MODELLING ABALONE FISHERIES

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Introduction

Abalone are valuable marine molluscs which have been exploited for their meaty foot and bowl-like shell by coastal communities since prehistoric times. In modern times it is particularly Japanese and Chinese ethnic groups which value abalone as ebible symbols of prosperity and well-being. Globally the world's abalone fisheries have had a poor management record. In 1969 the annual global production was about 24,000 t per annum compared with today's 12,000 t (FAO 1963-1984). This decline reflects the decline of the Californian abalone fishery which sustained production from last century through to the middle of this century. In recent times the global decline in abalone landings has also been exacerbated by the gradual decline of Japanese landings despite a 16-fold increase in the amount of juvenile abalone artificially produced and seeded into the environment. Today Japan and Australia dominate world production, each producing about 40% of annual production which is worth approximately $200 million in export income to Australia's rural maritime economies.

The Japanese pioneered abalone research beginning around the turn of the century and continuing until the present day, reflecting the traditional importance they place upon abalone. During the 1960s and 1970s the Japanese used the techniques of Leslie and Davis (1939) and Delury (1947) to analyse seasonal trends in artisanal catch rates and estimate recruitment trends within wild stock fisheries. Through the rigours of translation their diagnosis seems to have been that the artisanal fishery was recruitment overfishing of abalone stocks but that this exploitation could not be controlled. Consequently Japan appears to have diverted abalone research away from wild stock research and into aquaculture research.

Since the 1960s and 1970s general understanding of abalone biology in the west has increased considerably and this has been reflected in the development of models to describe abalone stocks.

Modelling Growth

The earliest models of abalone documented in the English literature described abalone growth. A range of authors sought to fit Walford plots or von Bertalanffy growth curves to the growth of tagged abalone (Harrison and Grant 1971; Quayle 1971; Poore 1972; Shepherd and Hearn 1983). During the 1960s estimates of growth were combined with early estimates of mortality within yield-per-recruit models to estimate minimum legal size limits which would maximize the yield per recruited abalone (Prince and Shepherd 1991).

To the extent that these studies described the growth of tagged populations, they remain sound early studies of growth. However most of the studies centred on recruited mature populations of abalone which because of their size and non-cryptic nature could be easily tagged and recaptured. Few examined the growth of juvenile abalone directly. Many of these early authors extrapolated growth curves fitted to adults, to describe the growth of juveniles, with misleading findings. It is now broadly accepted that abalone growth does not conform to a von Bertalanffy shape throughout their life (Prince 1989; Shepherd, personal communication). Juvenile growth is linear or sigmoidal until the age of maturity when growth slows significantly as resources are allocated away from somatic growth and into reproduction. Gompertz equations or hybrid curves marrying linear equations with bounded von Bertalanffy curves approximate abalone growth throughout their life more adequately than simple von Bertalanffy curves. The extrapolation backwards over juvenile age classes, of a simple von Bertalanffy curve fitted to tagged mature abalone, will lead to the age of juvenile abalone being underestimated by one or more years (Prince 1989).

Age and Length Structured Modelling

While Japanese workers estimated relatively stable trends in annual recruitment to fisheries from surveys and long term catch sampling, Sainsbury (1982 a; b) was the first to apply an age and length structured model to analyse population dynamics within an abalone population near Kaikora, New Zealand. Within a skilful doctoral project Sainsbury studied a population of *Haliotis iris* and using estimates of growth and mortality obtained through tagging analysed the sampled size structure of the population to derive estimates of previous recruitment and other biological parameters. Sainsbury used a sophisticated age and size structured model to obtain the surprising conclusion that his study population had been without recruitment for 14 years. This result in no small measure helped to establish the dogma that abalone recruitment is extremely variable temporally. In hindsight it would appear that as with most other workers of that time, Sainsbury failed to adequately sample juvenile abundances.

Fournier and Breen (1983) also followed a similar age structured approach to analysing length frequency histograms of abalone in British Columbia to derive estimates of mortality and growth rates. However much of the results of their analysis must also be questioned because of the under-representation of juveniles in the samples they analysed. In both these studies the fundamental weakness of the approach was the sampling regime rather than the model structure and framework.

Until the advent of technical aids for sampling cryptic age classes of abalone in the 1980s (Prince and Ford 1985; Shepherd and Turner 1985; McShane and Smith 1988) cryptic age classes of abalone were seriously undersampled in almost all scientific sampling programs for abalone. The literature still describes the classic abalone population structure as being skewed to the right of a length frequency distribution curve (Tegner 1992). This is now known to be representative of less-cryptic adult populations only (Prince *et al.* 1988a). In stable abalone populations recruitment is undoubtedly abundant as measured by McShane and Smith (1991) and although patchy most probably relatively stable over areas the size of a normal reef. In terms of numerical abundance the youngest age classes overwhelm older age classes by several orders of magnitude (Prince 1989). There is good evidence that for abalone (Saito 1984; Prince *et al.* 1988a), as for most other organisms, mortality rates are age related, highest on small abalone with thin shells and lowest for older and larger, thicker-shelled age classes.

Biomass Modelling

Harrison (1983) and Breen (1986) continued the modelling of abalone fisheries during the 1970s and 1980s. Harrison applied Fox's (1970) technique of surplus stock production to the Tasmanian abalone fishery. The essence of surplus-production modelling is studying the relationship between effort and catch in a fully exploited equilibrium stock. The level at which catches plateau, despite growing effort, is considered to be the optimum sustainable yield. However in abalone fisheries the relationship between catch and effort has a surprising tendency to be linear throughout all but the terminal phase of overexploitation (Prince and Guzmán del Próo 1993). A surprising feature of abalone fisheries is that catch per unit effort often increases when effort and thus catches rise (Prince 1989). Harrison applied Fox's modelling procedure to Tasmanian catch and effort data in 1979 and 1983 and in both cases the estimated level of optimum sustainable yield approximated the level at which the fishery was then operating. In his 1983 analysis Harrison invoked a regime of effort standardization to produce discernible plateaus in his surplus production analyses. Without recourse to this, at times apparently spurious correction factor (Prince 1989), this analysis would have undoubtedly failed to derive unique estimates of MSY even fitting by eye.

Breen (1986) applied techniques of stock reduction analysis (SRA) to analyse gross trends in the abalone stock of British Columbia. This technique estimates stock histories using an index of stock abundance showing a decline over time, together with catch records since the fishery began exploiting the virgin stock. The internal structure of the SRA is an age structured biomass model based on Deriso's (1980) equation. Kimura and Tagart (1982) who formulated SRA realised that if the assumption of an equilibrium stock prior to exploitation is accepted, virgin or replacement levels of recruitment can be estimated for any virgin biomass given estimates of natural mortality and growth. Following prevailing opinions about the likely size of unit stocks of abalone (Tegner and Butler 1985) Breen treated the entire B.C. fishery as a unit stock. Using survey data derived from repeated searches in a number of broad locations, together with the assumption of constant recruitment, Breen derived an estimated reconstruction of the stock's history. Breen's analysis indicated a decline of 80-90% in stocks, a decline which had not been mirrored in commercial catch rates.

Modelling Spatial Dynamics

Hilborn and Walters (1987) through participation in Fishing Industry Research Trust Account funded workshops in Australia and by creating models to simulate fleet dynamics across spatially heterogeneous stocks, formalized the concern of Australian abalone biologists about the impact of spatial variability on the analysis of abalone catch statistics. Their simulations indicated that due to the ability of the fishing fleet to allocate effort accross a range of fish stocks the relationship between catch rate and stock abundance was likely to be extremely tenuous for abalone. This simulated result supported the observations of Breen (1986) and were in turn supported by experimental fish-down experiments conducted by McShane and Smith (1989) and Prince (1989). Prince (1989) produced a detailed age and spatially structured simulation model of a single abalone reef. The results of simulations with that model suggested that even within a single reef the aggregative behaviour of abalone together with the behaviour of abalone divers could severely disrupt the relationship between CPUE and stock abundance. The nature of the relationship between CPUE and stock abundance was found to be entirely reliant on the exploitation regime.

Egg Production Modelling

Accepting that the scale of abalone stocks is probably around the scale of individual reefs (Prince *et al.* 1987; 1988b; McShane *et al.* 1988) and that fisheries statistics for abalone probably contain little retrievable information about stock abundance, created something of a vacuum for fisheries managers reliant on monitoring their abalone fisheries using catch and effort statistics. In Australia considerable effort had been spent developing catch and effort databases internationally recognized as being some of the best fisheries data sets in existence (Hilborn personal communication).

Sluczanowksi (1984), however, stepped into this vacuum with his egg per recruit analysis. This used simple biological parameters for an abalone population to assess the level of egg production from an exploited stock in relation to the potential production of the same stock in the virgin state. This analysis is basically a yield per recruit model extended to include parameters that describe age-fecundity schedules. With abalone, as with most marine organisms, the potential egg production of an age class is maximized some time after somatic growth slows and yield per recruit is maximized. The particular importance of this work for abalone was that it allowed the potential egg production of identifiable populations to be ascertained. Moreover it clearly demonstrated that in Australia the size limits applied in the 1960s were almost invariably holding the level of potential egg production too low. The interesting point that Sluczanowksi made was that because adult mortality rates are relatively low, raising size limits to increase potential egg production usually has little impact on long term yields.

McShane (1991) and Shepherd *et al.* (1991) have since used the same techniques to provide assessments of abalone reefs in Victoria, Australia and Baja California, Mexico. The technique is basically a proxy for more rigorous stock assessment because while the relationship between stock and recruitment has not been documented for abalone, the optimal level of egg production which will maximize long term recruitment levels remains unknown. But the technique has led to important realizations. Size limits set on the basis of yield per recruit enforce low levels of egg production per recruit; and suitably spaced pulse fishing can significantly increase egg production without changing size limits or overall yield levels.

The Future of Abalone Modelling.

But, where to now for abalone modelling and management? Some state authorities are now responding to their lack of stock assessment information by developing programs of direct stock surveys. But the chaotic (Gleick 1987) nature of abalone distribution makes quantitative surveying within a single reef complex a non-trivial exercise. This is without addressing the issue of how to scale-up within reef population trends to a wider fishery composed of 100 to 1000s of reefs. But the spatial intricacy of abalone stocks does not just affect stock monitoring. Optimal management of these valuable renewable resources requires management regimes to be developed and implemented on a reef by reef basis. But how can a modern "small government" afford to manage a resource this intensively? Modern governments maintain centralized fisheries agencies in which few staff are dedicated to abalone research, monitoring and enforcement. Data collected in the field, together with compulsory returns from commercial fishermen are fed into large centralized data bases which are rarely analyzed thoroughly due to the shortage of resources. Legislation controlling size limits, quotas and access are necessarily applied over broad areas (often on a statewide basis) because centralized fisheries enforcement agencies are unable to enforce more effective legislation on the spatial scale required. These modern techniques of fisheries assessment and management have been proved effective for fisheries comprising a few large units of stock, but their centralization, and the restricted availability and expense of fisheries expertise make them ill-equipped to manage spatially intricate renewable resources like abalone stocks.

A single reef of abalone less than a kilometre square may be capable of sustaining an annual catch worth $200 000 - $400 000 and commercial divers find it difficult to understand why monitoring and research commensurate with the value of these stocks is not forthcoming. Commercial divers find it difficult to understand that the general public which votes governments into power demands that little of the resource rent the divers pay is actually returned to the research and management process. At the present time Australian governmental fisheries agencies operating under budgetary restraints are unable even to monitor long term trends in abalone abundance, let alone assess the optimal sustainable potential of the resource. Management of the resource continues, quotas for abalone are set annually, but the process is quantitatively blind relying entirely on qualitative anecdotal information provided by the divers.

Many commercial divers who wish to have security in the sustainability of their livelihoods know that some legal fishing practices are inappropriate for particular reefs. But there is no incentive to change diving practices because of the "law of the commons" framework which promotes the thinking "if I don't do it the next person will". The resource is caught in the middle, inadequately monitored and managed, and on many reefs evidently declining.

Where is the way ahead for abalone modelling and management?

Integrated Fish Stock Management Software

Prince and Sluzcanowski (1992; 1993) are proposing that an integrated modelling/software framework should be developed to empower the abalone industry to become self-reliant in accumulating time series data on a reef by reef basis, and developing reef by reef management strategies. This idea has grown out of the model of a single abalone population developed to integrate complex research results (Prince 1989) and which was made visually interactive by Sluzcanowski's Fish Insight group. The resulting software package ABASIM (Prince *et al.* 1991) was widely acclaimed as offering powerful insight into population dynamics of exploited species through its visual and thus intuitive impact (e.g. Megrey 1992; Jacobs 1993).

Specifically designed, integrated and personalized stock management software for laptop computers may provide a way through the present conundrum by empowering a larger number of less technically trained personnel to monitor the abundance of abalone on individual reefs and conduct sophisticated stock assessments.

Specifically designed software could:

- Provide users with visual maps of their reefs showing topographical features and the structure of permanent abalone survey systems.
- Provide spreadsheets into which annual survey data collected by commercial divers could be easily entered, together with annual catch details.
- Analyse survey data to provide maps of stock abundance from which reliable indicators of stock abundance can be estimated.
- Analyse trends in indices of annual stock abundance together with catch trends to provide estimates over time of the relationship between brood stock left on individual reefs and future recruitment.
- Translate the results of complex stock assessment analyses into easily understood moving, colour simulations. This could provide relatively unskilled operators with "flight simulators" of abalone stocks on individual reefs enabling commercial divers to establish their own reef by reef management regimes.

All of these features can be provided by existing software. The power of this concept is in the integration and combination with easily assimilated colour graphics. These factors have the potential to lift the complicated science of fisheries stock assessment out of the exclusive realm of population modellers and stock assessment experts and make them intuitive and easily understood by anyone with a modicum of common sense and interest.

What are the prospects of this idea coming to fruition? Initial development and research suggests that computing power equivalent to a Unix or Sun is probably required to provided the integration of databases, analysis and graphics required. The nature of the industry is that until this sort of computing power is available in a laptop or small portable P.C. the idea will stay locked in the centralized facilities now charged with these roles. However the development of suitable hardware looks to be less intractable than the fundamental issue of resource security.

The system of self-management envisaged here requires individual divers or collaborative groups of commercial divers to have exclusive harvesting rights to particular areas of abalone stock. The management system envisaged will require an additional expenditure of labour and finance beyond that required now simply to collect abalone. Under the present "law of the commons" system of resource management no individual or groups of individuals have the personalized incentive to invest in the long term future. Industry may be expected to use this software to manage individual abalone reefs if they have exclusive harvest rights. An integrated software package could record and analyse annual reef surveys, and catch data. Colour simulations of population dynamics based on analysed trends could translate technical facets of population modelling and assessment. Opportunities could be created for a larger number of less highly qualified stock managers who might become analogous to the game-keepers of a bygone age.

Could this be the way to double the number of fisheries biologists employed in Australia?

Conclusions

The effectiveness of models of abalone stocks has generally been limited by inadequate understanding of abalone biology and the dynamics of abalone fisheries. At the present time our general understanding of abalone biology and our modelling frameworks appear to be sufficiently well developed to support the sustainable management of abalone fisheries. However this goal still appears beyond our reach due to the institutional arrangements we in the western world erect to manage fish stocks. Until effective long term stock monitoring and management can be implemented on the scale of individual reefs it is unlikely that this situation will be seriously improved.

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