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Cooperative versus non-cooperative management of shared linefish stocks in South Africa: an assessment of alternative management strategies for geelbek (*Atractoscion aequidens*)

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Abstract

The South African boat-based linefishery is a multi-species fishery with participants broadly divided into commercial (approximately 3000 vessels) and recreational (at least 4000 vessels) components. *Atractoscion aequidens* is an important species which, owing to a migratory lifestyle, is targeted by commercial communities throughout its estimated 2000 km distribution along the eastern seaboard of southern Africa. The national government is responsible for the management of South Africa's marine resources; in the case of the linefishery this is effort-based, with limits on minimum size, daily bags, the number of commercial permits and to some extent operational area. Results from an age-structured model reveal that the South African geelbek stock is heavily depleted, and that long term biological sustainability would require an increase in the current minimum size limit and/or a daily bag limit for commercial fishers. Compliance with regulations and thus cooperation with the responsible management authority is also essential. Cooperative versus non-cooperative management of the South African *A. aequidens* stock is explored using game theoretic bio-economic modelling, which simulates the effects of alternative size limits and effort restrictions on two separate jurisdictions that compete for this common-pool resource. The large number of players (licensees) within the linefishery creates a costly situation in terms of facilitating cooperative management, in spite of the potential greater long term social and economic benefits that such management arrangements can yield. The distribution of the different life-history stages of geelbek among competing interests on the east coast of South Africa exacerbates the problem of facilitating cooperative management, because the short term private economic benefits of non-cooperation exceeds the long term overall economic benefits from cooperative management.

Keywords: Bio-economic analysis; Game theory; Shared stocks; Fisheries management policy

1. Introduction

The South African boat-based linefishery consists of approximately 3000 commercial and at least 4000 recreational vessels (5–20 m in length) which, using rod and reel or hand-line, target more than 95 species

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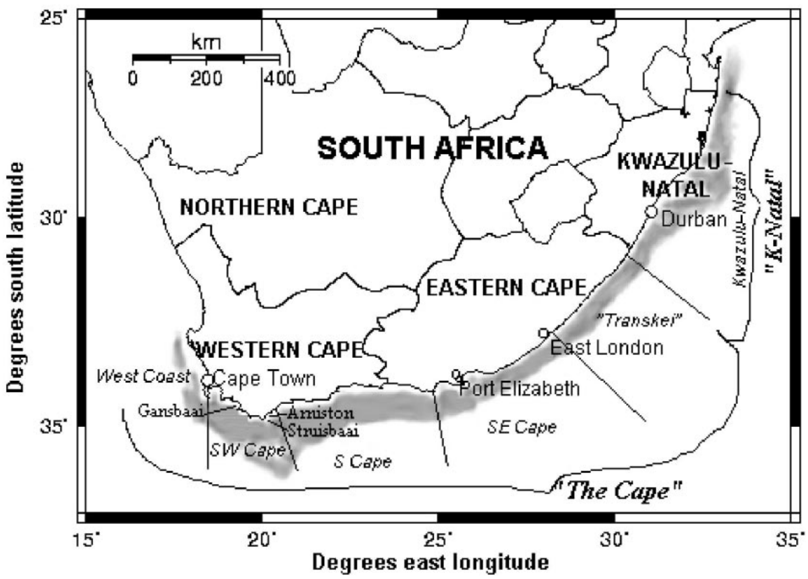

Fig. 1. The distribution of geelbek (*A. aequidens*) along the eastern seaboard of South Africa from the West Coast to northern KwaZulu-Natal (K-Natal). Also shown are the four coastal provinces, the two areas used in this study ("*the Cape*" and "*K-Natal*") and the division of the "Cape" into five regions: the West Coast, the SW Cape, the S Cape, the SE Cape and the Transkei, as used by Griffiths and Hecht (1995) to describe the life history of the species.

of marine teleost (Griffiths, 1997). The geelbek *Atractoscion aequidens*, a medium size sciaenid (maximum size 18 kg; Biden, 1948), has been among the six most important species ever since the linefishery was first established in the 1800s (Penney et al., 1989). It is found along the entire eastern seaboard of South Africa from Cape Town to northern KwaZulu-Natal (Fig. 1) where it exists as three age/size related sub-populations with juveniles (<51 cm) found in the SE Cape, sub-adults (51–87 cm) in the SW Cape and the adults (>90 cm) undergoing an annual spawning migration to KwaZulu-Natal. As a result, the stock is shared by fishing communities throughout its approximately 2000 km distribution. The central government is responsible for the management of South Africa's marine resources, which in the case of the linefishery, is effort-based, consisting of limits on minimum size, daily bags, the number of commercial permits and marine reserves. A recent survey of the boat-based fishery revealed that the fishery enforcement agency is inadequate and that non-compliance with management regulations is high (Sauer et al., 1997). Cooperation is therefore essential for effective management of the linefishery. Current catch restrictions for geelbek consist of a bag limit of 10 fish per day for recreational anglers (introduced in 1984) and a minimum size limit for both recreational and commercial fishers. Therefore fishing effort can be directly controlled either through a reduction in the number of commercial permits or indirectly through the imposition of bag limits. In this study the possibility of effort control is considered, that is how much should fishing effort be reduced or increased, but this is not translated into bag limit reductions or estimates on how many commercial permits should be issued.

A minimum size limit of 40 cm total length (38 cm fork length) was first introduced in 1940, but in the absence of biological information this limit was determined arbitrarily. Based on the large size at sexual maturity for this species (90 cm fork length; Griffiths and Hecht, 1995), the minimum size limit was increased to 60 cm in 1992. The size limit was not set at the size at which 50% of the stock are estimated to be mature, as has been done for other linefish species, as this would have excluded the majority of the catch made in the SW Cape (see Fig. 2). Ever since the amended minimum size limit was implemented, there has been considerable pressure from SW Cape

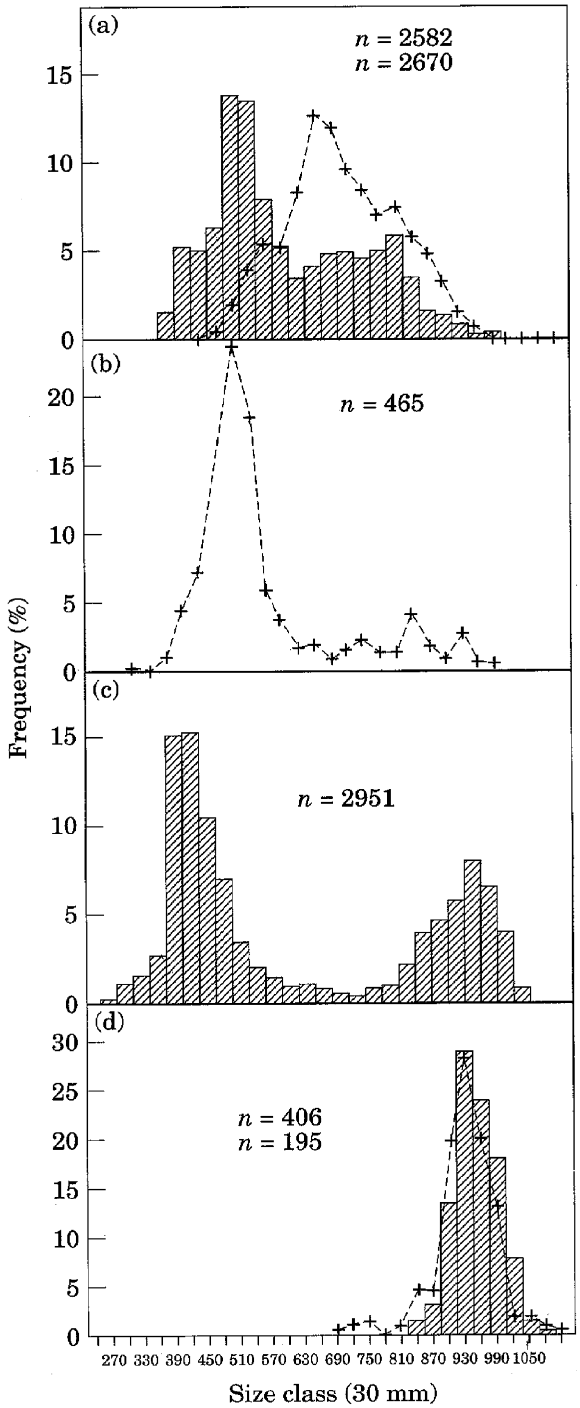

Fig. 2. The fork length–frequency distributions of *A. aequidens* for the periods 1985–1987 () and 1990/1991 (+) in (a) the SW Cape, (b) the S Cape, (c) the SE Cape and (d) Natal (figure from Griffiths and Hecht, 1995).

communities at Arniston, Struisbaai and Gansbaai to reduce it to 55 cm. Given the economic hardship of commercial fishers in these communities (Schutte, 1993; Hutton and Lamberth, 1997), and the fact that geelbek is a high value species (landed value of R10/kg), the resistance to the new size limit is hardly surprising. This was identified as one of the many reasons why the establishment of cooperative management arrangements would be problematic in communities such as Arniston (Hutton et al., 1997; Hutton and Lamberth, 1997). Nevertheless, a smaller size limit is unlikely to be conducive to long-term sustainability and in addition is expected to detrimentally impact on the catches made in regions which are dependant on the adults, e.g. SE Cape and KwaZulu-Natal. Preliminary per recruit analyses indicate that the geelbek stock was already overexploited in 1985 (Griffiths, 1988). In addition, the average catch per boat year has dropped to 2.49% (in the South West Cape), 4.32% (Southern Cape) and 1.46% (in the South Eastern Cape) of historical values (1897–1906) (Griffiths, 2000). This has occurred even though there have been major technological advances such as combustion engines, nylon lines, echo sounders, electronic navigational aids, onboard freezer facilities and larger vessels, all of which have dramatically increased the harvest capacity of modern vessels (Griffiths, 2000).

The objectives of the present study are to:

1. determine the current status of the South African geelbek stock and to develop management recommendations for sustainable exploitation using age-structured models, although since only 10 years of catch data are available it is not possible to undertake a rigorous assessment, rather the aim is to introduce the game theoretic methodology;
2. evaluate the economic impact of the above management recommendations on regions exploiting different life-history stages, i.e. the Cape and KwaZulu-Natal. Use a dynamic bio-economic model to analyse the trade-offs in the short term versus the long term, per size limit, per effort regime, per region (see e.g. Lowe et al., 1991; Djama and Pitcher, 1997);
3. apply game theory to evaluate the consequences of non-cooperation in these two regions (see e.g. Nash, 1951; Munro, 1990; Sumaila, 1997a,b) and

to predict whether user groups would comply with recommendations deemed necessary for sustainable utilization.

2. Methods

The following basic data were used in the modelling exercise which follows:

1. Catch and effort and length frequency data for six statistical areas (areas shown in Fig. 1) for the period 1985–1996.
2. Growth parameters — obtained by fitting the von Bertalanffy growth function, using an iterative least squares procedure (using Microsoft Excel Solver routine with the Newtonian algorithm option), to age-length data ($n = 558$) presented in Griffiths and Hecht (1995) for 1985 and 1986 (Fig. 3).
3. A length–weight relationship ($L = aW^b$, where $a = 8.42 \times 10^{-6}$ and $b = 3.01$) — from Griffiths and Hecht (1995).
4. Estimate of natural mortality ($M = 0.5$) — obtained using Pauly's (1980) empirical equation and an average sea temperature of 16°C.

2.1. Fishery models: virtual population analysis (VPA)

VPA or "cohort analysis" can be used to estimate the magnitude of fishing mortality and the numbers-at-age in a stock from catch data provided M is known (Pitcher and Hart, 1983). An ad hoc tuning procedure was used, that is the model was tuned such that the terminal F's in each year, were set to be equal to the average F for particular age classes in that year (Butterworth et al., 1989). Estimates for $F_{y,a}$ (for each year y and each age a) were solved iteratively using Newton's method for the period 1985–1996. An average instantaneous $F = 0.65\ \text{year}^{-1}$ was obtained by averaging the F's for ages 2–9+ in the terminal year. Fig. 4 shows the average F's for each age class estimated by the ad hoc tuned VPA. This value of $F = 0.65\ \text{year}^{-1}$ was used in the rest of the analysis as the value for the average instantaneous fishing mortality. The numbers-at-age matrix estimated in the ad hoc tuned VPA was used to obtain a stock–recruitment

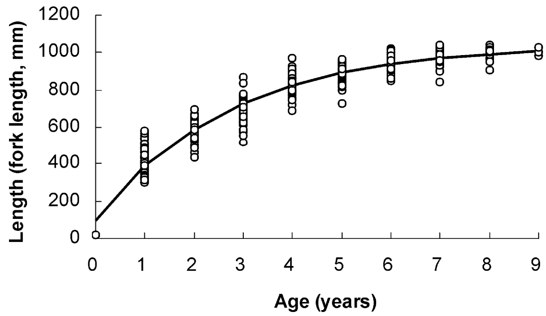

Fig. 3. Mean observed length-at-age and the fitted von Bertalanffy (–) growth curve for *A. aequidens* sampled along the eastern seaboard during 1985 and 1986. The parameters of the growth relationship are $L_\infty = 1.419$ mm, $K = 0.367$ and $T_0 = -0.266$ (where $n = 588$).

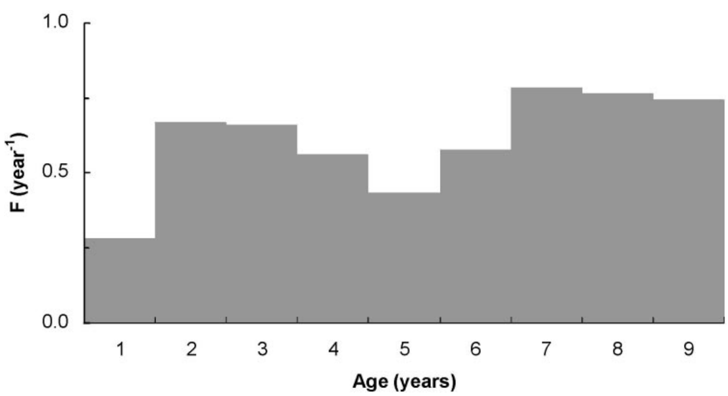

Fig. 4. The estimates of instantaneous fishing mortality (F) for each age from the ad hoc tuned VPA analysis. The age class, age 9 (9), is a plus (+) group.

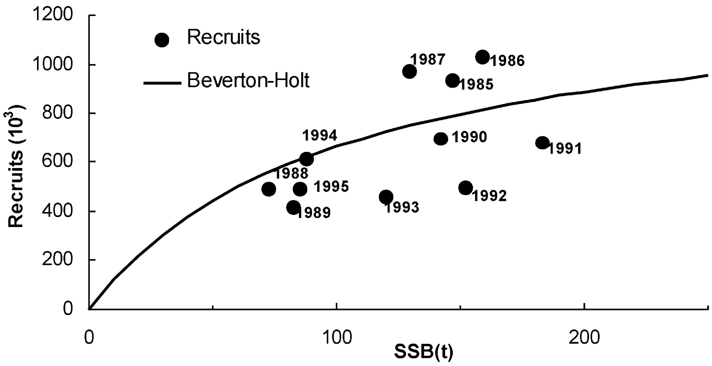

Fig. 5. The Beverton–Holt stock–recruitment relationship (SSB versus recruits) fitted to the VPA estimates of SSB and recruits using least squares. The parameters are $\alpha = 1344515$ and $\beta = 102$.

relationship (fitted by least squares regression) by taking the recruits per year vector at age 1 and total spawning stock biomass (SSB) for ages 5–9+ for the period 1985–1995. The relationship is shown in Fig. 5 and it was used in a forward calculating age-structured model.

2.2. *Yield simulation*

A dynamic pool model was formulated to predict changes in population size and yield under different patterns of selectivity. The aim was to consider changes in the size limit as the current size limit results in an age of capture of approximately 2.25 years (60 cm) whereas age of 50% maturity is 5 years (90 cm) (Griffiths and Hecht, 1995). This approach involves constructing a deterministic age-structured population model which assumes that recruitment is related to SSB. These simple age-structured models include numbers of individuals at each age, age-specific mass, age-specific fishing selectivity, as well as natural mortality rates and stock–recruitment parameters and yield. Generally age-structured models can be written in a variety of different ways. The choices that must be made are whether the fishing and natural mortalities are assumed to be continuous processes acting simultaneously, or separate discrete time events (Hilborn, 1990). The general age-structured model can be written simply as

$$N_{y+1,a+1} = N_{y,a}\,\mathrm{e}^{-(M_a+S_aF_y)} \tag{1}$$

where $N_{y,a}$ is the number of fish of age a at the start of year y and maximum $a = 15$ years, M_a the rate of natural mortality on the fish of age class a, S_a the selectivity of the fishery on fish aged a years $(0 < S_a < 1)$, F_y the fishing mortality for fully vulnerable individuals in year y, i.e. fish with $S_a = 1$ (the year effect for the fishing mortality).

To take age effects into account fishing mortality-at-age ($F_{y,a}$) is separated into an age-component which is common to all years (age-specific selectivity, S_a) and a year-component which is common to all ages within a particular year (year effect of fishing mortality, F_y). This assumption is justifiable if the distribution of fish and fishing vessels does not vary substantially from 1 year to the next, which might be pertinent to any fishery (Punt, 1991). The separability assumption is based on the following relationship:

$$F_{y,a} = F_yS_a \tag{2}$$

where $F_{y,a}$ is the instantaneous rate of fishing mortality on fish of age a during year y.

The spawning stock biomass SBB_y can be calculated as

$$\mathrm{SSB}_y = \sum_{a=m}^{\mathrm{Max}} N_{y,a}P_aW_a \tag{3}$$

where SSB_y is the spawning biomass at the beginning of the year y, W_a the mass-at-age for a fish, P_a the proportion mature-at-age a, m the age at sexual maturity (see Table 1).

It is assumed further that there is a relationship between the spawning biomass SSB_y in 1 year, and the

Table 1
The maturity-at-age vector used in the age-structured model[a]

	Age (years)								
	1	2	3	4	5	6	7	8	9+
Proportion mature	0	0	0	0	0.5	1	1	1	1

[a] The values are based on Griffiths and Hecht (1995) who found that 50% maturity occurs at age 5 (90 cm) and 100% maturity-at-age 6 (95 cm).

average recruitment in the following year (Beverton and Holt, 1957):

$$N_{y+1,1} = \frac{\alpha \mathrm{SSB}_y}{\mathrm{SSB}_y + \beta} \quad (4)$$

where α and β are the stock–recruitment relationship parameters.

Eqs. (1)–(4) define the dynamics of both numbers-at-age and biomass-at-age. The model-predicted catch (or sustainable yield if F is held constant) is

$$C_y = \sum_{a=1}^{\mathrm{Max}} W_{a-} S_a F_y N_{y,a} \frac{(1 - \mathrm{e}^{-(M_a + S_a F_y)})}{M_a + S_a F_y} \quad (5)$$

In the case where alternative scenarios for effort control are simulated for different areas, F_y is computed to be area specific ("the Cape", KwaZulu-Natal) by multiplying F_y, by the proportion of the catch-at-age data for that area versus the catch-at-age data for all the areas (using the data presented in Fig. 2). In order to include stochasticity into the model, a coefficient of variation (COV) of 0.28 was used to add random noise (a normal distribution) to the recruitment function. The COV was calculated from standard deviation and the mean value of the estimated recruitment (from 1985 to 1995). If the COV was computed from the residuals around the fitted stock–recruitment relationship it would lead to an overestimate of the variability in the relationship as only a few years of data are available.

2.3. Selectivity-at-age

The selectivity-at-age vectors for the alternative size limits used is shown in Fig. 6. The values used for each age at alternative size limits were computed from the proportion of that age available to the gear at a particular length and were estimated from the growth curve.

2.4. Bio-economic analysis and predicting game theoretic outcomes

Game theoretic modelling allows for the analysis of strategic interaction between agents (Osborne and

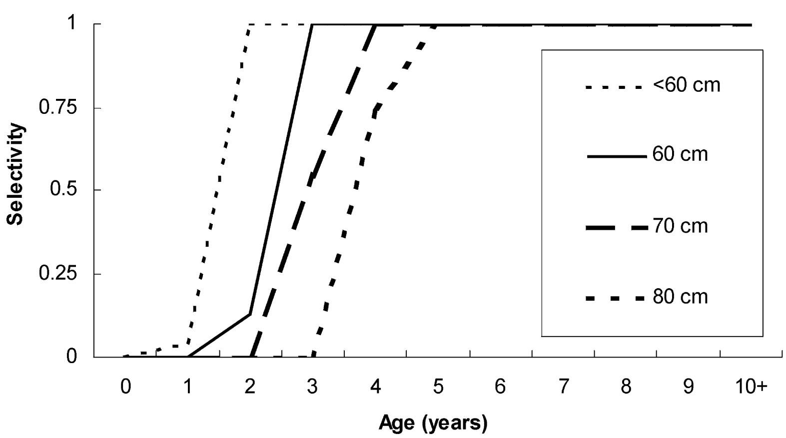

Fig. 6. The different selectivity curves used for the alternative size limits in the age-structured model.

Ruberstein, 1994). As more than one agent typically has property rights to fisheries, game theoretic modelling has been used to consider non-cooperative and cooperative outcomes between agents within alternative fisheries management systems and property rights regimes (Ostrom et al., 1997). A review of game theoretic models of fishing has been undertaken by Sumaila (1999) who notes that only a few attempts have been made to develop empirical game theoretic model of fisheries.

2.4.1. Using non-cooperative game theory

In many fisheries the specific rules for allocation do not exist for scarce resource, thus fishing units compete for access. The outcome of this competition is often negative leading to overfishing, overcapitalization and conflict between interest groups. Non-cooperative game theory (Nash, 1951) allows us to consider the equilibrium outcomes of this competition. Within non-cooperative theory a two-player game suffices as illustrative as it reveals the critical trade-offs for situations where there are greater than two players (Nash, 1953).

Cooperative strategies are used interchangeably with cooperative management throughout this study. This is realistic considering that cooperative management is only possible if participants are willing to engage in binding agreements implying they will behave in a cooperative fashion. Fishers will not enter agreements if the benefits of non-cooperation are much greater than those from cooperation. One can compute the net present value (NPV) of the stream of benefits over the time horizon of the game. The aim is to isolate the negative effects of these non-cooperative strategies by using non-cooperative game theoretic analysis, an approach similar to that applied in Sumaila (1995). Thus the assumption is that binding agreements are not feasible at this stage. For example, in South Africa various interests are in a real competitive situation for rights to the resource. The aim is to isolate the negative effects of non-cooperation (e.g. biological), and evaluate whether there are economic incentives to co-operate or not. This method is presented in Clark (1981, 1990) and for the sake of simplicity the computation is open-loop. Clark's (1981) terminology of "*deplete=non-cooperative*" and "*not-deplete=cooperative*" is used in this study. Fig. 7 is adapted from Clark (1990, presented in OECD, 1997) and is simplified from his two strategies of "*conserve*" or "*deplete*". Furthermore, based on Clark's analysis, the OECD (1997) presents two cases: **Case 1** $B > H/2\delta$ (see Fig. 7).

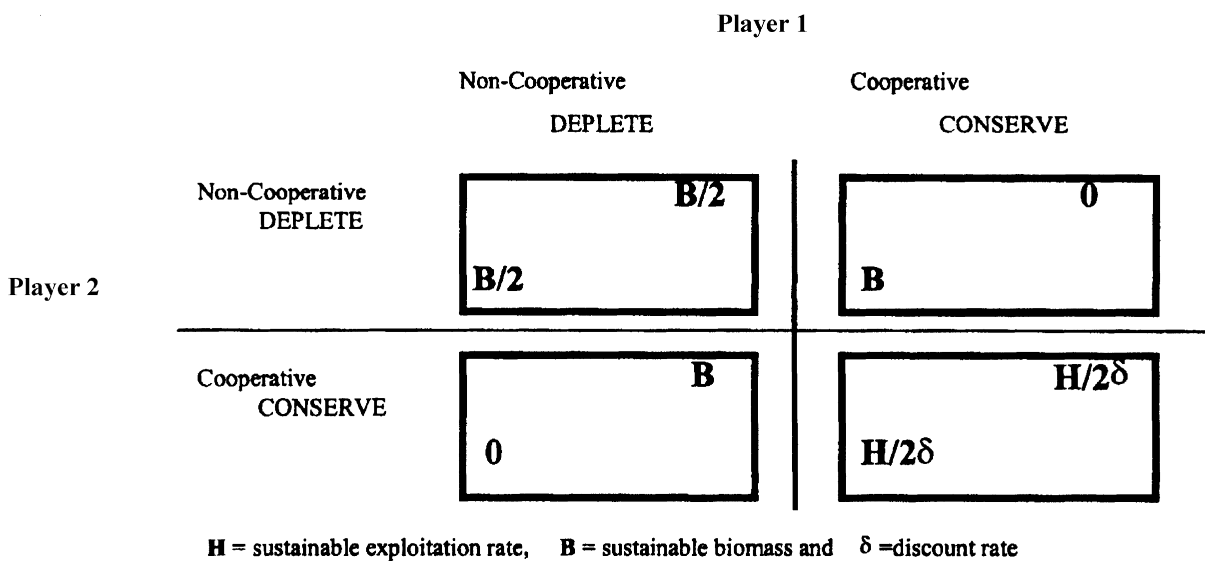

Fig. 7. The theoretical outcomes of a two player model as described by Clark (1990 and presented in OECD, 1997). In each of the four scenarios above, the predicted benefits to Player 1 appear in the top right-hand corner and the predicted benefits to Player 2 appear in the bottom left-hand corner.

When the discount rate (δ) is large, the economic benefits from exploiting at the sustainable rate (*H*) are less than those obtained from depleting the sustainable biomass (*B*) and therefore, larger payoffs are obtained from depletion or non-cooperative behaviour even if others cooperate.

Case 2 $B > H/2\delta$ (see Fig. 7)

There is an incentive to cooperate and conserve (the discount rates are low and there are only a few players). However, if the number of players (*N*) is large then each one receives a payoff of $H/\delta^{*}N$. A ''cheater'' can then achieve a much larger share of *B*, than if he/she cooperates. Thus there are huge incentives to cheat as the number of players becomes large. This is possibly the case for geelbek and the linefishery as there are large numbers of players participating in the fishery (approximately 3000 commercial and semi-commercial fishing units).

Therefore in this case study, two regions are chosen (''the Cape'' and KwaZulu-Natal). The aim is to show the consequences of non-cooperative behaviour by the two regions and to generalize for greater than two players, that is, to postulate why each individual fishing unit decides to cooperate or not. Other studies have considered transboundary stocks — two countries, or two regions or two sectors (Munro, 1979; Sumaila 1997a,b). The present paper is also a two region model, focussing specifically on South African fisheries.

The possible scenarios for alternative management strategies for geelbek are presented in Fig. 8. Here, non-cooperative behaviour is interpreted to imply participants target fish <60 cm, whereas cooperation implies they obey the size limit of 60 cm. An accepted biological reference point (BRP) in stock assessment is the estimated current spawning stock biomass (SSBCURR) as a percentage of the estimated pristine SSB. In the rest of the paper this is referred to as %SSB/SSB(pristine). For effort control, fishers would have to decrease effort by at least 43% under any cooperative management strategies. The value of 43% for a decrease in effort is not chosen arbitrarily, rather this is the effort reduction needed in order to meet %SSB/SSB(pristine) value of 25%, as explained further in this study. The value of 25% is accepted as a threshold (or limit) reference point to lower the risk of stock collapse due to recruitment overfishing by Griffiths et al. (2000). For the effort control option, non-cooperative behaviour implies the participants maintain fishing effort at its current level (i.e. $\mathrm{Fm} = 1$, where Fm is the *F*-multiplier). Lastly, for the combined control, the size limit and effort control scenarios are, combinations of the above size limit and effort control assumptions with regard to non-cooperative and cooperative behaviour, as illustrated in Fig. 8.

2.5. Calculating the PV of revenue

The benefits in the above scenarios are calculated by computing the NPV which depends on the discount rate (δ); a factor that is affected by, amongst other variables, the inflation rate in the economy and the interest rate charged by financial institutions on money borrowed. Here, we calculate the PV of revenue (PVR) rather than the NPV for three reasons. First, it is too difficult to include costs as we are dealing with a multi-species fishery for which obtaining cost estimates for geelbek-directed effort is problematic. Second, McGrath et al. (1997), the only study of this fishery to include costs, presents only average cost per trip for commercial ''ski-boat'' operators coast-wide for all the species. ''Ski-boats'' (typically fibre-glass vessels with outboard motors which are trailer drawn) only represent one type of vessel used in the commercial linefishery which targets geelbek, and therefore it is not appropriate to apply McGrath et al.'s (1997) data to this study. Third, it is accepted that the cost components (e.g. fuel and bait) between the two regions do not differ significantly per kilogram landed. Labour costs may differ between the two regions. However, as fishers receive payment as a share of the landed catch, the cost components for labour between the two regions are similar. Hence, using only prices should give us a good picture of the relative bargaining powers of the two regions. To calculate revenue, the fish prices used were R10/kg in ''the Cape'' and R14/kg in KwaZulu-Natal. The results of the analysis will not be biased by our use of PVR rather than NPV as we have assumed costs are similar in both regions.

The discount rate used in this study is $\delta = 0.1$ (10%), which is high, however it is satisfactory for South Africa, as the South African economy is an emerging market in the world economy with an inflation rate on basic food items in the region of

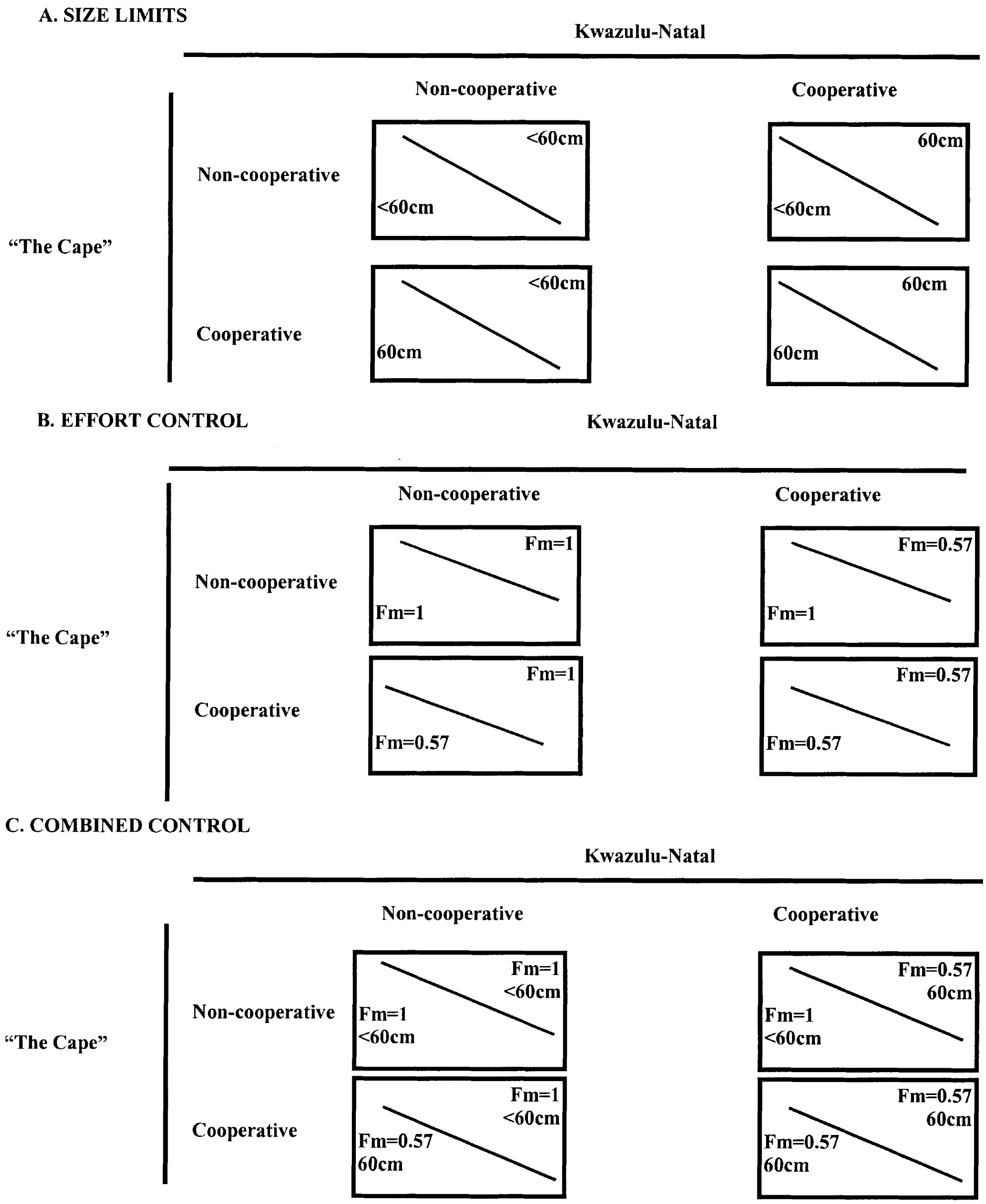

Fig. 8. The three alternative control methods considered in the analysis of management scenarios for the geelbek stock off the coast of South Africa: (A) size limits, (B) effort control and (C) combined control. In each scenario, the assumed choices made by Player 1 (KwaZulu-Natal) appear in the top right-hand corner and the assumed choices made by Player 2 ("the Cape") appear in the bottom left-hand corner. The choices include size limits (cm) or the factor (Fm) that fishing effort must be reduced by (see Eq. (6)).

10% and a prime interest rate on money borrowed of 18% (June 1999). The sensitivity of the results to a range of discount rates were tested (i.e. 5, 10 and 15%).

3. Results

The total catch (in this case reported landings) along the South African coastline for the period 1985–1997

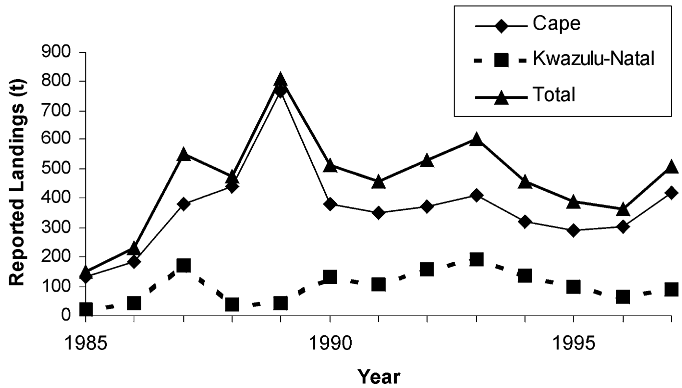

Fig. 9. The total catch along the South African coastline for the period 1985–1997 as well as the contribution from "the Cape" (the West Coast, the SW Cape, the S Cape, the SE Cape and the Transkei) and KwaZulu-Natal.

as well as the contribution from "the Cape" and KwaZulu-Natal are shown in Fig. 9, however this does not indicate to us what the current status of the stock is. The most relevant factors in stock assessment, apart from uncertainty, are the predicted sustainable yields of a stock under different effort regimes and/or size limits, and the current status of the stock. The stock status is especially important in the case of geelbek because this fish is exploited prior to maturity and is consequently vulnerable to recruitment overfishing — 50 and 100% maturity attained at 5 and 6 years, respectively (Griffiths and Hecht, 1995). Spawner biomasses of 25 and 40% of SSB(pristine) have recently been accepted as reasonable threshold and target reference points for linefish species, respectively (Griffiths et al., 2000). Since the estimated current spawner stock biomass is low and exact magnitude is an estimate with considerable uncertainty (see below), it was assumed that the initial management goal would be to rebuild the stock to the 25% SSB/SSB(pristine) threshold level as soon as possible.

Thus, the age-structured model was run under different scenarios, the aim being to achieve on average the threshold value of 25% for %SSB/SSB(pristine). Fig. 10 shows a typical run where the variation is due to stochasticity in recruitment. In order to obtain probabilities for %SSB/SSB(pristine) value approaching the 25% criterion over a 40 year period, the model was run at least 40 times until the estimate for the probability value stabilized, that is until the standard deviation of the sample was very low.

3.1. Biological model results

Fig. 11 shows the results for the alternative scenarios. Reductions in the size limit or reductions in effort results in an increase in the long term %SSB/SSB(pristine). At first, a scenario with an effort reduction of 25% was run ($\mathrm{Fm} = 0.75\,\mathrm{year}^{-1}$) (Fig. 11). However, the only scenario that achieves a probability value of 0.5 (for the 25% SSB/SSB(pristine) criterion), is the case in which there is both a size limit and effort control, in this case a legal size limit of 60 cm and an effort reduction coast-wide of 43%, that is, $\mathrm{Fm} = 0.57\,\mathrm{year}^{-1}$ (the average of 200 runs) where

$$F_y = \mathrm{Fm} * F \tag{6}$$

and since $F = 0.65\,\mathrm{year}^{-1}$, the value of $F_y = 0.37$ year^{-1} (see Fig. 11).

Another way of visualizing the effect of alternative scenarios for the management of the geelbek stock is to consider sustainable yield under an equilibrium model (the recruitment variability is removed) for different levels of fishing effort and size limit control. The results are shown in Fig. 12. A higher yield can be obtained if the fishers obey a size limit of 60 cm. The estimated current low stock levels are supported by trends in CPUE (the historical trends mentioned in Section 1). It is predicted that there will be a 265 ton increase in sustainable yield if the size limit is obeyed and a 333 ton increase in the sustainable yield if there is a reduction in effort and the size limit is obeyed. The fishing mortality for different BRPs and the current status of the geelbek stock are shown in Table 2.

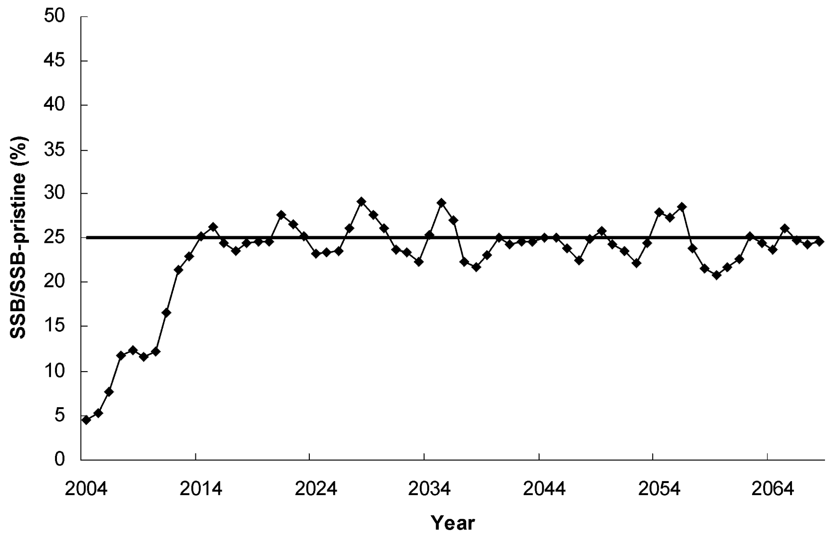

Fig. 10. A typical trajectory of the SSB as a percentage of SSB(pristine) (%SSB/SSB(pristine), from the predictions of the age-structured model for the years 2004–2068. In this case the size limit is 60 cm and the effort in the entire fishery has been reduced by 43%. The horizontal line shows the threshold value (25% SSB/SSB(pristine)).

In Table 2, the SSBCURR as a percentage of SSB pristine, provides us with a measure of stock status, since geelbek have a late age at maturity which has to be considered. The other factors to consider are fishing mortality at MSY (FMSY), the fishing mortality at a spawning biomass of 25% of pristine (FSB25) and the fishing mortality at a spawning biomass of 40% of pristine (FSB40), as these have been accepted as the default threshold and target levels by Griffiths et al. (2000). At a 60 cm size limit, the FMSY $\gg$ FSB25 or FSB40, implying that in order to reach FSB25 (the threshold) or FSB40 (the target), the sustainable yield is estimated to be less than MSY. An increase in the size limit to 80 cm implies FSB25 can be obtained at the current fishing mortality (FCURR), but this would have significant impacts on “the Cape” in the short term as indicated in the bio-economic model.

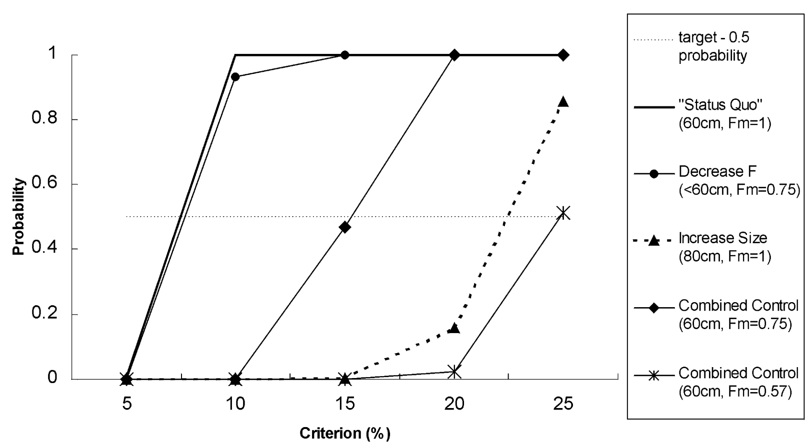

Fig. 11. The probability of the SSB as a percentage of SSB(pristine) (%SSB/SSB(pristine)), being below the criterion chosen (5, 10, 15, 20 or 25%) for alternative scenarios. Fm is the factor that fishing effort is reduced by (see Eq. (6)).

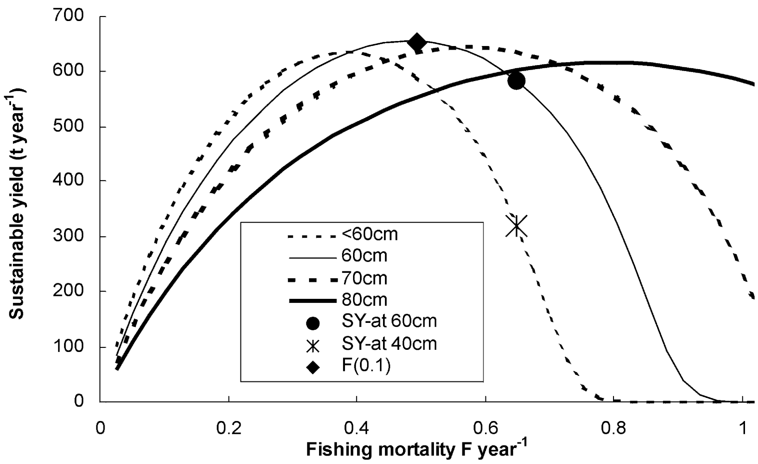

Fig. 12. The sustainable yield (SY) for different size limits (<40, <60, 60, 70 and 80 cm) versus fishing mortality (F) for the geelbek stock for alternative size limits. Also shown is $F(0.1)$ for a 60 cm size limit ($F(0.1)$ is the fishing mortality rate which is 10% of the fishing mortality rate when F approaches the limit, $F = 0$).

3.2. Bio-economic simulations

Bio-economic results were computed for the three different control measures mentioned earlier and expressed as sustainable yield (SY at equilibrium), PVR (long term: 70 years), PVR (short term: 5 years) and the short term (5 year) average catch. The only result which is presented for all three control measures, to illustrate the trade-offs, is the PVR (short term: 5 years). Thus in Table 3, the PVR (short term), is shown for size limit control (row 4), effort control (row 5), and combined control (row 6). Table 3 also illustrates the results for all the output variables for size limits (row 1–4). This is done to illustrate the differences and similarities between the output variables expressed in the results, and to indicate that the

Table 2
The fishing mortality for different BRPs and estimated current status of the geelbek stock off South Africa: SSBCURR (current SSB as a percentage of unexploited levels); FMSY (fishing mortality at maximum sustainable yield (MSY)); FSB25 and FSB40 (the fishing mortality at a spawning biomass of 25 and 40% of pristine, respectively); $F(0.1)$ (the fishing mortality rate which is 10% of the fishing mortality rate when F approaches the limit, $F = 0$); FCURR (current fishing mortality); BCURR (current biomass as a percentage of pristine biomass)

BRP	Size limit		
	40 cm	60 cm	80 cm
(1) FSB25 (threshold)	0.30 (46% FCURR)	0.37 (57% FCURR)	0.60 (93% FCURR)
(2) FSB40 (target)	0.20 (31% FCURR)	0.25 (39% FCURR)	0.4 (61% FCURR)
(3) $F(0.1)$	0.36 (56% FCURR)	0.44 (68% FCURR)	0.65 (100% FCURR)
(4) FMSY	0.39 (60% FCURR)	0.49 (76% FCURR)	0.78 (120% FCURR)
Current status[a]			
(5) FCURR	N/A	0.65	N/A
(6) SSBCURR[b]	2.0%[c]	6.7%[c]	N/A
(7) BCURR	N/A	9.5%	N/A

[a] Status in 1999 depends on situation in 1997 and 1998 — did some places still land fish smaller than 60 cm? Model projects forward for 1997, 1998 and 1999, etc.

[b] Estimates from VPA (data: 1985–1996) give mean of 2.3% of pristine. In 1980's fish <40 cm were landed.

[c] Thus if the 60 cm size limit has been obeyed (circa. 1996–1999) the current status of the resource is between 2.3 and 6.7% SSB(pristine), if not (i.e. landed fish are <60 cm), it is between 2.0 and 2.3% of the pristine SSB.

Table 3
The results from the model for six alternative scenarios in terms of changes to the output variables (sustainable yield, the present value of revenue (PVR, 70 years), PVR (5 years) and the short term (5 year) average catch) to each region that targets geelbek in the linefishery[a]

Control	Measure	Outcomes	Non-cooperation	Cooperation	Only the Cape co-operates	Only KwaZulu-Natal (K-Natal) co-operates
(1) Size limit	Sustainable yield	Total yield (ton)	316 ± 30	587 ± 45	582 ± 45	315 ± 29
		Yield to the Cape	302	539	537	301
		Yield to K-Natal	14	47	46	14
(2) Size limit	PVR (70 years)	Revenue (rand millions)	22.7 ± 1.6	31.4 ± 1.7	31.6 ± 1.8	22.5 ± 1.6
		Revenue to the Cape	21.5	28.4	28.6	21.3
		Revenue to K-Natal	1.2	3.0	3.0	1.2
(3) Size limit	Average catch (5 years)	Total yield (ton)	186 ± 15	156 ± 13	157 ± 13	185 ± 15
		Yield to the Cape	178	146	147	178
		Yield to K-Natal	8	10	10	7
(4) Size limit	PVR (5 years)	Revenue (rand millions)	7.2 ± 0.6	6.0 ± 0.5	6.0 ± 0.5	7.2 ± 0.6
		Revenue to the Cape-	6.8	5.5	5.5	6.8
		Revenue to K-Natal	0.4	0.5	0.5	0.4
		%SSB/SSB(pristine)	*1.9%*	*6.7%*	*6.6%*	*16.6%*
(5) Effort	PVR (5 years)	Revenue (rand millions)	7.2 ± 0.5	6.2 ± 0.5	6.0 ± 0.5	7.2 ± 0.5
		Revenue to the Cape	6.8	5.6	5.3	7
		Revenue to K-Natal	0.3	0.6	0.7	0.2
		%SSB/SSB(pristine)	*1.9%*	*10.1%*	*13.9%*	*2.8%*
(6) Combined	PVR (5 years)	Revenue (rand millions)	7.2 ± 0.5	4.4 ± 0.4	4.7 ± 0.4	7.2 ± .05
		Revenue to the Cape	6.8	3.9	3.9	7
		Revenue to K-Natal	0.3	0.5	0.8	0.2
		%SSB/SSB(pristine)	*1.9%*	*24.7%*	*20.5%*	*2.8%*

[a] The mean number is shown for each outcome (cooperative versus non-cooperative) as well as standard deviation for the totals for each outcome ($n = 200$ simulations). The %SSB/SSB(pristine) is shown in italics.

PVR (short term: 5 years) suffices as a output variable to show the consequences of non-cooperation in terms of the gains in revenue over the next 5 years.

If we consider non-cooperation versus cooperation for size limit control in terms of the long term sustainable yield (Table 3, row 1), it is clear that the long term benefits of cooperation are greater. The biological objectives are not met, however, the %SSB/SSB(pristine) is a higher than under non-cooperative management ($6.7 > 1.9\%$). This indicates that the current size limit regulations will not in themselves suffice to meet the biological objectives. Note that, due to the occurrence of adults in KwaZulu-Natal, the region is not affected to the same degree as ‘‘the Cape’’ by the effect of size limit control. In stark contrast, when the PVR (short term) or the short term average catch (for size, effort or combined control) is calculated, the benefits of non-cooperation are much greater than those from cooperation in all cases.

In fact the economic benefits are a gain of R1.2 million from non-cooperation versus cooperative management (R7.2 − R6 million) for size limit control in the short term. The only scenario which achieves the government target of greater or equal to 25% SSB/SSB(pristine) is the case where there is combined control (size limit and effort control) and there is cooperation between the parties. In this case a value of 24.7% SSB/SSB(pristine) is obtained. Therefore, for a 23% (i.e. 1.9–24.7%) increase in the average %SSB/SSB(pristine) our model estimates that it will cost the government R2.8 million just for geelbek (R7.2 − R4.4 million, Table 3, row 6).

This value of R2.8 million depends on the chosen discount rate. In Table 4, the relationship between discount rate and the benefits due to non-cooperative strategies are shown. It indicates that it will cost the government less the higher the discount rate of the participants, which is at first counter-intuitive, but on

Table 4
The relationship between discount rate and the additional rent (Rand millions) for a 5-year period (1998–2002) due to non-cooperative management

Discount rate (%)	Rand millions
5	2.949
10	2.741
15	2.442

further reflection, occurs because the participants get less in the future as the discount rate increases and therefore the opportunity cost of changing their practices is lower.

4. Discussion

The objectives of this analysis were to evaluate the status of the stock and consider what size limit and/or effort restrictions would allow the stock to re-build. The stock is estimated to be below 3% SSB/SSB(pristine) based on the assumptions of the ad hoc tuned VPA (see Table 2). Game theoretic modelling was used to evaluate outcomes of assumed non-cooperative versus cooperative management of fishers in the two regions (as juveniles and sub-adults occur in the Cape whereas adults can be found in KwaZulu-Natal waters). The model results show that if the only consideration is the SSB criterion then combined control (size limit and effort control) will suffice, but only if there is cooperation between the fishers in these regions. One future option is to apply a cooperative game theoretic analysis as in other studies which assume that binding agreements are feasible (see e.g. Amstrong and Flaaten, 1991; Kaitala and Munro, 1993; Lewis and Cowens, 1982; Munro, 1979, 1987, 1992, 1994, 1996; Sumaila, 1997a; Yeto et al., 1997). However, the large number of participants and extensive scale of this common-pool resource result in a situation where the establishment of binding agreements are problematic thus the approach used in this study (non-cooperative game theory) can be used in similar situations to evaluate the economic incentives users are faced with.

The paper shows that there is an economic gain of R1.2 million over the 5-year period when we simulate cooperative versus non-cooperative management for size limit control, thus allowing one to postulate why each individual fishing unit decides on non-cooperative strategies rather than cooperative strategies. It is not in their short term economic interests to conserve the resource or to cooperate. Long term benefits do exist, but high interest rates in South Africa only exacerbate the situation and create a Case 1 situation as defined by OECD (1997). Thus short term economic factors impose major constraints on the potential for co-management of marine resources in South Africa. The large number of participants further exacerbates the problem (Case 2, see OECD (1997), where $N \geqslant 1$) as any government wishing to co-opt fishers into obeying regulations and not cheating, would have to cover transaction costs, and/or mandate lower interest rates, and/or make transfer payments (pay fishers not to catch fish). Thus, in terms of its descriptive power, the study shows that if the government insists on its biological objective, then enforcement costs will be very high. The only scenario that meets the government target of 25% SSB/SSB(pristine) is a 60 cm size limit and 43% decrease in effort. The model predicts that it will cost the government R2.8 million to achieve this. If the discount rate is low this value increases, which is at first counter-intuitive, but this occurs as the stock is close to depletion and the greatest economic benefits can be obtained through a rapid depletion strategy. Considering the present status of stock, at the very least, the 60 cm size limit should be strictly enforced even if there is no decrease in effort.

Thus, in summary, any inclusion of users in a co-management arrangement is not only dependent on the political reality in South Africa, that is, the willingness and ability of the government to share decision-making power, but also on the economic circumstances the participants operate within. Although this is an illustrative example, it is postulated that all shared stocks (most of the linefish species) suffer from the same constraints. It is likely, therefore, that many South African fishing communities are subject to the same economic incentives, thus threatening the long term sustainability of these marine resources. Management policies which ignore economic incentives will fail unless policies are incentive "adjusting". It is assumed that incentives can be "adjusted" to result in positive outcomes when the rules governing participation (i.e. rights) and the allocation of benefits for shared stocks are well defined and constrained. Otherwise the consequences of unfettered competition for access to scarce marine resources will result in their depletion.

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