The Brazilian sardine. Is there any room for modelling?

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Abstract. Brazilian sardine (*Sardinella brasiliensis*) production has declined along the last 30 years, being today around 40 000 tons. The fleet, despite the reduction in number of boats still has an excessive fishing power when related to the stock size. It is probable that besides overfishing, climatic and oceanographic phenomena interfere with recruitment success. Several hypotheses were suggested and a few models implemented aiming at the correlation of recruitment and environmental variables. In almost all cases, in spite of environmental variation, the spawning stock biomass seemed to be a main factor for recruitment success. The state of overfishing prevailing in the international scenario has determined the proposal of more robust strategies for fisheries management, based in marine protected areas and in a sharp reduction of fishing effort. The management of the Brazilian sardine stock is set up in an inefficient system of special permissions granting and in the definition of closed seasons. The slight trend of catches recovery, in the latest years, impelled the fisheries authority to reduce the closed seasons, showing a misled policy intended to capitalize on any apparent stock increase or marginal fishing opportunity. In fact, modeling is always necessary to better understand and represent nature, but in the case of the sardine stock a sound management based on the preservation of the spawning stock size above a critical value through effective control of licensing and closed seasons deserves priority.

Key words: *Sardinella brasiliensis*, environmental variables, management strategies.

Resumo. A sardinha brasileira: Ainda há lugar para modelagem? A produção da sardinha verdadeira (*Sardinella brasiliensis*) vem declinando ao longo dos últimos 30 anos, estando atualmente em torno de 40.000 t. A frota, apesar da redução do número de embarcações ainda detém um poder de pesca excessivo para a magnitude do estoque. É provável que além da sobrepesca, fenômenos climáticos e oceanográficos afetem o sucesso do recrutamento. Foram sugeridas diversas hipóteses e implementados modelos para a correlação do recrutamento com variáveis ambientais. Em quase todos os casos, a despeito das variações ambientais, a biomassa do estoque desovante mostrou-se como o fator principal para o sucesso do recrutamento. A situação de sobrepesca predominante no cenário internacional tem determinado a proposição de estratégias mais robustas para a gestão da pesca, baseadas em áreas protegidas e na redução radical do esforço de pesca. A gestão do estoque de sardinha verdadeira no Brasil é baseada em um ineficiente sistema de concessão de permissões e na implementação de períodos de defeso. A leve tendência de recuperação das capturas, nos últimos anos, levou a autoridade pesqueira a reduzir a duração dos períodos de defeso anuais, mostrando uma política equivocada de tentar capitalizar qualquer oportunidade de incremento marginal da pescaria. A modelagem sempre será necessária para a melhor compreensão e representação da natureza, mas no caso da sardinha verdadeira, a prioridade deve ser dada a medidas de gestão voltadas para a manutenção do estoque desovante acima de seu valor crítico, por meio do efetivo controle da operação da frota licenciada e da definição de períodos de defesos.

Palavras-chave: *Sardinella brasiliensis*, variáveis ambientais, estratégias de gestão.

Introduction

The Brazilian sardine, *Sardinella brasiliensis*, occurs in the area between Cabo de São Tomé - RJ (22º S) and Cabo de Santa Marta - SC (29º S), in the region known as the southeastern Brazilian bight (Figure 1).

The fishery is carried out by the purse-seiner fleets based in the states of Rio de Janeiro, São Paulo and Santa Catarina and directed to schools

near the surface, covering from shallow areas to those with maximum depths of 70 meters, and around 30 nautical miles from the coast (Valentini & Cardoso 1991, Cergole 1993).
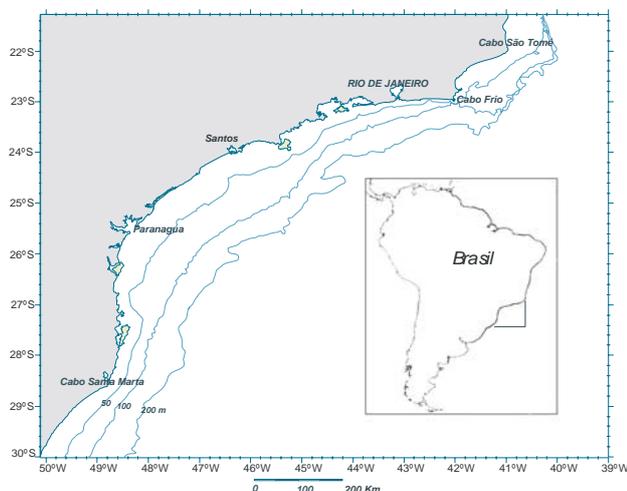

Figure 1. Map showing the southeastern Brazilian Bight (adapted from Jablonski 2003).

Maximum historic landing was registered in (see Figure 2, page 90) 1973, with 228 000 metric tons, with the major part of the catch derived from the Rio de Janeiro fleet. Since then there was a decreasing trend, reaching a mean of 140 000 tons, from 1977 to 1980; and of 125 000 tons, during the years 1983-1986 (IBAMA 2000). The displacement of the shoals to the southern part of the stock distribution area determined an increase of the contribution of São Paulo and Santa Catarina fleets from 1980 on. In 1990, production reached 32 000 tons, and after a following recovery in 1997 attained around 115 000 tons. Another sharp decrease led the production to a minimum of 17 000 tons in 2000. In the latest seven years landings have shown a slight recovery trend, but with strong oscillations. Total landed reached almost 40 000 tons in 2001; 22 and 25 000 tons, in the two following years, reaching a maximum of 53 000 tons, in 2004. In 2005 and 2006 (estimated data), the total production was around 40 to 45 000 tons.

The number of sardine boats increased until the 1980's, when the fleet came to a record of around 500 boats (350 boats licensed and 150 without the required special permission), despite the fact that fishing effort has been formally limited in 1976 to 200 boats (Dias-Neto & Dornelles 1996).

Today there are 183 boats licensed to catch sardine, yet this number is not representative of the total fleet acting upon the resource. Surveys carried out in the states of São Paulo and Santa Catarina showed that around 45% of the boats were not

granted with the special permission (IBAMA 2006), suggesting a fleet of 300 or more boats in activity.

Despite the significant reduction of the fleet size, the remaining boats are characterized by an elevated fishing power (larger boats, equipped with sonar, power-block and bigger nets, favoring fishing in deeper areas). This high fishing effort when applied in periods of low abundance of the stock (resulting either from overfishing or environmental factors) put the fishery at risk (Valentini & Pezzuto 2006).

The remaining fleet tended to compensate the low level of the sardine stock directing its activity to other potential resources such as some seasonal pelagic (mullet *Mugil* spp. and blue fish *Pomatomus saltatrix*), or to other alternative species as chub mackerel (*Scomber japonicus*), other sardines (e.g. *Opistonema oglinum*), Atlantic bumper (*Chloroscombrus chrysurus*), Atlantic moonfish (*Selene setapinnis*) and Brazilian menhaden (*Brevoortia* spp.). Despite the increase of catches of some of those species observed from 1996 to 2004, they were clearly insufficient to compensate the sardine losses. During the latest years, even demersal resources as croaker (*Micropogonias furnieri*), traditionally caught by pair trawlers and gill-net boats, and also object of fishing effort limitations, have been targeted by the sardine fleet (Valentini & Pezzuto 2006).

The Brazilian sardine is probably the most studied marine fish resource in the country. There is a massive collection of papers, theses and studies on its biology, feeding habits, biomass and population structure (See IBAMA (2006) for a detailed revision).

The effect of environment on recruitment

It is probable that environmental effects, related to atmospheric and oceanic conditions, in a regional scale, affect sardine recruitment. The weak intrusion of the South Atlantic Central Water (SACW), in some years, could have affected the survival of sardine larvae and determined recruitment failures (Matsuura 1996, 1999). As the catches are strongly based on individuals of age one and two, a decline in recruitment in any year will immediately affect landings and also would likely be associated with a decline in the spawning stock biomass (Matsuura 1996). Those effects are specially noticeable when compared with long lived species with catches composed by a greater range of age classes.

Rossi-Wongtschowski *et al*. (1996) suggested that the observed fluctuations of the

sardine stock could be related to climatic changes in a global scale. However, Matsuura (1996, 1999) did not find any evidence to establish a link between global warming, or even *El Niño* events, with the Brazilian sardine behavior. The author suggested that catch fluctuations, in the 1970's, derived from recruitment failures, as a result of low frequency oceanographic anomalies, some of them caused by climatic disturbance during spawning season. He also stated that the size of fish populations in Southwest Atlantic was mainly affected by recruitment variations, related to atmospheric and oceanic conditions, in a regional scale, but not to global climatic changes.

According Wainer & Taschetto (2006) there is a significant correlation between the *El Niño* - Southern Oscillation (ENSO) and Sea Surface Temperature (SST) anomalies in the north tropical Atlantic, but the ENSO consequences in the south Atlantic are not well known yet.

Paes & Moraes (2004), however, showed evidences of ENSO influences over the water mass regime and biological productivity; and therefore, over the dynamics of living resource in the southeastern Brazilian Bight - after intense *El Niño* events, the primary productivity and the pelagic fisheries production would be higher than in normal periods and after "moderate" or "weak" *El Niño* and intense *La Niña* events the pelagic production would be lower.

Cergole *et al*. (2002) suggested that variations in sardine recruitment and biomass showed not only a marked yearly variation but also changes at a decadal scale.

A "virtual population analysis" of the sardine stock showed the existence of two different "states" for the stock - a steady state from 1977 to 1986, and a second period of decline from that time on. During the steady state, total biomass was evaluated in 668 000 tons, decreasing, in 1989, to 213 000 tons. The reasons for the decline were supposed to be due mainly to overfishing, and secondarily, to environmental factors (Cergole 1993, 1995). Also the recruitment–spawning stock relationship showed a linear trend from 1987 to 1989 indicating that the reduction of the stock determined a smaller number of recruits leading to a subsequent failure in the spawning stock restoration (IBAMA 1994).

Cergole (1995) suggested that a spawning stock biomass of some 180 000 tons would be a critical minimum size; below that, its maintenance would be strictly dependent on recruitment success.

Sunyé (1999) tried to establish linear relations between annual catch and different meteorologic and oceanographic variables, using the "Climprod" model (Fréon *et al*. 1993). The model allows the introduction of one "climatic" variable at a time in a "general production model"; the best fit was attained by the combination of sea level at the coast and fishing effort. Although results have indicated a greater importance of the environmental factor on the explanation of catch variance, the author considered the possibility of distortions caused by the short data series available and also the lack of marked variations in the fishing effort during the period.

Vasconcellos (2000) suggested different hypotheses to explain the variability observed in the sardine recruitment, all of them having overfishing, and the consequent reduction of the adult stock as the determinant factor. The author also suggested that depensation phenomena could be in course, related to ecological and behavioral changes which could prevent the stock recovery even in the case of fishing effort reduction. Another hypothesis related the overlap of low frequency environmental effects to the spawning biomass reduction. These effects would be in synchrony with oscillations observed in other marine populations along the 70-80's.

Environmental variability effects are more striking during the phases between spawning and recruitment due to the higher sensibility of eggs, larvae and juveniles in relation to environment. Studies carried out in different regions pointed to the importance of oceanographic variables for the comprehension of the dynamics and management of fisheries resources (e.g. Bakun & Parrish 1990, Glantz & Feingold 1990, Sherman 1992, Bakun 1996, Myers 2001).

It is quite probable that the fluctuations observed for the Brazilian sardine stock, besides overfishing, would also reflect oceanographic and climatic phenomena in variable scales (Matsuura 1990, Matsuura *et al*. 1992, Cergole 1993, Dias 1995, Rossi-Wongtschowski *et al*. 1996, Sunyé 1999). The evaluation of these effects were performed generally in a semi-qualitative fashion using seasonal means of wind stress, Ekman transport and temperature (Bakun & Parrish 1990), or, also, in a punctual form, comparing recruitment success with the position of the SACW front in successive spawning seasons (Matsuura 1996).

A recent attempt to show a possible evidence of the environment effects on sardine recruitment was based on nonparametric additive models (Jablonski 2003). The best fittings for additive models were obtained for combining spawning stock biomass and Ekman transport as

predictor variables. Transformations showed a "dome-shaped" curve for Ekman transport with limits of 520 and 700 kg.s^{-1}.m^{-1}, corresponding to winds of intensity around 3.0 and 4.5 m.s^{-1}. However, it was noted that the models could behave in strange ways for small data sets when the "equivalent number of parameters" required to the fitting increase. Although environmental variables were important to explain recruitment variability, the effects derived from them were less important when compared to the magnitude of the spawning stock. For additive models, the biomass transformations showed a value around 200 to 250 000 tons as a limit between the "linear" portion of the curve and the region where recruitment is fairly constant in relation to the magnitude of the spawning stock (Jablonski 2003, Jablonski & Legey 2004).

In general, due to the evident failure of traditional fish stock assessment and management in a world scale, it is possible to observe a trend to approaches that take into consideration more elements drawn from ecology.

The international scenario
In 2001, the UN Food and Agriculture Organization (FAO) conference, in Reykjavik, reached agreement that "in an effort to reinforce responsible and sustainable fisheries in the marine ecosystem, we will individually and collectively work on incorporating ecosystem considerations into management" (Royal Commission on Environmental Pollution 2004).

Even though not yet clearly established, the concept of "ecosystem based management" should include trophic interaction between species, habitat impacts of various gears, and so on. However Pauly *et al.* (2002) pointed out that single-species assessment models have not succeeded due to different problems, but first of all, because assessment results implying limitation on levels of fishing mortality have often been ignored. "Between a biological may and an economic must, the economy will win" (Schrank 2007).

The inclusion of environmental variables and the consideration of their effects on recruitment and natural mortality, through alterations in predator / prey relationship is yet more complex due to the uncertainties involved. Maybe because of that "environmental information is most often used for retrospective explanations of fisheries failure, and rarely as an intrinsic part of the stock assessment process itself" (Schrank 2007). Nevertheless to change this picture with accurate models has been proven extremely complicated.

Sissenwine (1984) concluded with the statement ''that recognizing uncertainty is a necessary step to learning to live with it'' what implicitly means that fishing mortality rates have to be reduced.

As an alternative to complex models the adoption of more straightforward strategies to avoid the depletion of stocks has been discussed in the scientific community. For example, the implementation of marine protected areas are suggested as an auxiliary tool of fishery management that is relatively insensitive to scientific error and probably rely least upon scientific stock estimation (Doubleday 1993). It would also prevent overexploitation by setting an upper limit on fishing mortality and still help to rebuild the complexity of the habitats destroyed by trawling (Pauly *et al.* 2002). Hence it is possible to come with more radical propositions such as "to change the view of seas open to fishing with small exceptions (i.e., marine protected areas) to the opposite view, that the seas should be closed to fishing, with small exceptions" (Jacquet & Pauly 2007).

Going farther in the direction of operational simplification it has been considered the sharp reduction of fishing effort and also the evaluation of the usual meaning of the sustainability concept. According to Pauly *et al.* (2002) "there would be little point in sustaining stocks whose biomass is but a small fraction of its value at the onset of industrial-scale fishing" and in such a way a "practical restoration ecology for the oceans that can take place alongside the extraction of marine resources for human food" is needed.

The underlying idea it is not to ignore the existence of natural cycles, but that the problem with fisheries and sustainability is that overfishing has reduced the biomass of populations so drastically, that they might not recover from lows in their natural fluctuations, leading to population collapses (Zeller & Russ 2004). "What managers can do is recognize that environmental factors do change and adopt strategies that permit the fish stock to withstand strongly negative environmental change. This reinforces the idea that fishery managers must avoid operating at the margin" (Schrank 2007). "The problem is management immediately tries to capitalize on any apparent stock increase or marginal fishing opportunity, but only slowly responds to apparent decreases in the stock, resulting in resource declines" (Rosenberg 2003).

The management of the Brazilian sardine stock

A first closed season of 40 days from December 23, 1977 on was established aiming to protect the sardine spawning stock during the austral summer. In the subsequent years the closed season increased to 60 days until 1991, when two different periods of interdiction were set up – one in the winter months to prevent fishing on juveniles during recruitment and a second during summer. Each year different time periods were established varying from 50 to 85 days, in the spawning season, to 45 to 90 days during recruitment. In 1995, with the increasing sardine production only the summer closed season was maintained with durations varying each following year from 90 to 135 days. From 1998 on the closed season was reduced to 60 days. The sharp decreases observed in 1999 and 2000 led to a reconsideration of the winter interdiction from 2004 on. The closed season of 90 and 60 days respectively in summer 2003/2004 and winter 2004 was enlarged in 2005 and 2006 reaching 120 and 60 days respectively. However the "recovery" of landings observed since 2004 led to a new regulation defining shorter periods of around 100 and 50 days for the next three years, until the winter of 2009.

Besides the closed seasons the management of Brazilian sardine enforces a minimum landing size (17 cm) and an attempt to control fishing effort through granting special permissions. Both attempts are important but ineffective if not properly enforced. For instance, IBAMA (2006) mentions a steady increase in catch of sardine juveniles, specially after 1985, when landings comprised by as much as 95% of young sardines were observed.

One should note that the resulting legislation not always follows the propositions of the scientific committee; on the contrary, the decisions on the management of the stock often passed through a "revision" due to the fishermen and industry pressure, sometimes leading to significant reductions of the proposed closed seasons and occasionaly even disregarding the recommendations. For example, in 1993 a recommendation of the scientific committee for a total closure of the fisheries for a period of 28 months, as a drastic effort to guarantee the economic survival of the fishery (IBAMA 1994), was simply ignored.

In 2006, the scientific committee approved a management plan for the Brazilian sardine (not implemented) and recommended a reduction of the fleet to the equivalent to 80 "standard" boats – 25 meters long, 350 HP engine, ecosounder/sonar and power-block equipped (IBAMA 2006).

Despite the findings that the magnitude of spawning biomass was a critical factor for the stock management, no strategy to evaluate the biomass size was adopted, even though the methodology of acoustic surveys and the necessary equipment were available in the country. In fact an acoustic survey carried out in 1988 showed a very low level of sardine biomass, and indicated the imminence of the stock collapse (Castello *et al*. 1991).

It is also interesting to note how Brazilian fisheries authority has chosen "to operate at the margin" and also "to capitalize on any apparent stock increase or marginal fishing opportunity" by reducing the closed season for the next three years based on the apparent recovery of the landings. Figure 3 shows in detail the trend of recovery as probably "seen" by the fisheries authority. A simple comparison with Figure 2 is sufficient to get the correct perspective and scale.
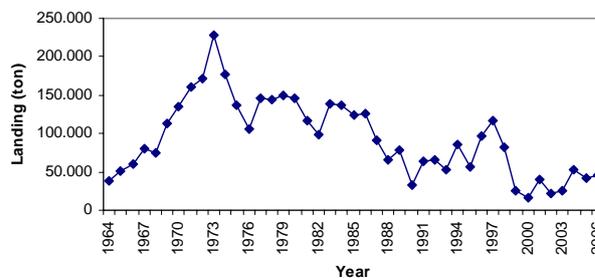

Figure 2. Brazilian sardine landings from 1964 to 2006. Data from "Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis" - IBAMA/RJ, IBAMA/CEPSUL/SC and "Instituto de Pesca de São Paulo".
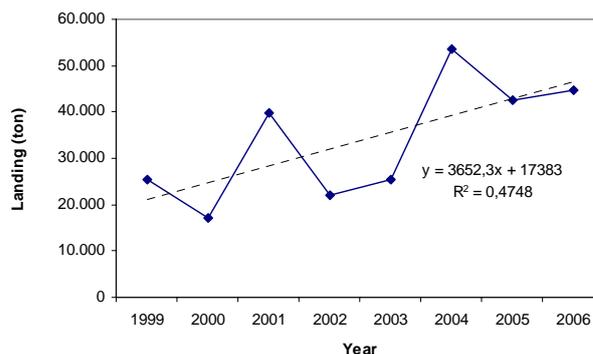

Figure 3. Brazilian sardine landings from 1999 to 2006 and the regression line. Number for 2006 was partly estimated.

However it is worth noting that the preservation of the two periods of closed seasons by itself for the next three years is relevant and seems to reflect a more careful and precautionary position of the fisheries authority, motivated by the recommendations of the scientific committee (historically the winter closed season was suspended at any sign of stock "recovery")

Conclusions

It is not difficult to verify that the sardine stock is in a state of overexploitation and threatened by a fleet (partly illegally operating) with a fishing power much over the reasonable one. It is quite probable that environmental factors in a regional scale or even those related to ENSO are affecting the recruitment success. Nevertheless as observed above a "solution" for the survival of the sardine fishery is much more related to the reduction of fishing effort and to the recovery of spawning biomass than to the accuracy of models involving climatic variables or ecosystem considerations. Results clearly indicate that the maintenance of the spawning stock size above a critical value is the main factor for the stock conservation and fisheries sustainability, despite any influence of environmental factors.

Is there any room for modeling? In fact, modeling is always necessary in the long and hard search to better understand and represent nature. The evolution of the understanding of the structure and function of the ecosystem is part of the natural path of scientific knowledge, but, in what refers specifically to the management and protection of Brazilian sardine a sound management could be achieved through the use of the most ordinary tool of the toolbox (the simplest to define but certainly not to enforce) – the control of fishing effort in its various forms – closed seasons or areas, and the direct limitation of the fleet and its fishing power.

Acknowledgements

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