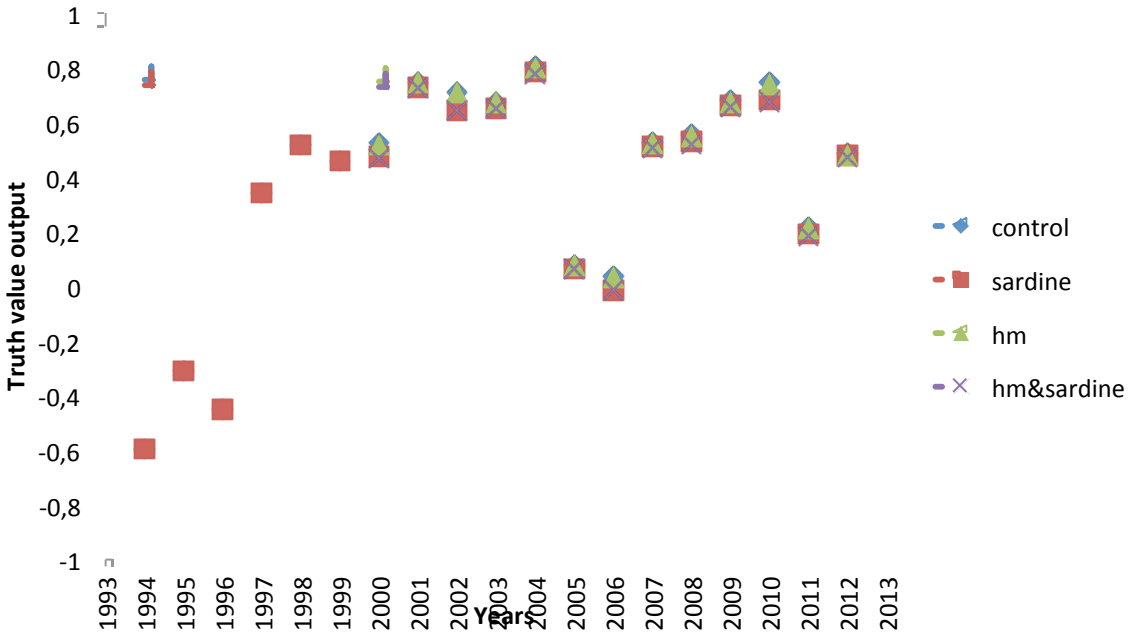


**Figure 22: Sensitivity analysis on the indicator thresholds for the sardine and horse mackerel bycatch indicators evaluating how sensitive the overall truth values are to changes for each indicator and both indicators combined. The blue line is the control, the red line is with the sardine thresholds changed to good – 10%, ok – 20% and bad – 30% and horse mackerel thresholds unchanged, the green line is the horse mackerel thresholds changed to good – 25%, ok – 50%, bad – 75% and the sardine thresholds unchanged, the purple line is both the sardine and horse mackerel thresholds changed.**

## 4. Discussion

This expert system was created by discussions with experts over the objectives and indicators which were put into a hierarchical tree. Their opinions on thresholds and weights were then used to create the expert system. This provided insight into how well the South African anchovy fishery has been performing from the perspective of the ecological well-being dimension of an EAF. The truth values are low in the 1990s meaning to say the implementation efficacy of the anchovy ecological dimension was doing badly; this agreed with experts' expectations which stemmed from the performance of the fishery. During this time there was lower recruitment of anchovy but high catches. The truth values show that in the 2000s the anchovy ecological dimension is doing well, which again is to be expected; there are no current concerns over the anchovy fishery. During this time there was high anchovy recruitment and lower catches, compared to in the 1990s.

The pressure values appear to follow the recruitment indicator, which is because this indicator is weighted 70% whereas exploitation is weighted 30%. Although the pressure value appears to follow the same curve as the recruitment indicator, it is still important to include both of the indicators for these years where these is a high fishing pressure on anchovy.

The sensitivity analysis showed that the changes in the weights did not make a big difference in the truth value. This allows for some flexibility and alleviates the worry to get the weights perfect; if there is a small dispute over the weights, it is unlikely to have a big impact on the truth value. However, the expert agreement on weights was an important process. In the sardine expert system, for example, pressure objectives were weighted 70% whereas the state objectives were weighted 30%. Spatially disproportionate fishing is a big issue for sardine which is a pressure, therefore this was weighted higher (McGregor, PhD in prep).

The sensitivity analysis of the thresholds showed that it is important to think about the thresholds carefully and make sure they are justifiable as they can impact certain years. However, the change in the thresholds made no change to the overall truth value, this is probably due to the multiple indicators leading into this value. When looking at the

overarching objective of maintaining target species in a productive state, the change in thresholds did impact some years, but the majority was the same. Although the change in thresholds does have an impact in the value, when looking at the overall truth value there is not a difference. As it makes a difference at the indicator level, and can sometimes cause a difference at the intermediate specificity level of objective, experts should try to agree as much as possible with the thresholds.

Bycatch is known to be an issue in the anchovy-directed fishery, however the sensitivity analysis on the on the bycatch indicator thresholds did not make a big difference to the overall truth value, and did make a slight difference on the state output values. The sensitivity test on the weighting again showed that the weighting did not make a big difference to the overall truth value. On the one hand, this reflects the context of bycatch issues as one of several concerns in the anchovy-directed fishery, as reflected in the objective hierarchy. On the other hand, the results of this sensitivity test highlight a potential weakness of the procedure of using weighted means in the expert system throughout the entire objective hierarchy. Should stakeholder wish to see a stronger "flagging" of a concerning situation with a specific indicator (e.g., sardine bycatch), such indicators, and their associated branches in the objective hierarchy, would either need to receive very high weights in the expert system relative to all other issues (i.e., indicators), or a different logical framework would need to be explored (e.g., fuzzy logic, as discussed in Jarre et al. 2008). This was, however, beyond the scope of the present project.

Nevertheless, the original aim was to have a meeting with the small pelagic working group in order for them to discuss the expert system created and to allow them to have their input. However, due to circumstances outside the control of this study, this was not possible. When the circumstances change, it would strengthen the study to have a meeting with the small pelagic working group so more experts and their knowledge are included in the expert system (see McGregor, PhD in prep).

Although some of the data series start in 1984, it is not until 1987 where there is data for all of the indicators, excluding the horse mackerel PUCL indicator. The horse mackerel PUCL indicators starts in 2000. Therefore, there is a lot of missing data values of 0

in 1984-1986 so the truth value may not be that reliable. It is probably more meaningful to look at the values from 1987-2012 instead.

The horse mackerel indicator needs to be adapted; the PUCL has now changed so that the total bycatch over three years cannot exceed 18000 tons, however, previously it was 5000 tons per annum. The current thresholds will then have to be adapted to incorporate the change. This will need to be discussed with experts to ensure everyone is in agreement with the new thresholds and adapted indicator.

Some indicators would be better suited in the ability to achieve dimension which comprises of drivers from outside of the fisheries system, such as climate. The indicator relative weight is one of these, it is driven strongly by environmental conditions outside the control of fisheries management, however, it is also internal food web dynamics that determine the availability of zooplankton to anchovy. However, that dimension is not currently being assessed, and the objective that the anchovy are in good condition is important and needs to be included in the ecosystem dimension so it can raise awareness to any issues. When the ability to achieve dimension is further investigated and specified into an expert system in a similar way as done here for the ecological wellbeing dimension, then the objective will need to be reconsidered. Revisiting the objective hierarchy may result in moving this objective from ecological well-being to the ability to achieve dimension.

Another ability to achieve issue is compliance. It is currently an issue in fisheries; there is no monitoring at sea. Illegal, unreported and unregulated (IUU) fishing can impact the ecosystem; all three of the dimensions interact and can therefore cause problems when trying to separate the issues. As this expert system is only looking at the ecological wellbeing dimension, compliance is not included, even though IUU fishing does have the ability to impact the ecosystem. Fishermen are meant to stop fishing when they reach their PUCL or TAB but if there is no monitoring, there is potential for dumping so they can carry on fishing for anchovy. Fishermen that were interviewed by Hara (2013) said they consider dumping and high grading to be one of the main factors that negatively impact the ecological wellbeing dimension.

Some objectives were not used due to the lack of available data, or due to the species not being specifically anchovy feeders (McGregor, PhD in prep). As an example,

some studies have been done on cetaceans to determine that they do feed on anchovy (Sekiguchi *et al.,* 1992), however the data is not easily available, and cetaceans appear to have a varied diet not consuming anchovy alone, therefore cetaceans were not included.

The anchovy-directed fishery is normally a recruitment fishery; it only fishes the new recruits, however the anchovy fishery in Gansbaai also targets adult fish as well as the new recruits. This issue was not raised in the ERA (Nel *et al*., 2007) or any subsequent ERA reviews, however it could be worth keeping it in mind as a potential objective in the future.

Spatially disproportionate fishing was raised as an issue in the ERA (Nel *et al.,* 2007) for sardine, but seeing as there is negligible anchovy fishing along the south coast, the objective was not considered. If a high amount of anchovy fishing does start to occur along the east coast then it will need to be considered as a potential objective in the future.

The pressure and state values from the anchovy knowledge based tool were compared with the pressure and state values from the sardine knowledge based tool (McGregor, PhD in prep) to see if any patterns could be identified. When comparing the pressure values, no visible pattern between the two could be seen. There were times when the ecological dimension of the anchovy EAF was doing well and the ecological dimension of the sardine EAF was doing badly, like in 2007-2012. There was also years when both ecological dimensions were doing badly, e.g. 1984-1990. There were also years when the anchovy ecological dimension was doing badly but the sardine ecological dimension was doing well-ok, e.g. 1992-1996. When comparing the state values, no pattern between the two values could be seen.

The next step would be to combine the anchovy expert system with the sardine expert system (McGregor, PhD in prep) to give a full overview on how well the ecological dimension of the small pelagic fishery in South Africa is doing. The weighting of the two expert systems will have to be discussed with experts for them to combine to make an overall truth value of the small pelagic fishery. As the seabird objectives occur in both expert systems, experts will have to also decide if the seabird objectives and indicators should be removed from either one of the expert systems so it only occurs once in the overall small pelagic expert system, and possibly then revise weighting. Sardine and anchovy fulfil different roles for seabirds at different life stages, and an objective pointing to total biomass

would therefore need to be formulated very carefully. Although low biomass of total forage fish in marine ecosystems has more recently been highlighted as a potential source of concern for seabirds (Cury *et al.,* 2011), the extension of the objectives beyond those reported in Nel *et al.* (2007) were beyond the scope of this thesis.

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