8 A BRIEF OVERVIEW OF CURRENT BIOECONOMIC STUDIES OF NAMIBIAN FISHERIES

Ussif Rashid Sumaila and Stein I. Steinshamn[*]

Abstract

This contribution provides an overview of bioeconomic studies of Namibian fisheries available in the literature, and then lists interesting research ideas that are waiting to be explored. We found that there are very few papers in the literature that study the bioeconomics of Namibian fisheries. In all, three types of papers are present in the literature, namely, those that look at the bioeconomics of hake stocks; a few that develop bioeconomic models of Namibian sardine; and one paper that explores the economics of Namibian fisheries in an ecosystem context. Clearly, there is a severe lack of bioeconomic studies to support the optimal, sustainable management of Namibia's fisheries. The overview also revealed the need for bioeconomic models to support the transboundary management of the shared stocks in the Benguela Current Large Marine Ecosystem.

INTRODUCTION

The objective of this chapter is to briefly give an overview of the few bioeconomic models that have been developed to study the fisheries of Namibia. Bioeconomic models have been used extensively by fisheries economists since 1954 when Gordon published his seminal paper (Gordon, 1954) to help fisheries managers decide the amount of fishing effort (and therefore total allowable catches) to exert on fish stocks in order to maximize economic rent. Gordon's work was followed by works by Scott (see, Christy and Scott, 1965 and Hannesson, 1993), to mention but a few, that helped to spread the application of bioeconomic models and the results derived therefrom in the management of fisheries. Most of the models have been applied to analyze fisheries located in the economically more developed countries of the world. Hannesson (1983), Steinshamn (1992); and Sumaila (1995) are examples of

* Sumaila thanks the Research Council of Norway, the Sea Around Us Project and the Pew Charitable Trusts for their support.

applications of bioeconomic models to study the fisheries in the Barents Sea; Clark and Kirkwood (1979) is an application of bioeconomics to the Gulf of Carpentaria prawn fishery.

Bioeconomic models that study fisheries in the less developed countries of the world, such as Namibia, are rare. However, a number of other economic papers are more common. Two examples are (i) work on natural resource accounting (Lange and Motinga, 1997; Manning and Lange, 1998; Lange, 2000), and (ii) work on the valuation of recreational fisheries (Kirchner *et al.,* 2000; Zeybrandt and Barnes, 2001; Sumaila, 2002).

In the next section we present bioeconomic models of Namibian hake. This is followed by an overview of bioeconomic models of Namibian sardine. Key elements of an ecosystem-economic model of the Benguela current ecosystem, which supports the Namibian Exclusive Economic Zone (EEZ), among others, are then presented. Finally, a discussion of potential research areas is given.

THE HAKE BIOECONOMIC MODELS

This section of the chapter summarizes work published in Sumaila (2000, 2001). These two papers addressed the question of which of the two main vessel types used to exploit hake, that is, wetfish and freezer trawlers, should harvest what proportion of Namibian hake, given Namibia's fisheries policy objectives? Sumaila (2000) addresses this question after the total allowable catch (TAC) for hake has already been decided (the 'after-TAC' analysis). In other words, the determination of the TAC for hake is exogenous to the analysis. The second paper, on the other hand, develops a full-fledged bioeconomic model in which both the biology of hake, and economics of the fishery are endogenous to the model (the 'before-TAC' analysis).

Why are these studies interesting? First, the fishing sector is an important part of the economy of Namibia, with the hake fishery being one of the main contributors to the sector. It has been estimated (by the Ministry of Fisheries and Marine Resources of Namibia, MFMR) that hake contributed about 7.4 per cent of Namibia's estimated exports in 1994, and contributed about N$ 951 million to Namibia's GDP in 1997 (MFMR, 1997).[1] It should be noted that these figures include only the direct contribution to GDP; additional contributions from secondary industries and the multiplier effects of spending hake-related incomes are not included. Secondly, before Namibia became independent in 1990, freezer trawlers have been the dominant vessels employed in the harvesting of the hake stock in the Namibian Exclusive

[1] One US$ was equivalent to about N$7.07 in March 2004.

Economic Zone (EEZ). Namibia saw its rich fishery resources as one of the vehicles available to it for the badly needed economic development of its people. Hence, the country took an important fishery policy decision that called for the restructuring of the trawler fleet in favour of wetfish trawlers. Third, because of the difference between the two vessel groups both in economic and biological terms, determining the optimal proportion of the hake TAC that should be landed by the two vessel types is not trivial.

In 1992 wetfish trawlers landed only about 5 000 tonnes out of a total reported hake landing of 87 498 tonnes. The announced government policy with respect to the allocation of the TAC between the two fleet groups is that 20%, 40% and 60% of it should be allocated to the wetfish trawlers in 1993, 1994 and 1995, respectively. The ultimate aim is to maintain an allocation of 60:40 in favour of the wetfish trawlers into the future. Performance against stated objectives has been quite good up to 1994: in 1993, 19.9% of the TAC was allocated to wetfish trawlers. The corresponding allocation for 1994 was 48.9%, well over the target of 40%. However, the target of 60% could not be achieved from 1995 to 1998, mainly because there was no increase in the TAC in these years. One reason for the decline of the wetfish trawler share of the TAC was that the biomass of Cape hake, which forms the basis of the wetfish catch, was decreasing during this period (Dave Boyer, pers. comm.). Progress in this direction is again being made given the recent upswing in the total allowable catches approved by the Minister of Fisheries and Marine Resources (see Oelofsen, 1999).

The main reason for committing to the above policy is to encourage onshore processing, and thereby reap benefits such as increased employment for workers from the north of the country. This move would make companies process their catch on land in Namibia to encourage the development of value-added fish products by the country. In this way, the country hopes to ensure participation in the fishery by Namibians, with the attendant positive effect on their economic welfare.

Interesting questions to ask here are, is this new policy economically rational; if not, are there any reasons other than economic that may justify this move? For example, is it the case that the gains in employment due to the restructuring can compensate for the resulting economic loss, if any?

The principle underlying the work from which we report here is *economic efficiency*, in other words, it is assumed that the primary objective is to harvest and process the stock in the most economically efficient manner. Notwithstanding the Namibianization policy of the Ministry of Fisheries and Marine Resources, this assumption appears to be reasonable in the case of Namibian fisheries, which unlike the fisheries of most developing countries, are mainly industrial.[2] Thus, most of the complications that usually arise due to the community-based nature of certain fisheries are simply not present here. There is, therefore, an excellent opportunity for pursuing and, indeed, achieving economically optimal management of the resources of the Namibian EEZ. Moreover, the results computed are meant to serve as benchmarks for determining the trade-offs between different government policies: we should, for instance, be able to discover what is being sacrificed in economic terms due to a government policy that is geared towards increasing Namibian employment in the industry (see Armstrong *et al.*, this volume), as against one based purely on economic efficiency criteria.

In more concrete terms, the study sought to: (i) test the government TAC allocation policy target of 60:40 for the wetfish and freezer trawlers, respectively, to see if it is optimal in an economic sense,[3] (ii) determine what discounted economic benefit would accrue to society at large under the optimal allocation regime, (iii) find out the optimal number of both wetfish and freezer trawlers needed to achieve these objectives, and (iv) look at the employment-generating capacities of the wetfish and freezer trawlers. The trade-offs between the economic gains and the employment-generating capacities of the two classes of vessels are also discussed.

WETFISH VERSUS FREEZER TRAWLERS: THE AFTER TAC ANALYSIS

In the after-TAC analysis, the objective was to determine the proportion of an already decided TAC that should be landed by the wetfish and freezer trawlers, respectively. In addition, the specific questions listed under the introductory section are addressed using the analytical framework outlined below.

Method

A typical freezer trawler is usually larger than a typical wetfish trawler. It fishes in deeper waters, probably catching larger and more valuable fish. In addition, it can stay offshore for longer periods than the wetfish trawler. The freezer trawler is equipped fully for catching, freezing and packaging at sea.

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2 Although small coastal communities caught fish in coastal lagoons during pre-colonial times, the only indigenous fishing tradition amongst the peoples of the interior was freshwater fishing in the streams and rivers of the north.

3 By an optimal quota allocation we mean the allocation that would maximise the social planner's, that is, the Namibian government's overall economic benefit from the resource.

Therefore, all the processes needed, from actual harvesting to packaging in readiness for export, are undertaken offshore.[4]

The following assumptions underlie the analysis in Sumaila (2000):

- Annual TACs are assumed to be optimally and exogenously determined by the MFMR. Hence, this study does not seek to give advice on what the optimal TAC for hake should be, but rather on what percentage of the decided TAC should be harvested by the wetfish and freezer trawlers, respectively.
- It is assumed here that there are no interactions between the two agents at the market-place. This assumption is reasonable because the agents sell their landings at competitive markets where prices are exogenously determined.
- It is further assumed that there are no significant natural interactions between the hake species and others. This implies that externality, due to say, predator-prey relations, is ignored. Given the lack of adequate studies on interspecies interactions between the species living in the Namibian EEZ, this assumption is considered to be a pragmatic one, which will be relaxed as more biological information becomes available.
- The model is deterministic in the sense that all parameters of the model are assumed to be known with certainty. Also, future TACs are assumed to be known. Clearly, these are strong assumptions. In the case of future TACs, for instance, we know that yearly allocations are based on both scientific knowledge concerning the biomass of hake and policy-related considerations, both of which vary from year to year. In general, the MFMR has a policy of limiting the variability of TAC to an increase of no more than 5% and a decrease of no more than 10% in any one year. A future task would be to introduce uncertainty into the model.[5]

Input data, constraint and objective functions. - The assumption of no interaction at the market-place necessarily implies that both wetfish and frozen fish are supplied at given prices, implying that the price the fishermen receive for their produce is inelastic to the quantities of fish they supply to the market. It

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4 One major difference between wet and freezer trawlers is that to a large extent they target different species. The wetfish trawlers target shallow-water hake (*Merluccius capensis*) while the freezer trawlers catch deep-water hake (*Merluccius paradoxus*). It is worth noting that the incorporation of this information could have affected the results of this analysis. Similarly, the cannibalistic nature of hake, which is not explicitly incorporated in this paper, needs to be included in future studies.

5 In the meantime, the model is designed to be flexible enough to allow quick sensitivity analysis, making it possible to vary important parameters as new information flows in.

should be noted that the main market for Namibian hake is Spain. This is a large international market supplied by many other sources, of which Namibia is only one of many suppliers. For Namibia, or any of the other suppliers, to be able to influence the market price, one of two things will have to happen. The supplier will have to withdraw from the market a large proportion (if not all) of its output, or else there has to be a sudden large increase in its supply to the market, both of which are unlikely to happen under normal conditions.

Modelling the cost of landing hake. - In general, two types of costs can be identified depending on whether one is talking about the costs directly incurred by the agents in the model, that is, *private costs* or costs incurred by society as a whole, that is, *social costs.*[6] Usually these two are not identical because of distortions in market prices and/or costs. As the focus of this study is on the benefits to society as a whole, the study applied social costs.

The production and profit functions. - In both theoretical and applied fishery economics, it is common to assume that the production (harvest) function depends on the stock size or biomass, the vessel efficiency (that is, the catchability coefficient) and the number of vessels taken out to fish in a given period. The underlying idea is that, other things being equal, the ability to harvest fish at any point in time is proportional to the biomass available in the habitat. This is particularly so in the case of non-schooling species such as hake.[7] The profit accruing to a given vessel group in any given year is the total revenue from fishing less the total cost of fishing in that year.

Stock dynamics and constraints. - The stock constraint in this model comes in the form of the TAC fixed annually by the government. The players are free to maximise their profits from the fishery so long as their combined harvest does not exceed the TAC. Given the assumption that TACs are optimally determined to ensure the long-term survival of the stock, they implicitly ensure that the underlying stock dynamics and constraints are respected all the time.

The social planner's objective. - It is assumed that the objective of the social planner, that is, the Ministry of Fisheries and Marine Resources of Namibia,

6 It is the government that is concerned about these costs; private agents would usually be concerned with only their private costs.

7 It should be noted that even though not a schooling species such as sardines, it also aggregates into less dense shoals.

is to choose a sequence of TAC shares, $\zeta_{i,t}$ (t=1,2, .. ,T), to obtain the highest possible discounted profit from the TAC, using social costs and prices.

Results and Discussion

The data required on the Namibian hake fishery to numerically implement the model presented above were collected and/or calculated (Sumaila, 2000), and the algebraic modelling language AMPL (Fourer *et al.,* 1993) was used as computational aid. The key results obtained are presented below (see Sumaila, 2000 for details).

The total present value of economic rent from the resource given the government target of 60:40 allocation of the annual TAC to *w* (wetfish trawlers) and *f* (freezer trawlers) is *N$*10.42 *billion*. On the other hand, the economically efficient allocation turns out to be 100:0 to *w* and *f,* respectively. This allocation results in a total present value of economic rent of *N$*11.69 *billion*. Thus, the economic loss due to the implementation of the current government target rather than the economically optimal share is *N$*1.27 *billion*, about 11% of what is achievable.

In terms of employment generation, more allocation to the wetfish trawlers is a good thing, as this class of vessels generates more than six times the employment generated by the freezer trawlers for the same TAC allocation. It is possible to generate a total of up to 7 800 positions of various kinds annually from the activities in the hake fishery if the optimal solution is implemented (Sumaila, 2000).

The fleet size necessary to land the optimal allocation of the TAC is 53 wetfish trawlers of size class 1400-2000 HP or their equivalent. In the case of the declared government policy of 60:40 allocation, the necessary fleet sizes of both wetfish (size class 1400-2000 HP) and freezer (size class 1500-1999 HP) trawlers are 32 and 13, respectively.

Based on the results outlined above, one may come to the conclusion that the freezer trawlers should be banned from the exploitation of hake altogether: both economic efficiency and employment generation criteria support this change. There are, however, other issues to be taken into consideration. First, we should be interested in benefiting from certain intrinsic advantages of harvesting hake with freezer trawlers. An advantage of the freezer trawlers (but a disadvantage of wetfish trawlers) which needs to be taken into account is the fact that generally freezer trawlers fish in deeper waters than their wetfish counterparts, thereby ensuring a better spread of fishing activity than would be possible if only wetfish trawlers were employed. Such a spread is positive for the biological well-being of the habitat and the fish contained therein, especially because many believe that the freezer trawlers are by and large targeting a different species of hake. Another point to note with respect to the finding of this paper is that turning the hake fishery into a wetfish-trawler-only fishery may be ill-advised, because building a large land-based industry in a situation where the industry can swing widely due to environmental and other human factors can be very risky. The task of isolating the risk factors and the potential benefits of using freezer trawlers is left to future research. Another important issue, not taken up in this chapter but addressed elsewhere (see Manning, 1998), is the question of rent capture, its distribution and Namibian participation and ownership (Armstrong *et al.*, this volume).

WETFISH VERSUS FREEZER TRAWLERS: THE BEFORE-TAC ANALYSIS

The analysis reported in this section is more ambitious, in that the determination of the TAC is assumed to be endogenous to the analysis. In other words, both the biology of hake and the economics of the fishery are explicitly taken into account in deciding the total harvest in a given year.

From the biological perspective, an age-structured model of the Beverton and Holt type is employed. This basic model is extended to allow for the inclusion of demographic diversity concerns. To incorporate economic behaviour, game theory is applied. Combining biology and economics, Sumaila (2001) develops a game theoretic modelling framework for the assessment of the trade-off between economic efficiency gains and demographic diversity conservation in a fishery. The paper introduces a *demographic diversity index*, and develops an application of the method on Namibian hake fisheries.

Biodiversity refers to the variety of life forms: the different plants, animals and microorganisms, the genes they contain, and the ecosystems they form. The concept emphasizes the interrelated nature of the living world and its processes. Biodiversity is important because human beings rely on biological systems and processes for their sustenance, health and well-being. Biotic resources[8] also serve recreation and tourism, and underpin the ecosystems, which provide us with many services. In addition, biodiversity has important social and cultural values. Thus, due to the many values humans derive from biological diversity, studies of this type are necessary to help decision-makers make sound decisions in situations where biodiversity conservation is at stake.

An underlying premise of the paper is that one can divide the management goal of a fishery into two broad categories, namely, conserving the biological diversity of the resource, and ensuring economic efficiency in the use of the resource. It is easy to see that in most situations these goals conflict with each other. To maximize biodiversity fully implies zero harvesting of fish, in most instances. Also, to pursue the absolute maximization of economic benefits will most likely imply the depletion of biodiversity. The challenge for Sumaila (2001) was to develop a modelling framework that would allow the exploration of the nature of the trade-offs between economic benefits on the one hand, and biodiversity conservation, on the other.

The work from which we report here contributes to the literature by focusing on demographic diversity concerns in fisheries, and how this can be incorporated into a bioeconomic model. The paper provides a framework that can be used to value some aspects of biodiversity, and help determine the opportunity cost of achieving different levels of biological diversity. Furthermore, it extends the current literature by developing a 'rare' computational game-theoretic model, which explicitly incorporates demographic diversity concerns.

Method

Modelling demographic diversity. - The paper specifically studies the economics of conserving demographic diversity within a population of fish. Diversity measures generally take into account two factors, namely, *species richness* (that is, number of species) and *evenness*, sometimes known as equitability (Magurran, 1988). The present paper looks at evenness within a fish population. It is concerned with maintaining diversity between, say the male and female parts of a population; the juvenile and mature parts of a population; or even the proportion of the different age groups of fish in the population. The index of demographic diversity in this paper is therefore the proportion of male to female, juvenile to mature; the different age groups in a population, or any such measures.[8] The benchmark index is the ratio of say, the standing juvenile biomass to the standing adult biomass when there is no harvesting. This ratio is given a value of 1 or 100%. The benchmark index captures the demographic diversity of the population, and therefore the "perfect" diversity level. The index for any other scenario, I, is then given by the following equation:

$$I = 1 - \frac{|y - x|}{x}$$

where x denotes the ratio of the juvenile to the mature parts of the biomass when there is no harvesting, and y represents the ratio when there is harvesting. It should be noted that the smaller the value of I the less demographic diversity there is in the population, since that signifies either too many or too few juveniles in relation to the 'no harvest' situation.

8 In the original paper, the index is labelled genetic biodiversity index. A reviewer of this contribution made the point that this index is actually an index of demographic diversity. We agree with the reviewer.

Modelling management scenarios. - It is assumed that the regulator of a given fishery, say a government ministry, has devolved or delegated the authority to manage the fishery to the fishers. Hence, they decide how much of the fish to harvest in each period. In such a decentralized setting, the participants can pursue their fishery goals in a cooperative or non-cooperative game situation.[9] Hence, to address the issues raised by this paper, cooperative and non-cooperative game theoretic models are developed.[10] Two versions of the cooperative model are presented: one in which a demographic diversity conservation objective is explicitly incorporated, and one in which it is not. In the case of the latter, we look at cooperative 'with' and 'without' side payments.

The cooperative model. - Consider a fishery with two groups of participants, say w and f.[11] Let the net private economic benefits to these groups be B_w and B_f, respectively. These benefits depend positively on the quantity of fish harvested by the two users, that is, H_w and H_f, which in turn depends on the stock size, N, and the amount of fishing effort, e, that each player takes out fishing. On the other hand, B_w depends negatively on the amount of fish harvested by f, and B_f, depends negatively on the harvest of w.

Discounted joint economic benefits and diversity indices for different values of a preference parameter $0 \leq \omega \leq 1$ for a given player are computed for different runs of the model under various management scenarios. The parameter ω plays an important role in differentiating between the outcomes for the different versions of the cooperative model. In the cooperative with an explicit demographic diversity conservation objective, the optimal ω is the one that produces the *highest diversity index,* 1. In the cooperative with side payments management scenario, the optimal ω is the one *that maximizes joint discounted economic benefits*, even if that implies pensioning out one of the players. Finally, under the cooperative without side payments regime, the optimal ω is the one that *maximizes the product of the distance be-*

9 By a game we mean any activity involving two or more participants, each of whom recognizes that the outcome for himself depends not only on his own actions, but also those of other participants.

10 A non-cooperative game is one in which there is no "good" communication between the players in the game; no binding contracts can be entered into; and players take the actions of the others in the game as given, and then decide their own actions unilaterally. A cooperative game is the opposite of the non-cooperative (see Nash, 1953).

11 For mathematical and computational convenience, we develop what is termed in game theoretic terminology as "two-person" games. In principle, however, the qualitative results of the paper should be valid also for n-person games (n>1).

tween the cooperative outcomes and the threat point outcomes of the players (see Munro, 1979).

The non-cooperative model. - This model attempts to capture a situation in which devolving the responsibility to manage the resource leads to non-cooperative behaviour. This is likely to happen when there is no communication between the participants; the parties can enter into no binding agreements, and each of them goes about exploiting the resource unilaterally (see Sumaila, 1999, and the references therein). There are a number of good reasons why it is important to develop this model. First, it is well known that, most of the time, interaction between agents exploiting common property resources usually degenerates into something close to the kind of outcomes predicted by non-cooperative models. This is probably one of the causes of the many collapses of fish stocks around the world over time.[12] Second, it is important to keep reminding stakeholders, regulators and the general public of the potential losses from non-cooperative behaviour, with the hope that this will eventually help bring about more cooperative management regimes in the world's shared fisheries, and other natural resources.

Under non-cooperation, it is assumed that the objective of each player is to maximize *own private* benefits, B_p, $p=w,f$, from the use of the resource. The problem of the non-cooperating agents is therefore to choose harvest or effort levels in each fishing period so as to achieve own objective, without due regard to the consequences of their action on other participants.

There are two key differences between the cooperative with an explicit diversity objective and the non-cooperative model. First, the users in the non-cooperative setting do not incorporate diversity concerns into their reaction functions – they care only about the private benefit that accrues to them. Second, users race for the fish, as they unilaterally decide how much to take. It should be noted that the latter is also the main difference between the non-cooperative and the other versions of the cooperative model.

Results and Discussion

Again data on the Namibian hake fishery are applied to run the model. The general results of the study show that in the case of the cooperative with an explicit diversity conservation objective, the optimal ω (for the wetfish fleet) value is 0.2, as this is the ω value that gives the highest diversity index. At $\omega = 0.2$, the diversity index is 98% of the ideal "no harvest" scenario. When it

[12] Examples of collapses are Norwegian spring spawning herring; Atlantic cod fisheries off Newfoundland (Walters and Maguire, 1996); and Peruvian anchovies (Idyll, 1973). It should be noted that there are other competing reasons given for these collapses (El Niño, environmental regime shifts, etc.).

comes to the cooperative with side payments scenario, the optimal ω is 1, as this gives the highest possible joint discounted economic rent. On the other hand, the optimal ω for the cooperative without side payments turned out to be 0.6. This gives the Nash solution for a cooperative without side payments management scenario.

A key result of the paper is that the highest diversity index is achieved under the cooperative with an explicit demographic diversity conservation objective scenario. With an index of 98%, this version of the model conserves demographic diversity best. On the other hand, the non-cooperative model delivers the worst demographic diversity conservation, with only 56% of the 'no harvest' demographic diversity preserved. In between these two extremes lie the outcome of 65% in the case of cooperative with side payments, and 78% in the case of the cooperative without side payments.

Turning to the economic results, the study shows that the cooperative with side payments management regime produces the highest joint discounted economic rent, thus achieving what Munro (1979) calls the *optimum optimorum* (N$10.23 billion). The next best economic result is achieved under the cooperative without side payments scenario (N$7.14 billion). This is followed by the non-cooperative outcome (N$5.14 billion), and the cooperative with an explicit demographic diversity objective produces an economic result of N$4.94 billion, respectively.

These economic results are reflected in the harvest levels under the different scenarios. The only exception here is in the case of the non-cooperative scenario, where even though the harvest level is slightly more than that in the cooperative without side payments scenario, and about 50% higher than in the case of the explicit diversity objective scenario, the economic rent is much lower relative to that in the case of the former, and nearly the same in the case of the latter.

A number of interpretations, observations and deductions can be made from the results presented above. First, it is clear that the opportunity cost of achieving "near perfect" level of demograghic diversity conservation is high. This turned out to be over 50% of the potential discounted economic rent in our model. Second, a cooperative without side payments management scenario appears to do reasonably well on both economic efficiency and demographic diversity conservation criteria. This scenario produces an economic result, which is 70% of the potential discounted economic rent, and about 78% of the 'no harvest' diversity level. Hence, it is possible to attain reasonably high diversity level, and reasonably high economic rent at the same time. Third, non-cooperative behaviour is (as has been shown again and again by previous studies) bad on all counts – it delivers only 56% of the potential diversity level, and just over 60% of the potential economic rent. Fourth, the bargaining powers of the players, w and f, vary with the type of management scenario. For instance, in the scenario with an explicit demographic diversity objective, the freezer trawlers do most of the harvesting and therefore make the most economic rent. On the other hand, the wetfish trawlers do most of the harvesting in the cooperative without side payments scenario.

THE SARDINE BIOECONOMIC MODELS

Sardine is a pelagic schooling species mainly caught by purse seiners. It is the most important of the pelagic species in Namibia. It is a short-lived species with a life span of four to six years. Juvenile sardines measure up to 12 cm, immature from 12 cm to about 20 cm, whereas adult sardines are 20-26 cm. About 50 per cent maturity occurs at 21 cm.

There are two distinct stocks along the west coast of southern Africa, the South-African sardine and the Namibian sardine. The South-African and the Namibian sardine are biologically separated by the ecological barrier in the Benguela system not far from Lüderitz. Namibian sardine is shared with Angola, and this causes problems, as the fisheries management policy of Angola is different from the Namibian.

Commercial exploitation

The Namibian sardine was an unexploited stock until 1947 when the Walvis Bay Canning Company started an experimental fishery, first for fishmeal and fish oil, and already in 1949 for canning. The catch in 1948 was a modest 1000 tonnes. Only five years later, in 1953, six companies altogether were in operation, and the total catch had increased to 262 000 tonnes. After that the catch increased steadily, peaked at 1.4 million tonnes in 1968 and dropped steadily to a modest 100 000 tonnes a decade later. Unofficial sources have it, however, that the catch in 1968 was more like 2 million than 1.4 million. The catch dropped to 1.1 million in 1969, 565 000 in 1970 and 328 000 in 1971. After 1977 the stock more or less collapsed. In the eighties and nineties the stock size has varied between virtually zero and some 100 000 tonnes. This illustrates the need for bioeconomic models that can serve as basis for sound economic and biological management of the stock.

Models

Although there exist numerous biological studies of sardine, and quite a few of Namibian sardine, bioeconomic studies of sardine are rare (Johnston and Sutinen, 1996; de Anda-Montanez and Seijo, 1999); not to mention Namibian sardine. The only bioeconomic studies of Namibian sardine, to our knowledge, are the studies of Namibian sardine by Sumaila and Vasconcellos (2000) and Sandal and Steinshamn (1999, 2001a). Boyer and Hampton

(2001) give a nice overview over marine resources in Namibia and the socio-economic value of the Namibian fishing industry, and Cochrane *et al.* (1998) study South-African sardine. The latter draw some conclusions that may be relevant for Namibia as well.

Cochrane *et al.* (1998) discuss the lessons learned in the application of management procedures and their precursors in the pelagic fishery in South Africa (anchovy and sardine). The high variability in abundance of the two stocks, the trend in their relative abundance, the substantial uncertainties in information, strong pressure to meet socio-economic goals and the conflicting objectives that arose between the directed anchovy and directed sardine fishery are identified as major problems in the implementation of procedures and management of the resources. However, the use of management procedures is considered to have led to greatly improved communication with the industry and to substantial input by them into the management process in South Africa.

Sandal and Steinshamn (1999, 2001a) present applications of a single-species deterministic bio-economic model. An outline of the modelling technique can be found in Sandal and Steinshamn (2001b). One of the main aspects of this modelling technique is that it is a feedback model. This means that at any point in time, the optimal control (harvest) is a function of the state of the system (the stock size). It does not matter how the present situation has come about, it is the situation itself that determines the action. This is important as no decisions are made in advance; they are all made based on the most recent information about the system. The reason why it is possible to find the feedback solution of the dynamic optimization problem is that the model is non-linear. Non-linearities may enter through downward sloping demand or increasing marginal costs. Otherwise (with fixed prices or costs) the optimal solution is a very simple feedback, namely the so-called bang-bang solution defined as zero harvest when the stock is below the optimal steady state and maximum harvest when the stock is above the optimal steady state. This is obviously not a realistic alternative in practice.

The biological submodel is an aggregated model in the sense that it is not a year-class model. There are two types of aggregated models, namely the surplus production type (Schaefer model) or the recruitment type (Ricker model). In the applications, the surplus production model was chosen as this turned out to fit the data best, that is, it gave better statistical results.

The economic submodel is a net revenue function defined as gross revenue minus costs. The gross revenue is defined as price multiplied by harvest. The price determination (demand function) for sardine is particularly interesting as one part of the harvest goes to canning (human consumption) and another part goes to fishmeal. The size of the part going to canning depends on the total size of the harvest. For small harvests almost everything goes to canning. When the harvest exceeds a certain level, some of it goes to fishmeal. For an even higher level of the harvest, everything exceeding this level goes to fishmeal. To find this threshold level, however, may be problematic as hardly anything at all has gone to fishmeal over the last two decades.

The characteristic of the demand function mentioned above results in an optimal harvest function that is slightly stepwise, as shown in Figure 1.

The cost function is the most difficult one to estimate due to lack of appropriate data. The good thing about the modelling approach, however, is that it is possible to try a wide variety of non-linear cost functions.

Optimal harvest from a deterministic version of the model, as described by Sandal and Steinshamn (2001a), is illustrated in Figure 1. A stochastic version of the same model is described in the Steinshamn-Lund-Sandal chapter of this book.

Results and discussion

The main conclusion to be drawn from this section is that, according to the model, the sardine stock has been well below the harvest moratorium level almost continuously for two and a half decades even when we use discount rates up to 20 per cent. In practice this means that a harvest moratorium on sardine ought to have been instituted already in 1977.

At any point in time the model had been implemented, the stock would

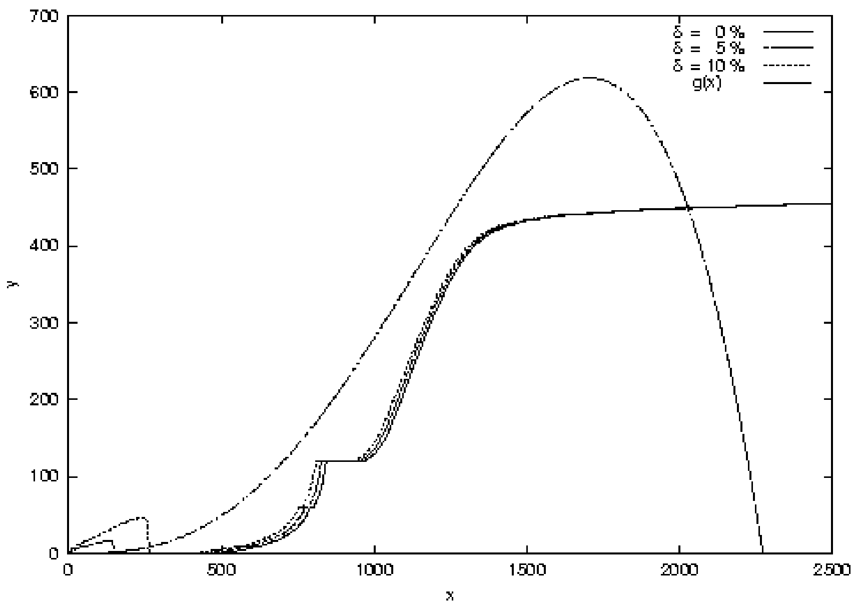

Figure 1. Optimal harvest paths as functions of the stock size with 0%, 10% and 20% discounting, and the estimated surplus production function. The uppermost harvest curve represents the highest discounting. Units are 1000 tonnes.

start growing towards the optimal steady state level of just over two million tonnes, which could accommodate a permanent annual harvest just over 400 000 tonnes. This is, however, in a deterministic setting. We all know that reality is much more volatile, and there is no guarantee that stocks grow according to models. At best, this is the case on average in the long run.

The good thing about the feedback model is that sporadic uncertainty is automatically taken care of. Therefore there is good reason to believe that after this has been applied for a while the stock will at least vary around two million tonnes and the harvest around 400 000 tonnes. If, on the other hand, there is systematic uncertainty, in the sense that the stochastic process depends on the stock level, a completely different approach is needed and stochastic dynamic programming must be used. This is the topic of another chapter in this book (Steinshamn *et al.,* this volume).

The bottom line therefore is that even though a simple deterministic bioeconomic model would probably yield much better results both economically and biologically, than the actual harvest pattern has done, the best choice would be to apply a proper stochastic bioeconomic model. Stock management according to such a model would yield both higher economic returns and more employment in the long run than the actual management.

An argument that is sometimes brought forward is that a higher harvest is needed in order to avoid labour unemployment in the short run. Unfortunately, this kind of policy always has to be paid for by lower employment in the future if it implies overharvesting of the stock.

ECOSYSTEM BIOECONOMIC MODELS

Namibia (and South Africa) has an extensive coastline bordering the highly productive northern Benguela current system. The Benguela system is dominated by pelagic fishes, mainly sardine, anchovy and horse mackerel. The demersal ecosystem is dominated by the valuable stocks of hakes. The food web off the Namibian coast is mainly represented by seals as the top predators, hakes, squid, snoek, and chub mackerel as the piscivorous species and horse mackerel, round herring, saury, sardine and anchovy as the main pelagic prey, and lightfish, lanternfish and goby as the main demersal preys (Shelton, 1992).

Distant-water fleets started operating in Namibian waters in the early 1960s. Fleets from the former USSR and Spain arrived in 1964; followed by Japan, Bulgaria and Israel in 1965; Belgium and Germany in 1966; France in 1967; Cuba in 1969; Romania and Portugal in 1970; Poland in 1972; Italy in 1974; Iraq in 1979; Taiwan in 1981; and South Korea in 1982 (FAO Yearbooks of Fishery Statistics for hake). With the announcement of the EEZ regime by the independent government in 1990, there was almost an instant drop to zero of the number of unlicensed foreign vessels fishing in the area (Sumaila and Vasconcellos, 2000).

Sumaila and Vasconcellos (2000) analyse the impact of the activities of distant water fleets on Namibia's marine ecosystem through the use of simulation modelling. Dynamic simulations were performed to capture the ecological impacts of the activities of DWFs in Namibian Exclusive Economic Zone (EEZ) during the pre-independence era. These impacts are then valued to give an indication of their economic effects. Scenarios of the Namibian ecosystem are developed using information on the catches of hake, horse mackerel and sardine during this period. Based on these scenarios, the following three questions were raised and addressed. Given the harvest of hake, horse mackerel and sardine in the years prior to independence, what are the impacts of DWFs on the biomass of the major species in the ecosystem? How do DWF activities impact the biomass and potential catches of the major commercial stocks off Namibia? How do the impacts on the catch levels affect economic values?

Methods

Simulations were based on an Ecopath model of the Benguela ecosystem off Namibia developed by Jarre-Teichmann and Christensen (1998) for the period 1971 - 1977. Ecopath is a mass-balance static model that describes the trophic relationships in an ecosystem in steady-state conditions (Christensen and Pauly, 1992) while Ecosim is the dynamic version of Ecopath (Walters *et al.*, 1997).

To carry out their economic analysis, Sumaila and Vasconcellos (2000) took the catches and fishing efforts generated by Ecosim under different DWF fishing scenarios, and applied appropriately determined unit prices for the fish landed; the cost of exploiting the fish; and the discount rate. This allowed the authors to compute the net discounted economic rent that is achievable under the 'with' and 'without' distant water fishing fleets scenarios, which in turn allowed them to determine the economic impacts of DWFs under these scenarios.

Results

The main results of the analysis are (i) for hake, the average standing biomass in the "with" scenario is only 51% of that in the "without" scenario. The equivalent numbers for sardine and horse mackerel are 68% and 60%, respectively. For the ecosystem as a whole, the effect of DWF activities is to reduce the potential standing biomass by about 16%; (ii) substantially higher catches of hake, sardine and horse mackerel are taken in the "with" than in the "without" DWF scenarios; and (iii) in the "with" scenario, the DWFs make on average Namibian dollar (N$) 1 011 million annually while the domestic fleet made only about N$112 million.

Distance water fleet activities have been cited as one of the reasons for the buildup of excessive effort and increasing stock exploitation in the years leading up to the extended fishery jurisdiction. Sumaila and Vasconcellos (2000) showed that exploitation of Namibian fisheries in the pre-independence era by the DWF is a good example of the exertion of excess effort and the consequent stock over-exploitation and economic waste that follows.

POTENTIALLY INTERESTING RESEARCH REMAINING

As can be seen from the short list of bioeconomic studies of Namibian fisheries, a lot remains to be done in this area. Even with respect to single-species-deterministic models, very few studies have been performed. The analysis in Sumaila (2000) can be fruitfully extended to include new biological knowledge about hake published since the publication of this paper. Another useful extension of this paper would be to look at the secondary economic benefits of the hake fishery.

The bioeconomic model for sardine (Steinshamn *et al.*, this volume) is a stochastic feedback model, but a lot still remains to be done with respect to the quantification of the stochastic processes. A useful method for quantifying stochastic processes, which is also relevant for Namibian fisheries, is the one described by McDonald and Sandal (1999). It is important to note here that this study is not only about passive uncertainty but also active uncertainty, in the sense that the stochastic process itself may be a function of the stock. The focus is mainly on uncertainty and stochasticity in the biology, but uncertainty may also be present in the economic part of the model. Bioeconomic models with both types of uncertainties deserve more attention.

Generally, even purely biological multi-species models are rare. To our knowledge, there are no bioeconomic multi-species models of Namibian fisheries. A multi-species bioeconomic model may be a model that only contains the multi-species aspect in the biological submodel, and this is the most common approach. However, there may not only be multi-species interactions on the biological side but also on the economic side, for example, if the supply of one species to the market affects the price of other species as well. In this case, a different kind of modelling that takes this into account is needed.

Another topic that is important for Namibia is the economics and management of shared fish stocks with South Africa and Namibia. This calls for a game-theoretic approach to the modelling of the Benguela upwelling system. Only very limited modelling has been carried out so far in this area (see Armstrong and Sumaila, this volume).

Finally, there are indications that the price of hake in Spain is not a constant that is determined by a competitive market. Namibia is one of the main suppliers of hake to the European market. The country could therefore be in a position to exert some market power. Studies that look at the market and price dynamics of hake will be very useful in helping us get away from the current assumption of constant prices applied in studying the bioeconomics of hake. Typically this will imply a more conservative harvesting pattern.

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