Ecosystem Approaches to Fisheries in the Southern Benguela
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CONTRIBUTIONS OF THE BENGUELA ECOLOGY PROGRAMME TO PELAGIC FISHERIES MANAGEMENT IN SOUTH AFRICA

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In 1982, the Benguela Ecology Programme (BEP) created a formal, multi-institutional research partnership in South Africa. During the next two decades, the BEP directed many aspects of pelagic ecosystem research in the southern Benguela upwelling region, aiming to improve fisheries management, particularly that of anchovy *Engraulis encrasicolus*. Although much reduced in scale, the BEP is now in its fifth phase. Its early critics believed that much of the money invested in its ecosystem-type research had not benefited fisheries management, whereas its supporters maintain that many aspects of current pelagic fisheries management are founded on the BEP legacy. Ecosystem research underpinned the design of hydroacoustic surveys, and resulted in the development of expert system models aimed at predicting recruitment strength of anchovy. Current efforts to develop an ecosystem approach to management of the pelagic fishery in South Africa draw on the knowledge and understanding generated by more than 20 years of ecosystem research. However, despite this strong foundation, there is still uncertainty about the causes of interannual variability in pelagic fish recruitment. It is suggested that this time span is too short, and ecosystem monitoring and research should persist for decades to reap their full rewards. The BEP enabled productive partnerships to be established between academic and State researchers and fisheries managers, and improved linkages and communication to the fishing industry.

Key words: anchovy, Benguela Ecology Programme, ecosystem research, pelagic fisheries, sardine

Increasingly, there are pressures to study entire ecosystems for fisheries management and other purposes. Single species are only rarely caught in isolation from other species, and targeted and incidental removals of living organisms from the oceans impact their own populations as well as those of others. Fishing affects ecosystems (Gislason *et al.* 2000), although the manner and extent of these impacts are sometimes unclear. In the past, any indirect and cascading effects of species' removals have been noted and then largely ignored, primarily because of difficulties in addressing them using the standard tools of fisheries stock assessment. Jackson *et al.* (2001) described massive, human-induced changes to a variety of ecosystems, and ascribed many of the changes to alterations in species interactions, caused in the first instance by overfishing, and going back thousands of years. Pauly *et al.* (1998) suggested that modern fishing practices employed over the past 50 years have altered the structure and/or functioning of ecosystems to the extent that current fisheries catches on a global scale are not sustainable.

In contrast to the effects of fishing on ecosystems, it is recognized that the marine environment can sometimes have a large influence on harvested fish populations, and that these environmentally induced population changes can happen on scales that equal or outstrip the effects of fishing. The *El Niño* phenomenon and its effects on the coastal fisheries of Chile and Peru is a well-known example of such influences (Bakun 1996).

There is therefore a compelling case for studying marine ecosystems in order to understand the influence of the environment on fish populations, and the effect of fishing on the marine environment. Unfortunately, in reality this is difficult to put into practice. Despite many years of research, there is still generally poor understanding of where and when human-induced impacts are likely to be amplified or dampened by biological interactions, and through what mechanisms. There are few datasets available that allow an unambiguous interpretation of changes that might occur in fished populations and their environment. As a consequence, the concept of "ecosystem research" has led to polarization within research communities. Proponents argue that it is foolish to ignore ecosystem effects, whereas antagonists argue that the ecosystem is too complex to understand and model effectively, so that ecosystem research wastes resources that can be better spent elsewhere. It is contended here that both these arguments have merit, but that they apply to situa-

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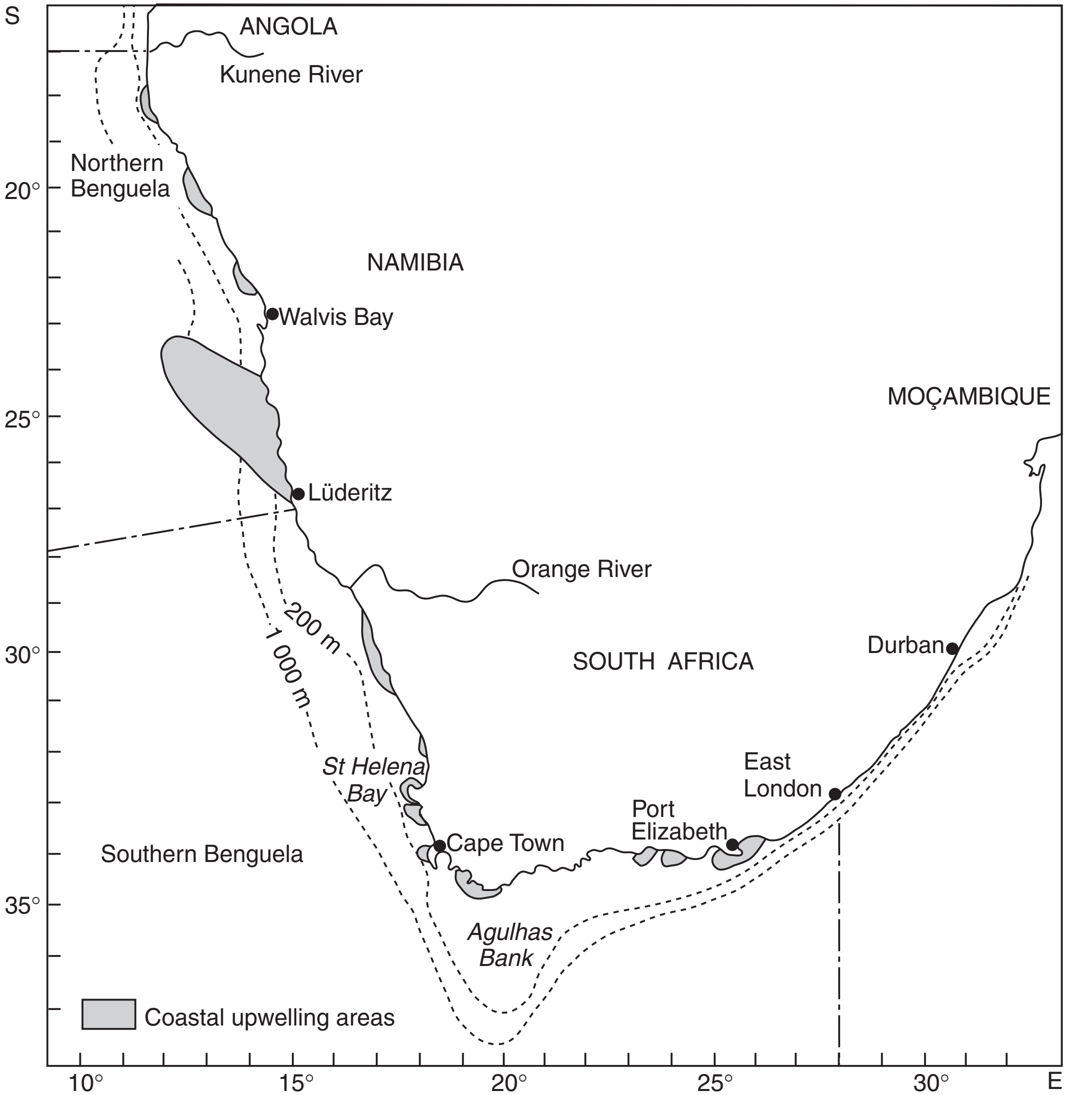

Fig 1: Map of southern Africa, showing the extent of the northern and southern Benguela upwelling ecosystems, and the location of the coastal upwelling areas

tions governed by different management objectives. When a short-term management decision is required, ecosystem understanding is unlikely to be appropriate or useful. However, when long-term strategic planning with multiple management objectives is required, understanding the interactions within ecosystems is crucial.

In 1981, a formal research partnership was established among government departments, universities and museums in South Africa, through the creation of the Benguela Ecology Programme (BEP). During the next two decades, the BEP and its associated structures directed many aspects of the research carried out in the pelagic environment of the southern Benguela upwelling region off the west coast of South Africa (Fig. 1). The BEP had an overall objective "to provide scientific information on the structure and functioning of constituent ecosystems, to complement the knowledge which is required for the management of the renewable natural resources of the Benguela Current region" (Siegfried and Field 1981, p. 4). Although now much reduced in scale, the BEP is currently in its fifth phase. Its early critics stated that much of the money invested in its ecosystem-type research did not benefit fisheries management (e.g. Butterworth 1989), whereas its early supporters maintained that improved ecosystem understanding underpinned many aspects of pelagic fisheries management in the region (e.g. Shannon *et al.* 1988). In subsequent phases of the BEP, research was re-aligned to make it more "applied" and thus address the issues raised by critics. Also, in the intervening years there has been a global paradigm shift in fisheries management towards an ecosystem approach. This new approach makes ecosystem research more relevant now than it was 20 years ago under the single-species paradigm that prevailed.

This paper aims to describe, in scientific and societal terms, the main contributions to pelagic fisheries management that resulted from the past 20+ years of ecosystem research, ultimately providing the backdrop to the workshop on "Ecosystem approaches to fisheries management in the southern Benguela" (Shannon *et al*. 2004). We highlight some advances in knowledge that resulted from the BEP, and indicate how ecosystem research is being used to underpin management of the pelagic fishery, identifying areas where preconceptions about the uses of ecosystem knowledge have turned out to be incorrect. At the same time, we show how management approaches for the pelagic fishery have evolved over the past 20 years, and highlight the role of scientific communication in facilitating these new approaches.

INTER-INSTITUTIONAL RESEARCH AND COLLABORATION

From its inception in 1981, the BEP was designed as a multi-institutional programme. Two large organizations have been involved continuously with the BEP: the research component of the South African government's Marine and Coastal Management (formerly Sea Fisheries), and the University of Cape Town, through the involvement of a number of academic departments. Other universities have also been part of the programme (Universities of Fort Hare, Rhodes, Port Elizabeth and the Western Cape), as have two museums (South African, in Cape Town, and Port Elizabeth). Various government and parastatal organizations have also been involved, including the National Research Institute for Oceanology, the National Physical Research Laboratory and the Institute for Maritime Technology. Initially, the (then) Council for Scientific and Industrial Research (CSIR) played a large co-ordinating and administrative role, which it transferred to the South African Network for Coastal and Oceanic Research (SANCOR). However, over the years and as overall funding for research decreased, there has been reduced funding for personnel to implement co-ordination within the research programme. As a result, the institutional linkages have weakened and they are now maintained in a less formal manner than previously.

Phases of the BEP

The BEP was designed as an interdisciplinary research programme, with a strong emphasis on ecosystem studies. Some of the key objectives of the programme are listed below:

(1) providing the knowledge necessary for a better scientific understanding of marine ecosystems;
(2) contributing the knowledge that could underpin wise management of marine renewable resources, especially pelagic shoaling fish;
(3) creating opportunities for research to meet requirements of national and international scientific importance;
(4) promoting the training of skilled personnel that are needed but in short supply.

The programme has progressed through four complete, sequential, five-year phases, and a fifth phase is currently underway. The first phase (BEP 1) culminated with an international symposium entitled "The Benguela and comparable ecosystems" (Payne *et al.* 1987). It was followed by BEP 2, where the emphasis of the research was on the dynamic processes controlling the distribution and abundance of key species (Shannon 1988). The end of Phase 2 was marked by an international symposium entitled "Benguela trophic functioning" (Payne *et al.* 1992). At that stage too, efforts were made to consolidate the research from the previous 10 years and to plan for future research within the BEP.

In response to changing socio-economic priorities in South Africa, the next phase (BEP 3) was designed to focus more directly on research to optimize the use and management of marine living resources, with emphasis still on pelagic fish, but a broadening of focus to include also the economically important chokka squid *Loligo vulgaris reynaudii* (Cochrane and Krohn 1994). The programme concentrated on intra-annual and spatial variability and changes in the driving forces and variables. This phase was completed in 1996, and its main results were presented in a symposium entitled "Benguela dynamics: impacts of variability on shelf-sea environments and their living resources" (Pillar *et al.* 1998).

At the start of BEP 4 in 1997, South Africa had undergone major political change and the country was in the midst of substantial social change. Research funding was uncertain and limited, and many of the institutions involved in the BEP were undergoing structural reorganization. As a consequence, the funding available for BEP 4 was much reduced, with a concomitant reduction in the number of funded contract research positions associated with the programme. Despite the funding cuts, the focus of the programme was broadened to include research on demersal fish species. Fortuitously, at a time when local research inputs were restricted, the research activities within the BEP were bolstered considerably by partnerships that were formed with foreign research institutions. In essence, the BEP became a sub-programme within a number of international collaborative research programmes. Most notable among these were the French–South African VIBES (**VI**ability of exploited pelagic fish resources in the **B**enguela in relation to the **E**nvironment and **S**patial aspects)/IDYLE (**I**nteraction and spatial **DY**namics of renewable resources in upwe**L**ling **E**cosystems) programmes, funded through the French IRD (formerly ORSTOM), the EU-funded Envifish programme, and the Benguela Environment, Fisheries, Interaction and Training (BENEFIT) Programme, which is a partnership among Angola, Namibia, South Africa, Norway and Germany.

ECOSYSTEM STUDIES AND PROGRESS IN UNDERSTANDING

Major impetus was given to ecosystem research in South Africa when the BEP was initiated, and several different disciplines were brought together. Whereas much research relevant to the major fisheries of the region had been conducted prior to 1981, many of those studies were carried out in relative isolation from other researchers in the country. The BEP represented the first occasion that an integrated, ecosystem approach was adopted in marine science in South Africa. Because the South African scientific community was largely isolated from international events, cooperative investigations were easy to instigate and integrate. In this section, a few pertinent results of the research within the BEP that relates to pelagic fish ecology are described, and the manner in which these results changed perceptions held at the start of the programme is indicated.

Ecosystem research: the sum of all the parts

One approach to studying ecosystems requires measurement of as many components as possible over time and space. The underlying basis of this approach is that an ecosystem functions as the sum of all of its individual parts. Taken to extremes, this approach is logistically impossible; no-one can measure everything, everywhere, all of the time. However, to understand ecosystem dynamics, it is necessary to have a comprehensive research programme that involves studies at all trophic levels. The bottom links in the foodweb can indicate short-term variability in the physical environment, whereas top predators such as seabirds and mammals are integrators of the ecosystem, responding to long-term changes, often on an ocean-basin scale. All major elements of the ecosystem have been represented in the research projects of the BEP, more obviously so during the first two phases. This section highlights the progress from 1981 to 2001 in some key elements of the research underpinning understanding of pelagic fish ecology.

PHYSICAL AND CHEMICAL OCEANOGRAPHY

During the 1960s and 1970s, international understanding of the appropriate time and space scales of upwelling improved immensely, mainly as a result of the multinational, multi-location surveys of Coastal Upwelling Ecosystems Analysis (CUEA) and JOINT I and II off Peru (Walsh *et al.* 1971), Oregon, North-West Africa (Barber 1977) and California (Bakun and Nelson 1977). Similar research into upwelling was taking place off South Africa, albeit at a lower level of effort. However, the knowledge acquired in comparable regions elsewhere was important in guiding South African research. Scientists in South Africa had an added advantage in that there are clear oceanographic signals off southern Africa, and much of the coastal upwelling activity happens in close proximity to Cape Town (Fig. 1), where the major oceanographic institutions are located. To some extent, therefore, they were able to "keep up" with international progress in understanding, despite their geographical and political isolation at the time (Bang and Andrews 1974, Andrews and Hutchings 1980).

When the BEP started in 1981, the frequency of upwelling was poorly understood. The South African west coast was initially considered a black box of overwhelming complexity, because early satellite imagery showed highly dynamic features of eddies, whorls, filaments and rings, all of which changed with bewildering rapidity. Physical oceanographic research focused on the use of satellite thermal imagery and measurements of winds and currents to understand the most important physical characteristics of the system. Results show just how dramatic the changes in the physical environment can be in the southern Benguela; understanding variability became a key element of research, and mesoscale features received increasing attention (Jury and Brundrit 1992, Shillington *et al.* 1992). Increasingly, analyses of integrated or average conditions were supplemented by studies of the intensity and timing of short-term events, such as enhanced mortality of pelagic fish larvae through entrapment in an Agulhas ring (Duncombe Rae *et al.* 1992), or enhanced recruitment of anchovy through sequential environmental events that favour first good transport and then good feeding conditions (Roy *et al.* 2001). Small scales are necessary to understand factors causing interannual variability, but on longer time scales, global events that are manifest as local phenomena such as Benguela *Niño*s (Shannon *et al.* 1992, Shillington 1998) are known to be important.

During the course of the BEP, the importance of the Agulhas Bank (Fig. 1) in the life history of pelagic fish in the southern Benguela was recognized (Cochrane and Krohn 1994). Variability in the quantity of warm water that penetrates onto the Agulhas Bank is considered an important factor that could affect recruitment success. Also important is the quantity of cool water that upwells inshore at headlands on the Agulhas Bank and forms the large subsurface "cool ridge" over the eastern-central Bank (Swart and Largier 1987). The expansion of the area of interest during the BEP was important, because it recognized that the Benguela ecosystem and its fish stocks were not restricted to the west coast of southern Africa.

BIOLOGICAL OCEANOGRAPHY AND PELAGIC FOODWEBS

At the start of the BEP, many ecological processes were poorly understood, including those involved in the seeding of newly upwelled water by phytoplankton, energy transfers through the foodweb, and nutrient cycling within the water column. The responses of bacterioplankton, phytoplankton and zooplankton to upwelling events were studied, mainly during the first decade of the BEP, using laboratory, field and modelling studies. Research was also carried out into the feeding energetics of the two most important pelagic fish species: anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax*. The roles of different sizes of organisms in transferring carbon in the foodweb and recycling nitrogen and other nutrients were examined. Most of these research findings are reported in the volumes edited by Payne *et al.* (1987, 1992). The net result of that research was semi-quantitative understanding of the roles of the most important plankton groups in carbon transfers and nutrient recycling in the ecosystem.

Conventional wisdom had attributed the large pelagic fish production in the southern Benguela to a short food chain, as proposed by Ryther (1969). The basis for this upwelling foodweb model was that pelagic fish were phytophagous. Field and laboratory studies on adult anchovy demonstrated that the species was primarily zoophagous and obtained most of its dietary carbon through selective, particulate feeding on large zooplankton such as large calanoid copepods and euphausiids (James 1987, James *et al.* 1989). Subsequent studies on adult sardine indicated that, whereas it was capable of ingesting appreciable quantities of phytoplankton, it was also primarily zoophagous (van der Lingen 2002a). In contrast to anchovy, sardine derive most of their dietary carbon through non-selective filter-feeding on small zooplankton such as cyclopoid and small calanoid copepods (van der Lingen 1994, 1998). Similarly, analysis of the diet of anchovy and sardine juveniles from mixed shoals indicated that sardine ingested significantly smaller zooplankton than did anchovy (Louw *et al.* 1998). In no other upwelling system does such detailed information concerning the trophodynamics of anchovy and sardine exist. Currently, zooplankton populations are monitored on a monthly basis (Hutchings 2002) to test hypotheses about ecosystem controls, and to assist interpretation and understanding of population trends of pelagic fish.

DISTRIBUTION AND LIFE HISTORY OF PELAGIC FISH

Prior to the initiation of acoustic surveys in 1983, information concerning the distribution, availability and movement of anchovy and sardine was derived from analyses of commercial catches (e.g. Armstrong *et al.* 1985). Southward shifts in catch positions during the fishing season, and length progressions in commercial catches, indicated that anchovy recruits moved south along the West Coast in winter, reaching the South Coast by the end of their first year (Crawford 1981). Anchovy were believed to be short-lived, surviving for only one to two years. Natural mortality was high, and the fishery could take as much as 50% of the biomass each year.

Data on the major spawning times and areas of pelagic fish and on dispersal patterns of their eggs and larvae showed that anchovy spawned mainly east of Cape Point over the Agulhas Bank (Fig. 1; van der Lingen *et al.* 2001) between October and January, and that the spawning products were dispersed around Cape Point to the West Coast nursery area by a shelf-edge jet current (Shelton and Hutchings 1982). That transport westwards out of the spawning grounds reduces cannibalism to some extent. After spawning, a portion of the adult anchovy stock returns to the West

Coast, but most fish move even farther east, moving close inshore in late summer. What had been estimated before the BEP as mainly natural mortality turned out to be emigration from the traditional fishing grounds. Those results were further corroborated by age studies, which showed that anchovy lived for 4–5 years, with most of the older fish on the Agulhas Bank (Barange *et al.* 1999).

Anchovy and sardine were determined to be serial spawners, producing batches of eggs at intervals over a prolonged spawning season of several months (Melo 1994a, b, Akkers *et al.* 1996). The prolonged spawning season was regarded as a "bet-hedging" strategy to overcome the dramatic short-term fluctuations in upwelling (Shelton 1987), which occur throughout the spawning season. Prolonged spawning is possible because of the fat reserves that are accumulated by recruits inshore on the West Coast, the main nursery area of pelagic fish. The fat reserves enable young fish to migrate against food gradients onto the Agulhas Bank, where consumption of plankton *in situ* also maintains serial spawning. The large calanoid copepod *Calanus agulhensis* is the dominant zooplankter on the Agulhas Bank. Its centre of distribution is over the eastern Agulhas Bank, where a subsurface ridge of cool water is often observed (Swart and Largier 1987). Depending on their fat reserves and the planktonic food supply, egg production by adult fish may or may not be curtailed. Juvenile anchovy are found inshore along the West Coast. How they arrive there, by swimming or by advection, is currently the focus of research. Inshore on the West Coast, good feeding conditions allow scope for rapid growth of the juvenile fish. However, these conditions are variable, and at the end of summer/autumn, when upwelling and light intensity are relatively low, the cohort biomass is most variable and natural mortality is large. The prolonged spawning season probably spreads the impact of large numbers of recruits appearing simultaneously on the West Coast.

Before 1983, virtual population analysis (VPA), based on the age structure of commercial catches, was used to estimate fluctuations in pelagic fish recruitment and spawner biomass (e.g. Butterworth 1983, Armstrong *et al.* 1985). However, commercial vessels did not sample the major part of the adult anchovy population (on the South Coast), invalidating the VPA estimates (Hampton 1987). In 1983, the then new fisheries research vessel *Africana*, which was equipped with quantitative acoustic technology, began conducting hydroacoustic surveys of pelagic fish stocks. It was quickly learned that estimates of anchovy spawner biomass made during spawner biomass surveys were 3–4 times larger than those derived from VPA, suggesting that the anchovy stock was less seriously threatened by catch levels then than had been believed (Hampton 1987). Results from VPA had, in fact, indicated that the anchovy stock was overexploited, a misconception that was changed by the catch-independent survey data. The daily egg production method of stock assessment, conducted from samples collected during hydroacoustic surveys (Shelton *et al.* 1993), corroborated acoustically derived biomass estimates (Hampton 1996).

RECRUITMENT OF PELAGIC FISH

At the start of the BEP there was a drive to develop predictive models for commercially important populations that were subject to large recruitment fluctuations, permitting timeous reduction of catches during periods of unfavourable recruitment. Some of the early hypotheses on the factors affecting recruitment focused on large-scale anomalies, such as annual above-average temperatures. Correlative studies (e.g. Villacastin-Herrero *et al.* 1992) were inconclusive, and it was realized that there could be no simple, predictive relationship between the environment and recruitment that could be used for management. However, the early studies paved the way for the development of event-driven hypotheses, and the recognition of the crucial role of mesoscale events (e.g. Roy *et al.* 2001). This truly integrated approach to the study of recruitment combined information on currents, the feeding habits and energetics of anchovy, the adaptations of the plankton, and the productivity of the stratified waters of the Agulhas Bank.

At present, a large number of factors are believed to affect the recruitment success of anchovy on a seasonal basis. Surveys of early life history of anchovy and sardine include the frequent monitoring of eggs and larvae in the jet current off the Cape Peninsula (Huggett *et al.* 1998) and annual surveys of pre-recruit abundance off the West Coast (van der Lingen and Merkle 1999). Empirical studies related anchovy recruitment strength to copepod biomass and production on the spawning grounds, the incidence of oocyte atresia in adult female anchovy, the distance offshore of the 16°C isotherm at Cape Columbine (Cochrane and Hutchings 1995), potential new production over the West Coast (Waldron *et al.* 1997), the South-East wind anomaly at Cape Point, the oil-to-meal ratio of pelagic landings made between January and April in a given year (Boyd *et al.* 1998), and the extent of thermally suitable (16–19°C) water for spawning (Richardson *et al.* 1998). Those empirical studies allowed the identification of key processes impacting recruitment success (Hutchings 1992, Cochrane and Hutchings 1995, Hutchings *et al.* 1998). This knowledge was incorporated into rule-based (Bloomer *et al.*

1994) and expert-system (Korrûbel *et al.* 1998, Painting and Korrûbel 1998, Miller and Field 2002) models that aim to predict anchovy recruitment strength. However, this approach has not been incorporated into formal management procedures.

TOP PREDATORS WITHIN THE ECOSYSTEM

Higher up the foodweb, the diets of major species groups and the impacts of top predators on pelagic fish were poorly known at the inception of the BEP. Some early projects studied the top predators and their roles in the ecosystem. Seabird biologists examined the distribution, feeding and reproductive success of seabirds that foraged on pelagic fish (Best *et al*. 1997). The initial estimates of seabird consumption showed that it was negligible in terms of total mortality of pelagic fish (Crawford *et al*. 1991). However, in-depth analysis of regular collections of stomach samples and indices of reproductive success allowed Crawford and Dyer (1995) to link changes in bird populations and diets to variations in the population strength of pelagic fish. In particular, there has been a steady increase in the biomass of sardine since 1983, whereas anchovy have fluctuated considerably over the same period (Barange *et al.* 1999). The data indicate that the principle of conserving a certain minimum biomass to allow for sufficient recruitment should be augmented with a further reserve of fish biomass as forage for top predators (Crawford 2004).

Ecosystem research: emergent properties

A second approach to studying ecosystems assumes that they have properties that result from the totality of their interacting components. It is therefore not possible to predict or understand the ecosystem merely by studying all its parts. Rather, it is necessary to study integrated aspects of its structure and function. This approach is theoretically attractive but logistically problematic, because there are no universally accepted ecosystem properties that will help guide all aspects of management. One of the early activities of the BEP was the construction of a preliminary carbon budget for the southern Benguela ecosystem (Bergh *et al.* 1985). Despite little being known about carbon fluxes in the ecosystem, the budgeting exercise accomplished its goals of providing an ecosystem framework within which to view the pelagic fishery. This study was expanded and added to as understanding improved. The detailed information on diets of anchovy and sardine was incorporated into trophic flow models (Shannon *et al.* 2003), and led to the development of a new foodweb model for the ecosystem, in which predation on zooplankton was highlighted as an important factor for spawning and survival of pelagic fish (Cury *et al.* 2000).

In order to understand the integrated flows within the ecosystem, studies of diets and associated trophic roles were expanded to include a wide range of predators (e.g. Armstrong *et al*. 1991, Crawford *et al.* 1991, Ebert *et al.* 1991, Meyer and Smale 1991a, b, Sauer and Lipiński 1991, Punt *et al.* 1995). Many of the important feeding interactions in the ecosystem were quantified (e.g. Jarre-Teichmann *et al.* 1998), and mass balance calculations helped constrain some early estimates of the roles of different groups as predators and prey. Currently, the use of ECOSIM and ECOPATH models (Christensen *et al.* 2000) is providing insights into the ecological effects of harvesting forage species and some of the top predators while protecting others, such as seals and dolphins (Shannon *et al.* 2003). In particular, these large-scale models are helping understanding of the key interactions within the ecosystem that might change during periods when sardine or anchovy dominate.

Size-based approaches have also been an important part of Benguela ecosystem studies. Theoretical size and biomass spectra were constructed for the southern Benguela by Moloney and Field (1985), and allometric relationships were used to investigate the theoretical dynamics of plankton communities (Moloney *et al.* 1991). Investigations of zooplankton communities indicated that the species composition and size structure have changed on decadal scales (Verheye *et al.* 1998), as has the size spectrum for demersal species and linefish. The effects of fishing on the size spectrum of the fish communities have been investigated using empirical datasets (Yemane *et al.* 2004) and with individual-based models (Shin and Cury 2001, Shin *et al.* 2004), and these studies currently are being used to help develop indicators for the state of the ecosystem.

PELAGIC FISHERIES MANAGEMENT IN SOUTH AFRICA

The pelagic fishery

Currently, anchovy and sardine are the two most important species in the South African pelagic fishery. Anchovy are reduced to fish oil and meal, whereas sardine are canned or frozen for human consumption, canned for pet food or frozen for bait (Armstrong and Thomas 1989). Directed fishing for adult sardine takes place year-round, whereas fishing for anchovy typically starts in February/March and continues up to August/September. Anchovy recruit to the fishery

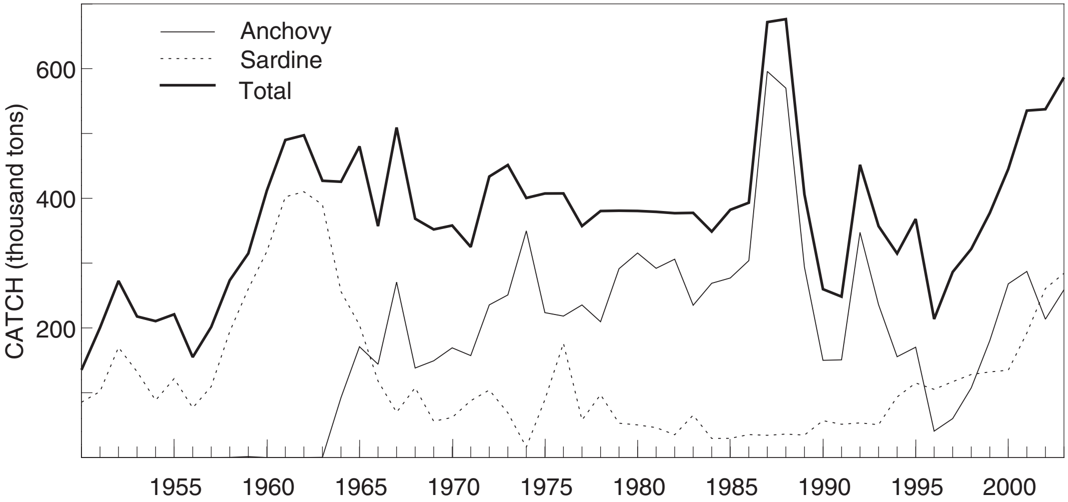

Fig. 2: Annual landings of anchovy, sardine and all species captured by the pelagic fishing industry (total) off South Africa, 1950–2003 (updated from de Oliveira *et al.* 1998)

in their first year, with recruits contributing up to 70% of the annual anchovy catch on average (Cochrane and Hutchings 1995).

Historically, sardine and horse mackerel *Trachurus trachurus capensis* were the primary targets of the commercial purse-seine fishery. Peak sardine catches of some 400 000 tons annually were made in the early 1960s (Fig. 2), but poorly controlled increases in effort and variable recruitment led to the collapse of the stock during the late 1960s, and catches remained depressed until the 1990s. From 1995, sardine catches exceeded 100 000 tons annually. To compensate for the decline in sardine catches in the 1960s, small-meshed (13-mm as opposed to 32-mm) nets were introduced in 1964 to target anchovy, with almost all vessels using such nets by 1966. These nets resulted in a change in the size composition of sardine catches, with juvenile (0+) sardine being taken as a bycatch in the anchovy fishery. Anchovy catches rose rapidly after the introduction of small-meshed nets, attaining levels of 200 000–300 000 tons during the 1970s and 1980s. Peak anchovy catches of close to 600 000 tons were landed in 1987 and 1988, but landings then decreased markedly (Fig. 2). Anchovy catches have since increased (van der Lingen and Huggett 2003).

Management of South Africa's pelagic fishery evolved in parallel with its development. A combined sardine and horse mackerel total allowable catch (*TAC*) of 226 900 tons was imposed in 1953 and applied somewhat flexibly until 1959, when it was abolished in the face of increasing sardine catches (Crawford *et al.* 1987). No catch limits were set during the 1960s, although unsuccessful attempts were made to restrict fishing effort through limitations of vessel capacity. In response to increasing fishing effort and the collapse of the Namibian sardine fishery in the late 1960s, a global *TAC* for all pelagic species combined was introduced in 1971, and this *TAC* fluctuated between 360 000 and 450 000 tons (Cochrane *et al.* 1998). This global *TAC* was not based on considerations of ecosystem carrying capacity. Rather, it was assumed that a global *TAC* would provide some insurance against adverse fluctuations in the stock of a particular species, given that a large number of species (sardine, anchovy, round herring *Etrumeus whiteheadi*, horse mackerel and chub mackerel *Scomber japonicus*) contributed to landings (Butterworth 1983). In 1975, the introduction of individual quotas for fishing companies as fixed proportions of the *TAC* meant that quota-holders could stop competing for *TAC* and hence rationalize their operations. This allowed the companies to take a longer term interest in the resource, and resulted in a decrease in both total fleet hold capacity and the number of vessels in the fishery (Cochrane *et al.* 1997). The global *TAC* was applied until 1983, when single-species *TAC*s for sardine and anchovy were introduced (Cochrane *et al.* 1998). For anchovy, the *TAC* was derived from a constant escapement and, later, a constant proportion harvest strategy, whereas for sardine the *TAC* was set using a conservative fishing mortality (15% of the adult biomass).

During the 1990s, a continued rise in the biomass of sardine resulted in mixed shoaling, which caused increasing numbers of juvenile sardine to be caught as a bycatch with anchovy, and adult sardine as a bycatch with round herring (de Oliveira 2002). The multispecies nature of the pelagic fishery and the bycatch problems with sardine necessitated the development of management procedures, which have been applied since 1998 (de Oliveira *et al.* 1998) and updated regularly (de Oliveira 2003, Cunningham and Butterworth 2004). In the absence of information about recruitment at the time of setting *TAC*s (January), this procedure assumes average recruitment and downscales the initial *TAC* estimate to allow for possible poor recruitment. After the recruit surveys in May/June, a final *TAC* is calculated. This current management procedure has a trade-off between sardine and anchovy catches, in order to allow for sardine bycatch. This inevitably results in anchovy landings that are smaller than might be allowed in a single-species calculation. There have also been operational problems associated with the mixed-species fishery, including an increase in discarding at sea.

It is worth noting that there was little discussion, during this period of depressed catches, of interspecies competition, and the advisability of deliberately overfishing one species in order to allow another to "recover". The detailed trophic studies of sardine and anchovy had indicated that the two species both fed primarily on zooplankton, but used different resources and probably slightly different habitats for feeding (van der Lingen 2002a) and reproduction (van der Lingen *et al.* 2001). In addition, bottom-up studies indicated that the notion of an overall "carrying capacity" for pelagic fish was unlikely to be a straightforward concept, because there appeared to be "excess" primary production in the ecosystem (i.e. not utilized directly by zooplankton and fish), and the links between phytoplankton and zooplankton, and between zooplankton and fish, were not well understood. Furthermore, intra- and interannual variability in the environment implied that any "carrying capacity" could vary widely from one year to the next. Ecosystem studies therefore effectively eliminated a potential management option, one that had had disastrous consequences when applied in Namibia (Butterworth 1983).

From the early 1990s, there was a shift towards using management procedures to set *TAC*s in the South African pelagic fishery. These management procedures use a set of decision rules and equations that produce *TAC*s based on inputs in terms of previous *TAC*s, and the results of spawner biomass and recruit surveys. The equations and decision rules are simulation tested after estimating key parameters using stock assessment models, and allowing for key uncertainties, including recruitment (Cochrane *et al.* 1998). A management procedure was first applied to the anchovy fishery in 1991, and in 1994 it was extended to include *TAC*s for sardine (Geromont *et al.* 1999). In 1997, a sardine-only management procedure was applied, following very low observed abundance of anchovy in the spawner biomass survey in November 1996. Subsequently, the anchovy population was found to have larger recruitment than had been anticipated, and the anchovy *TAC* was increased. There was a surprising acceptance of this situation on the part of the industry, first to the initial reduced anchovy *TAC* (zero *TAC*), and then to the subsequent upward revision that they had been warned in advance was unlikely to happen. Part of this acceptance was undoubtedly due to political and other factors within the industry, but some of it can be ascribed to improved communication between industry, scientists and government, whereby industry were informed early on about the survey results. The ongoing research within the BEP and other programmes had by this stage established that pelagic fish recruitment in the region was highly variable and influenced by many factors other than parent stock size.

Institutional arrangements and management tools

In the 1980s, management of South African fisheries was the responsibility of Sea Fisheries, a division of the Department of Environmental Affairs and Tourism (DEAT). At that time, the mode of management focused on monitoring, regulation and enforcement, and resource users had little input to the management process. Some 20 years later, after substantial political and social change in South Africa, resource users have more of a say in fisheries management. At present, the relevant authority is still located within the government's DEAT, but its name was changed in 1999 to Marine & Coastal Management, it has been given an elevated status within the department by becoming a branch headed by a Deputy Director-General, and has had its responsibilities increased to include not only fisheries management, but also management of the marine and coastal environment. These changes reflect substantive changes in the way of doing business, and are not unique to South Africa (Pinkerton 2002).

The essence of fisheries management is often assumed to be a combination of establishing controls on fishing, monitoring the activities of fishers, and enforcing regulations. However, there is an additional component that can be overlooked, but that is increasingly important under modern systems of governance. Where institutional arrangements allow for some degree of co-management (and often even where they do not), the interface between the regulatory authority and the resource user becomes that of a service provider and a client, with the client groups being fishers, decision-makers and the general public. Under these circumstances, fisheries management involves a whole new suite of activities (Pinkerton 2002). Managers are required to consider the aspirations of all users and user groups when setting policies and objectives, and they have to answer questions and handle and reduce conflicts when these occur. Liaison and consultation are an important part of such a management system. Information dissemination, communication and trust facilitate the process of developing working relationships among all interested parties, and good scientific information should underpin the management process (Cochrane 2002).

In the South African situation, where some of the current problems in fisheries management include weak enforcement, perceived poor legitimacy of management authorities, and uncertainties about long-term rights, the development of effective partnerships with users is important. The nature of fisheries management has changed, necessitating new approaches and understanding about the ecosystem, the fishers, and other affected and interested parties. It is easier to make and communicate difficult decisions when people are well informed about what is known and what is not, and where explanations are credible and consistent.

HAS ECOSYSTEM RESEARCH BENEFITED MANAGEMENT?

Ecosystem-based research has yet to be used explicitly in management of South Africa's pelagic fishery. However, such research has contributed substantially to increased understanding of the pelagic ecosystem and the role and position in the ecosystem of the major pelagic species (Shannon and Shackleton 1992, Cury *et al.* 2000). Ecosystem studies provide the context within which management decisions can be made, and such studies are needed to formulate and communicate long-term objectives effectively to all stakeholders. This contextual framework has been useful both to fishery managers and the industry. For managers, knowledge of the biology and ecology of commercially important species such as anchovy and sardine is important for purposes of understanding, providing background to, and explaining to the industry and decision-makers the response of these populations to external factors. Contextual information is also useful to the industry. For example, at a regional workshop held in 1996 to consolidate biological, assessment and management information then available for sardine, a representative of one of the big companies involved in the pelagic fishing industry had the following to say (Barnes 1996, p. 10):

> "In September 1986 the first five years of the [BEP] programme culminated in an international symposium. I would venture to say that this event probably marked the beginning of change in industry's perception of marine science. Well, for one thing we were invited to attend! It was here that industry was exposed to, and got to appreciate, the depth and breadth of the scientific effort, and also the complexity of the Benguela system itself. But most importantly, it was here that industry witnessed the marine scientific community taking a hard and critical look at itself. How purely descriptive biological projects should be incorporated in resource management began to be debated. We were exposed to a new emphasis on quantification and attempts at genuinely modelling the observed realities of the Benguela resources. BEP I pushed marine science up quite a few notches on the industry confidence index and the few industry members who were there carried the message back to the fisheries boardrooms."

Since 1986, the approach to managing the pelagic fishery has evolved, and so too has the relationship with industry. In 1998, members of the pelagic industry admitted to finding the current management approach "extremely complex", and accepted "with difficulty" the application of hydroacoustic survey results (Barnes 1999, pp. 1067, 1068). However, they also called for more attention to be paid to socio-economic inputs in management models, thereby broadening the scope of current management objectives, and suggested that, to accomplish this request, industry and government would have to work together. These sentiments mirror those expressed by Shannon and Shackleton (1992), but there has been limited progress in incorporating socio-economic research into the BEP and its sister programmes. The criticisms by industry of the *status quo* and suggestions for change are revealing in that they illustrate increased involvement by the industry with government scientists, and although that involvement can be antagonistic, it demonstrates the shift from a paradigm of law enforcement by DEAT to one of partnership and collaboration.

In more specific applications of ecosystem research, life history information of anchovy and sardine was used to determine the optimal position, in both space and time, of hydroacoustic surveys aimed at obtaining catch-independent information on population size for management purposes. Spawner biomass surveys were timed to coincide with peak anchovy spawning in November, and were initially largely concentrated on the South Coast. Recruit surveys focused on the West Coast, and were conducted in May/June, sufficiently late in the first-year cycle to ensure that most of the recruits were acoustically detectable, without being too late for the results to be used to regulate the recruit-based anchovy fishery (Hampton 1987). The hydroacoustic surveys have also monitored interannual fluctuations in population levels, a characteristic of anchovy and sardine stocks worldwide (Schwartzlose *et al.* 1999). This has permitted the pelagic fishing industry to take larger catches in years when recruitment has been good and allowed protection of the stock in years of poor recruitment. In essence, the surveys have allowed the adoption of a less conservative management approach for the pelagic stocks than would have been the case in the absence of fishery-independent data, resulting in substantially larger catches for the industry. In 1999 this was estimated to be worth more than R130 million (approximately US$16 million) annually (Barange and de Oliveira 1999).

The management procedures used in the pelagic fishery were developed at a time when there was a relatively good time-series of recruitment estimates, and it was believed that the magnitude of interannual variability in recruitment was fairly well understood. However, in 2000, this understanding was questioned by a bumper recruitment of anchovy, almost an order of magnitude larger than the previous long-term average, and four times larger than the previous maximum estimate. This “anomalous” recruitment was repeated the following year (van der Lingen 2002b), reinforcing the need for long-term data series to be maintained in order to understand and appreciate fully the variability within the ecosystem. It is worrying to local scientists that, after a switch in dominance from sardine to anchovy in the early 1960s that lasted for 25 years, followed by 17 years of steadily increasing sardine biomass and recent huge increases in anchovy, the mechanisms affecting short- and long-term changes are still tantalizingly unclear. This lack of clarity is the basis of two opposing arguments regarding ecosystem research. One states that it will never be possible to understand or predict the variability in recruitment. This school of thought proposes reducing ecosystem research and environmental monitoring, because it is not useful for management purposes. The second argument maintains that it is too soon to expect definitive results and to pronounce success or failure for ecosystem research, because ecological effects on an ecosystem level require long-term datasets. This school of thought opposes any reduction in research and monitoring effort, because it would seriously undermine the value of the existing datasets.

Short-term management objectives for the pelagic fishery necessarily are influenced by recruitment variability. Simulation studies have indicated that a cost-efficient improvement in average anchovy yields is feasible if crude predictions of recruitment strength are correct 70% of the time (Cochrane and Starfield 1992). The approach used in South Africa has been to make current management procedures increasingly robust to the “random noise” that represents recruitment in stock assessment models, rather than to attempt to predict its magnitude for each year. Perhaps expert system models can forecast likely recruitment, but their main use thus far has been to explain in hindsight the large annual variations in recruitment. The expert system approach has not been incorporated into formal management procedures in South Africa, partly because it has been treated with scepticism in some quarters, and partly because of insufficient human capacity. Therefore, the conflict between research into understanding the mechanisms affecting recruitment and simple representations of the statistical expression of such variability has not been resolved by the BEP.

Statistical management measures that are robust to fluctuations in recruitment and that utilize the results of fisheries surveys to adjust *TAC*s are useful for short-term planning, but fail when there are long-term shifts in the ecosystem, and they have limited utility in setting multiple objectives for fisheries management. At the start of the BEP, one of the many rationales for the programme was to help in formulating multiple objectives for management (Siegfried and Field 1981). This goal captures the essence of an ecosystem approach to management, because it forces an explicit recognition that all fished species have ecological roles in the ecosystem. In addition, multiple management objectives should cover both short- and long-term considerations. To date, this goal has not been met in the southern Benguela. However, after more than 20 years of gathering information and synthesizing it in ecosystem models, the process has started. The workshop on “An ecosystem approach to fisheries management in the southern Benguela”, organized by and held under the auspices of the BEP and Marine & Coastal Management (Shannon *et al.* 2004), has introduced the concept of an ecosystem approach to fisheries management to local scientists, and has initiated planning for future activities.

CONCLUSIONS

The collection of a wide range of environmental, acoustic and fisheries data, and the generation of good estimates of spawner stock biomass and recruitment strength are national assets that need to be maintained and strengthened. The BEP has functioned as glue for South African pelagic research, underpinning the management of the major pelagic fisheries in the region (Shannon and Shackleton 1992). The BEP's greatest contribution has been to facilitate strong inter-institutional links, so providing an effective multidisciplinary approach to addressing some of the major problem areas in fisheries. The exchanges of skills and knowledge that took place between academic institutions and the State are non-trivial. The BEP allowed academics and students access to facilities such as research vessels, and through their involvement with government researchers, university students became more attuned to the user-market, and gained valuable experience in practical applications of research and research results, including how to plan and cost projects. The BEP bursaries for postgraduate students attracted much-needed young blood into marine science, when there was little other incentive, and many of the BEP students were (and still are) recruited into the government research and management structures. State scientists perhaps benefited from reduced bureaucracy, but the intellectual interactions during the height of the BEP increased their research productivity and improved staff motivation. On all sides, prioritization and quality control was enhanced by focused and continuous peer-review (e.g. weekly seminars, workshops, symposia).

Interactions with industry were also improved during the course of the BEP. Furthermore, the trust between resource users and the State, including its scientists, is slowly improving, and part of this improvement can be attributed to academic scientists acting as inadvertent intermediaries. Partnerships provide mechanisms for communication, and the BEP made a substantive contribution by introducing important role-players to one another, thereby allowing them to develop interpersonal relationships that helped to develop and strengthen trust. Ultimately, it is hoped that resource users eventually perceive incorrect predictions or interpretations of change on the part of scientists not as management failures, but as an inevitable part of improving knowledge.

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