

Final Report

Developing a robust new empirically based Harvest Strategy for Gummy Shark

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Biospherics Pty Ltd

FRDC Project 2009/066

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Biospherics P/L



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FRDC Project – 2009-066

Jeremy Prince, Biospherics Pty Ltd

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2009/066 Developing a robust new empirically based harvest strategy for Gummy Shark.

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OBJECTIVES:

1. Develop a new harvest strategy for the Gummy Shark fishery based on empirical indicators.
2. Synthesize existing fisheries and biological data pertaining to the new harvest strategy and document the scientific rationale for the new harvest strategy.
3. Identify critical gaps in information needed to support the new approach and outline and scope the data collection systems, biological research and modeling studies needed to fill the critical gaps identified.

Non Technical Summary:

<p>OUTCOMES ACHIEVED TO DATE</p>

<p>The principle outcomes achieved to date have been:</p>

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| <ul style="list-style-type: none">• SharkRAG & COMFRAB members now have a shared understanding that the estimated trend in adult GS biomass is poorly informed by data, and does not provide sufficient basis for TAC setting.• A simpler and cheaper empirical approach to Gummy Shark TAC setting has been documented and discussed. Agreement has been reached to evaluate and develop it further for provisional implementation.• The 2010/12 Gummy Shark TAC was set on an interim basis using the empirical basis proposed for development, providing proof of the principle.• SharkRAG identified the critical gap in knowledge needed to continue developing the approach is quantitative evaluation and has initiated a proposal for a Management Strategy Evaluation study to develop and evaluate the concept for implementation.• A collaborative proposal, involving Biospherics P/L and CSIRO, was prepared and revised for COMFRAB on behalf of SharkRAG. COMFRAB gave the submitted full proposal a high priority for AFMA funding in 2011/12. |
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The Gummy Shark (GS – *Mustelus antarcticus*) fishery has lands an annual catch worth approximately \$13 million and comprises 15-20% of the value of the South East Shark and Scalefish Fishery (SESSF). The fishery has a long history of stable catches, which successive analyses attribute to recruitment remaining stable since the inception of the targeted fishery in the early 1970s, and there has been little investment in research on the fisheries ecology of Gummy Shark. However, the fishery displays a number of unusual, and poorly understood dynamics, which to some extent are incompatible with standard stock assessment assumptions.

An outcome of this project is that it is now clearly understood by Shark Resource Assessment Group (SharkRAG) members that the while Gummy Shark assessment reliably estimates the stable long term trend in recruitment, estimates of adult biomass are poorly informed by data and relatively unreliable. This shared feature of successive GS assessments was of less importance prior to the adoption of the Commonwealth Harvest Strategy Policy and the de facto decision that GS Total Allowable Catches (TAC) would be based on estimates of adult biomass. Since that decision the reliability of estimate of adult GS biomass has become a matter of some importance. The documents prepared and presented through this project to SharkRAG and the South East Management Advisory Committee (SEMAC) and the discussion these documents have supported in those forums, have enabled a shared understanding to be developed of the poor basis estimated adult GS trends provide for setting TACs. The GS assessment model contains virtually no data on adult biomass and consequently model estimates of current adult biomass are largely unconstrained by data. It emerges that the form of Density Dependence Mechanism (DDM) assumed for the assessment model largely determines the estimated trend in adult biomass and current levels, and a wide range of plausible DDMs exist which we have no informed ability to distinguish between. Despite appearances the model has no predictive value with regard the adult biomass trends.

This context provides the rationale, and creates the need for, the simpler empirical approach to GS TAC setting documented by this project. With the support of this project, SharkRAG identified that the critical gap in knowledge in this case is quantitative evaluation of the concept and agreed to support the development of collaborative Management Strategy Evaluation (MSE) study aimed at evaluating and developing the proposed empirical harvest strategy for implementation. Through this proposal a collaborative proposal was prepared and revised for Commonwealth Fisheries Research Advisory Board (COMFRAB) on behalf of SharkRAG and involving Biospherics P/L and CSIRO. COMFRAB gave the full proposal a high priority for Australian Fisheries Management Authority (AFMA) funding starting 2011/12.

KEYWORDS: Gummy Shark, *Mustelus antarcticus*, empirical harvest strategy

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The members of COMFRAB and SharkRAG are thanked for their support and contribution to the ideas presented here. Professor Norman Hall (Murdoch University) is thanked for his usual expert direction on matters of statistical technique. The Fisheries Research and Development Corporation is acknowledged and thanked for their funding.

Glossary of Acronyms

AFMA - Australian Fisheries Management Authority. The Australian Commonwealth Government's fisheries management agency.

COMFRAB - Commonwealth Fisheries Research Advisory Board. Convened by AFMA to advise itself and the Fisheries Research & Development Corporation about research priorities.

CPUE – Catch per unit effort. Commercial catch rates generally used in stock assessment as an index of biomass.

CSIRO – The Commonwealth Scientific and Industrial Research Organization. The primary research provider for AFMA.

DDM - Density Dependence Mechanism. The population dynamics mechanism that causes exploited populations to become more productive per surviving adult than in an unfished equilibrium. It is this mechanism which gives rise to Surplus Production or Surplus Yield which is the theoretical yield that can be sustainably harvested from a stock

GHATMAC – Gillnet Hook and Trap Management Advisory Committee. The Management Advisory Committee which advised AFMA on management and research of the Gummy Shark fishery. This committee has now been subsumed into the South East Management Advisory Committee.

GS - Gummy Shark *Mustelus antarcticus*.

GVP – Gross value of Production. A measure of the total annual value of the landed catch.

MSE - Management Strategy Evaluation. The fisheries modeling approach to simulation-testing of feedback-control management systems for fisheries management (Punt 2006).

SEMAC - South East Management Advisory Committee. The Management Advisory Committee now advising AFMA on management and research of the Gummy Shark fishery, into which the previous GHATMAC was subsumed.

SESSF - South East Shark and Scalefish Fishery. The umbrella name for the suite of shark and scale fish fisheries managed by the Australian Commonwealth Government's fisheries management agency on the shelf and slope adjacent to Victoria, Tasmania and South Australia in south-eastern Australia.

SharkRAG - Shark Resource Assessment Group. The Resource Assessment Group convened by AFMA to assess the GS fishery and provide advice on research and management for both SEMAC and the AFMA commission. Formerly called the Shark Fishery Assessment Group (SharkFAG).

TAC - Total Allowable Catch. The level of catch set by the ITQ system used to manage the GS fishery.

Background

The Gummy Shark fishery lands an annual catch worth (GVP) approximately \$13 million comprising 15-20% of the value of the SESSF. The fishery has a long history of stable catches which successive analyses show is due to recruitment to the fishery remaining stable since the inception of the targeted fishery in the early 1970s. With the exception of the collection of basic data from the fishery, the original biological studies undertaken by Mr Terry Walker during the 1970s, and the development of an initial stock assessment in the mid-1990s there has been little investment in research on the fisheries ecology of Gummy Shark.

The fishery displays a number of unusual, and poorly understood dynamics, which to some extent are incompatible with many standard stock assessment assumptions. The two most influential features of the fishery's ecology are the strongly dome shaped selectivity so that adult age classes are not fished, and the long-term stability of recruitment at pre-fishery levels. Together these features have caused annual catches of Gummy Shark to remain stable despite an initial fourfold increase in fishing effort, from the fishery's inception in the early 1970s through to the beginning of management in the late 1980s, and a subsequent managed effort reduction of 60-70% through to the present day. This stability of catch over a wide range of fishing effort gives rise to a strong negative relationship between the level of fishing effort and catch rate, which confounds the standard assumption that catch rate is an index of abundance. Historically low priority has been placed upon studying and understanding the dynamics underlying the extraordinary stability of catch.

During the late 1990s Dr Andre Punt as chairman of SharkRAG developed the synthesis stock assessment for Gummy Shark. The assessment confirmed that recruitment remains stable at pre-fished levels, but estimated that adult biomass has declining to around 35-45% of pre-fished levels and was still declining. At the time SharkRAG recognized that the actual dynamics of the fishery violated several fundamental assumptions of the model, and that consequently some aspects of its analyses are unreliable (Punt 2000; SharkRAG 2000). It cannot be said that SharkRAG as a group fully understood the detail of that acknowledgement which, as this report documents, means that estimates of recruitment trends for the fishery are robust and conclusive, but that estimated trends for adult biomass are unreliable, being a result of underlying assumptions which are poorly informed by data. At that time with less understanding, and because of the underlying stability of recruitment, and the positive management trends being observed, relatively little importance was attached to resolving the latter aspect of the assessment.

Cognizant of the dynamics of the fishery, and to some extent ignoring model estimates that initially suggested higher TACs were possible (Punt 2000; SharkRAG 2000), in 2001 SharkRAG and the Gillnet Hook and Trap Management Advisory Committee (GHATMAC) recommended that the TAC for Gummy Shark be set at the level of the long term average catch, and the TAC was reduced to 1800t from the level of 2100t set in 2000. The TAC has remained at 1800t through until 2010. The stated aim of the TAC reduction in 2001 was to drive catch rates higher and effort lower and it has been successful; levels of effort, catch rates and body sizes have all risen back to levels last observed in the late 1970s, soon after the fishery first developed. The most recent economic analyses of the SESSF suggest this sector of the fishery is the best performing sector.

Need

The adoption of Harvest Strategy Policy which mandates managing to a default of 48% of virgin biomass and the de facto decision that TAC levels would be set in relation to modeled estimates of adult Gummy Shark biomass has increased the importance of understanding the reliability of the adult biomass estimates that should now be driving TAC levels.

The first need addressed by this project was to establish the actual basis of the adult biomass estimates used in TAC setting for this fishery and document for the first time the problematic nature of using those estimates for TAC setting.

Over and above the need for an accurate stock assessment and a reliable basis for setting TACs under the Commonwealth Harvest Strategy Policy, there is growing public concern at the general unsustainability of most shark fisheries. To date this is being reflected in the Commonwealth Environment Department placing increasingly stringent Wildlife Trade Organization conditions on the shark fisheries managed by the states, and calls by some Non-Government Organizations for the closure of all shark fisheries. In this policy climate it can be predicted that the Gummy Shark fishery will be subject to increasingly strident demands to prove its underlying sustainability. In this environment the existing stock assessment, with its acknowledged weaknesses had become a liability. However, the unusual nature of this fishery's dynamics means that the current assessment cannot be simply improved by elaborating on standard assessment approaches, a better understanding of the underlying biology which give rise to this stocks unique dynamics is needed so that an individually tailored harvest strategy can be designed, justified and developed.

The second need this project addressed was documenting a SharkRAG, SEMAC and COMFRAB supported proposal for a simpler alternative empirical harvest strategy for GS TAC setting and preparing R&D proposals to support its development and implementation.

Objectives

1. Develop a new harvest strategy for Gummy Shark fishery based on empirical indicators.
2. Synthesize existing fisheries and biological data pertaining to the new harvest strategy and document the scientific rationale for the new harvest strategy.
3. Identify critical gaps in information needed to support the new approach and outline and scope the data collection systems, biological research and modeling studies needed to fill the critical gaps identified.

Methods

This project supported SharkRAG initiating a process for developing and implementing a new empirical harvest strategy for the Gummy Shark fishery.

The main components of the project were:

1. A desktop top study and analyses using existing information.

This primarily involved synthesis of past GS shark grey literature and analysis of catch & effort summary data provided by Walker and Gason (2009) and AFMA using Excel spreadsheets developed to prove the principals. Prof. Norm Hall and Hilborn & Mangels (1997) provided assistance in developing simple routines for estimating confidence intervals around the catch and effort model fitted to the historic data.

2. Review in the light of SharkRAG comment and modify the proposed approach and to identify critical knowledge gaps and implementation issues.

The project provided documents and powerpoint presentations to support discussion at meetings of SharkRAG in November 2009 (Appendix 3), and April 2010 (Appendix 5). The November 2009 powerpoint presentation was also used at the July 2010 SharkRAG meeting to initiate and structure discussions on the topic with Dr Andre Punt.

The project also provided a document and powerpoint presentation to the SEMAC TAC setting meeting in January 2010.

3. Documentation of the scientific justification of the approach, and further studies and data collection programs needed to implement the approach.

At the direction of, and with the support of SharkRAG, a proposal was developed for a collaborative Management Strategy Evaluation (Punt 2006) of the proposed empirical approach. The full proposal was developed and received a high priority from COMFRAB for AFMA funding starting in 2011/12.

Results/Discussion

Synthesis

The key feature of this fishery's dynamics include:

- The fishery is concentrated within a limited area of the species range (approximately <10-15%).
- Limited dispersal rates within the species range (approximately 35-50km/y)
- A behavior related dome shaped selectivity curve for the fishery that goes beyond the selectivity of the mandatory 6-6.5" mesh size, so that even within the fishing grounds adult age classes are not captured by the nets (Punt 2000b). Within the fishing grounds the fishery acts like a gauntlet fishing on just four sub-adult and maturing year classes (4-7 year olds). If GS survive the gauntlet of the fishery they grow into the relatively unfished adult population.
- The GS fishery has a long (40 yr) history of stable catches over a wide range of effort levels which successive analyses (e.g. Prince 1994, Punt 2000a, SharkRAG 2000, Punt et al. 2004a&b, Walker 2009) conclude is due to recruitment remaining stable since the inception of the targeted fishery in the early 1970s which is some 5-7 GS generations ago.

The biological mechanism for this stability of recruitment is not clear since, at least within Bass Strait earlier analyses suggested that during the 1980s and early 1990s fishing should have been heavy enough to close off the gauntlet almost entirely,

reducing survival to adulthood low enough for long enough to run down the parental biomass (Prince 1994, Punt 2000a, SharkRAG 2000, Punt et al. 2004a&b). More recently Walker (2009) and Punt & Thomson (2010) have estimated that the 1980s depletion cannot have been so extreme as earlier estimated, presumably because recruitment to the fishery continues to be stable. However, the current models assume DDMs which allow for extremely high survival rates of pups through to adulthood to explain observed trends. During discussion of this issue in June 2010 SharkRAG discussed the merit of scrutinizing the model estimated rates of survival during the period of most intense fishing, because it could be that some modeled scenarios require survival rates that are implausibly high. This was suggested as a diagnostic which might be used to narrow the range of alternative DDMs currently considered plausible.

Whatever, the mechanism that provides constant recruitment to the fishery, the constancy and level constrains the level of catch. Since the 1970s, in Bass Strait, and 1980s in SA, the catch has remained around the same level while effort has varied several-fold. This annual stability of the catch over a wide range of historic effort levels gives rise to a strong negative relationship between annual effort and annual catch rate which confounds the standard assumption that catch rate is an index of abundance. In this case the fishable biomass is remarkably stable being determined by annual recruitment, while catch rates maybe highly variable over time, depending mainly on annual effort levels.

Implications of the Stable Recruitment Based Fishery

The main implication of these dynamics for the synthesis stock assessment models is that the commercial catch rate data, which comprise most of the information being analysed, contain little information about the abundance of the fished year classes (SharkRAG 2000). This is because CPUE rises and falls in relation to how much effort is in the fishery while annual recruitment and the size of the fished biomass remains relatively constant. Furthermore because the adult age classes are not fished nor surveyed the assessment contains no trend data for adult biomass. The result of this is that the estimates of current adult biomass which are critical to the application of the Tier 1 Harvest Strategy are entirely peripheral to this analysis, and are not ‘fitted’ or ‘tested’ against any trend data.

If this is the case, what are the estimates of adult biomass trends based upon?

1. The synthesis model derives good estimates of the original and current level of recruitment precisely because the catch of just a few years classes has remained so stable for multiple generations of GS over a wide range of effort levels.
2. Given this estimate of initial recruitment, and given an assumed Density Dependence Mechanism (DDM) the model can estimate the original number of adult required to produce the original level of recruitment, and this becomes the starting estimate of Adult Biomass.
3. Current adult biomass is then estimated by extrapolating from this initial estimate of Adult Biomass for the effects of catch, growth, recruitment and natural mortality over 40+ annual steps. At no point of this extrapolation process are estimates of Adult Biomass fitted to data.

Importantly these extrapolated estimates of adult biomass trend are not tested against any data because there is no data on adults. The extrapolated estimates of adult biomass are only loosely constrained by the assumed form of the DDM, estimated rates of natural mortality, and the need to match the virgin level of recruitment observed in the fishery. More or less as long as a modeled adult trajectory does not collapse to zero through the time series, and can support current catch levels it will be accepted by these models as fitting the data. Given the flexibility provided by the range of plausible DDMs available a large number of possible adult biomass trajectories are equally plausible (Punt & Thomson 2010).

In parallel to the assessment logic assembled above, by this project and presented for debate by SharkRAG in November 2009, Dr Andre Punt completed a long held aim of his which had been to convert his original synthesis assessment of Gummy Shark (Punt 2000) into the newer SS2 assessment framework. Upon doing this Dr Punt discovered that the SS2 model predicted significantly different trends in adult biomass. After conducting diagnostics he also concluded that the estimated adult trajectory is heavily influenced by the choice of DDM assumed (Punt Personal Communication). Dr Punt confirmed this in discussion at SharkRAG in July 2010 and consequently agreed to incorporate uncertainty around DDM as an explicit part of the most recent Bayesian analysis. Consequently the latest assessment (Punt & Thompson 2010) presented to SharkRAG in Sept 2010 integrates its confidence intervals around estimates over multiple equally plausible forms of DDM, and predictably shows that we are much less certain about adult biomass trends than previous analyses that used a single assumed DDM.

Developing a Reliable Harvest Strategy for Gummy Shark

Accepting that there is an issue that prevents the current assessment reliably estimating adult biomass the question becomes what to do about a harvest strategy for Gummy Shark?

There are essentially two alternatives;

1. Solve the fundamental uncertainties about the fisheries dynamics, stock size and structure by collecting data on the abundance of adult Gummy Shark and rework an integrated quantitative model to produce reliable estimates of biomass.
2. Use the simple but informative data available from the fishery to develop an empirical based harvest strategy for GS based on easily estimated recruitment trends.

The first alternative is problematic, expensive and even if successful will take some time, probably 5-10 years, to develop a time series of adult abundances, along with an inherently risky investment in biological research to fill essential gaps in understanding about GS DDM and stock structure. There is no guarantee that an expensive program of research would adequately resolve the biological issues, and the fishery would be permanently encumbered with the surveys of adult abundance and expensive forms of modeled based stock assessment. Alternatively if simple data can be gathered from the fishery and used empirically and simply to set TACs there could potentially be great cost savings in assessment and management for the fishery.

Early discussions about this initiative in June (2009) between Jeremy Prince (Chair SharkRAG), Tony Smith and Geoff Tuck (CSIRO), Shane Gaddes (AFMA) and Beth Gibson (AFMA) decided that the first course of action involves the risk of biological research proving inconclusive with respect to the main issues, along with the long term expense of biomass surveys. Consequently it was decided that the preferred direction was to develop simple empirical indicators for TAC setting. If possible using aspects of data already, or easily, collected from the fishery. Indicators which previous experience suggest have proved informative to the assessment, and apply them in a manner, which is robust to biological uncertainties, by planning around the acknowledged uncertainties.

A parallel model of an empirical Harvest Strategy is also being developed in the ECTBF using catch rate target and size structure data within a Decision Tree framework to incrementally adjust TACs, and is accepted within the Commonwealth Harvest Strategy Policy (Anon 2007, Prince et al. 2010).

Harvest Strategy Outline

A Simple Fisheries Model as the Basis for an Empirical Gummy Shark HS

The dynamics of the GS fishery conform to a very simple model of catch and effort described by Beverton and Holt (1957), which describes a fishery competing for shares of an annual fishery with an average annual fishable biomass.

The model is described with the equation.

$$\text{Catch} = \text{Av. Biomass} \times (1 - e^{(-A \times \text{effort})})$$

This equation simply implies that the fishery gets a proportion of the annual Average Biomass which is proportional to the amount of effort applied at low levels of effort, but at higher levels each additional unit of effort becomes progressively less effective, contributing more to a general decline in catch rates than to increasing total catch towards its limit. This equation has now also been adopted in the latest GS assessment by Punt & Thompson (2010) to describe the dynamic of this fishery. A simple analysis of the GS catch and effort data using this model is presented here by way of proving the principle underlying the proposed empirical harvest strategy for GS. The limitations of this analysis are acknowledged but not elaborated on, it is anticipated that future stages of modeling and evaluation will quickly make this rudimentary analysis obsolete.

The simple catch and effort model advanced here has been fitted to the catch and effort data (1971 – 2006) taken from Walker & Gason (2009). The landings data for Victoria and Tasmania have been combined because the fishing fleets landing into each state principally fish the same fishing grounds in and around Bass Strait. The South Australian fishery is treated separately because their fishing grounds are distinctly distributed between Robe and the Eyre Peninsula (Figure 1a & b). Relationships were fitted to each of these two broad areas of the fishery using Excel Solver to minimize negative log-likelihood functions, as described by Hilborn & Mangel (1997), to estimate the parameter A, which scales how flat and abrupt, or smooth and curved the relationship is between catch and effort, and the Average Biomass (t. carcasse wt.) in the fishery. Confidence intervals ($\pm 95\%$) around these parameters have been estimated

using the techniques described by Hilborn & Mangels (1997) and involves plotting the negative likelihood function against fixed values of the parameter around the best fitted value.

The parameters ($\pm 95\%$) fitted to the Victorian and Tasmanian C&E data were:

$$\text{Av. Biomass} = 1134, (1040-1275)$$

$$A = 0.100, (0.064-0.21)$$

The parameters ($\pm 95\%$) fitted to the South Australian C&E data were:

$$\text{Av. Biomass} = 591, (518-710)$$

$$A = 0.059, (0.041-0.082)$$

The fitted models are shown in figure 1 a&b. Confidence intervals ($\pm 95\%$) around these relationships have also been estimated on the basis of the variation of the negative likelihood function around the fitted relationship, also as described by Hilborn & Mangel (1997).

These relationships can be used to predict future levels of catch, effort and CPUE in the fishery, and to detect departures from these observed relationship.

In fact SharkRAG has been implicitly using this approach to recommend TACs since September 2001 when SharkRAG argued that the current TAC level should be set around the level of the long term average catch (approximately 1700t for the gillnet sector, 1800t total), rather than the 2100t initially set using the synthesis model (SharkRAG 2000). SharkRAG's implicit approach has successfully managed the fishery back from moderate to high effort levels, down to moderate to low effort levels since 2001 while under a stable TAC. The long period of sustained moderate effort levels is now apparently fostering a yield per recruit increase for the fishery, as average carcass weights have returned from the 2.5kg averages seen in the early 1990s towards historic maximums observed of about 4kgs carcasse weight.

Accepting that these predictable relationships exist and that future catch levels can be confidently predicted, departures from the normal state of steady recruitment can be reliably detected, and used as the basis for a harvest decision rule.

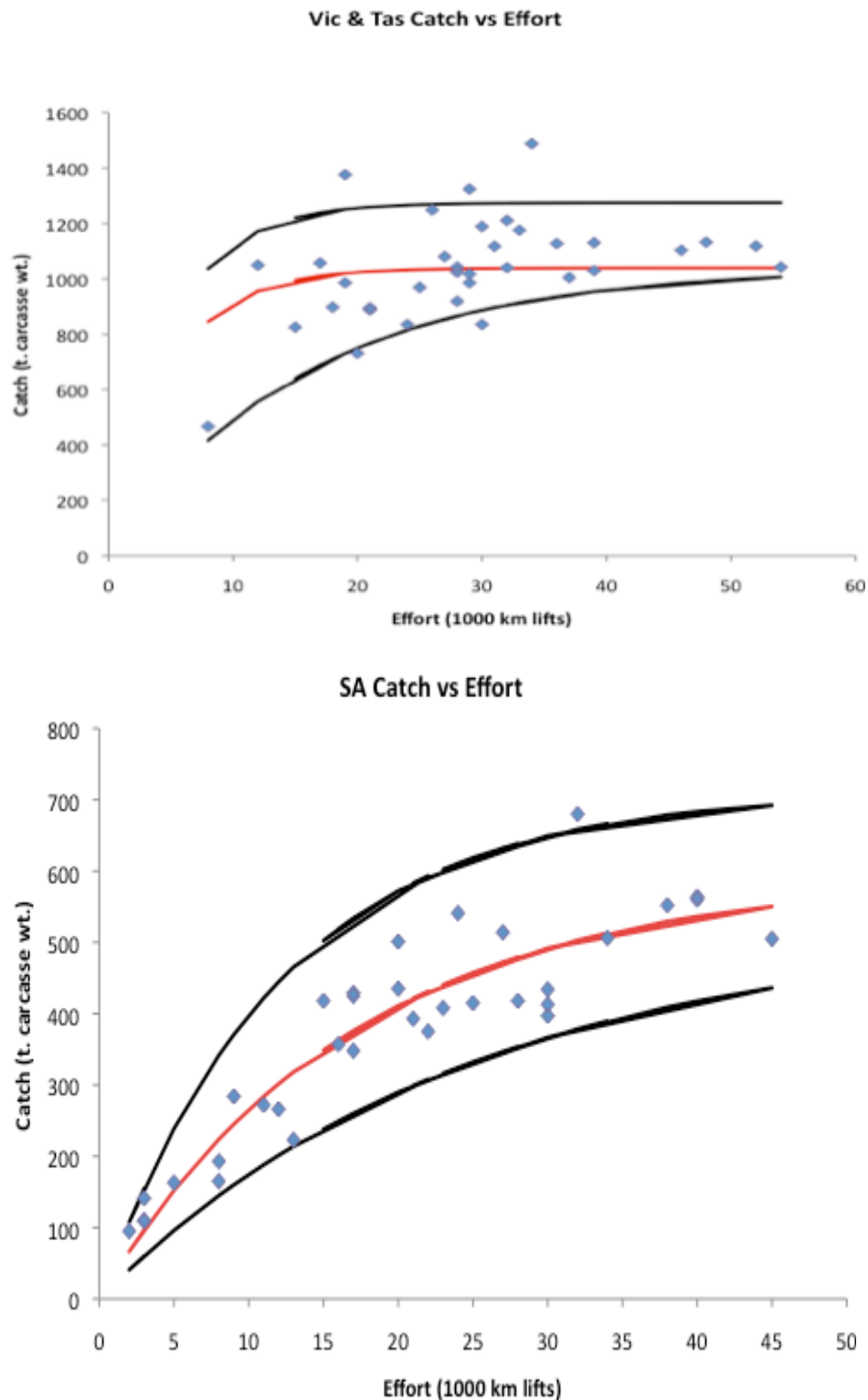


Figure 1 (A & B). Plots of the relationship between annual catch (t. carcass wt.) and annual effort (thousand km. lifts) for Gummy Shark from 1971 to 2006 for catch landed into (A) Victorian and Tasmanian ports (combined) and (B) South Australia. The fitted relationship is shown by the red line with the upper and lower 95% confidence intervals by black lines. Data source Walker and Gason (2009).

The factors underlying any departures from the relationships plotted in figures 1 A & B should be indicated by where the new (aberrant) data points fall relative to the historic relationship:

1. Because the fishery depends principally on just four year classes of sub-adults a decline in recruitment in any year will produce a rapid decline in catch and catch rates, and probably a concurrent increase in effort as quota holders struggle to fish up to the TAC under more difficult circumstances. In this case new data points will fall below and to the right of the historic relationship determined by the constant recruitment.
2. Alternatively because the fishery has not previously fished stably for any period of time at the current moderate to low effort levels an increase in yield per recruit from the fishery might be expected, and this should cause new data points begin to fall outside the observed relationships in the top left hand side of the plots,
3. Alternative the development of previously unfished areas in the far west of South Australia, or off the eastern, southern or western coasts of Tasmania could cause data points to fall above the relationship, most probably in line with the initial linear part of the curve. Spatial analysis of catch returns will be indicative in this situation, and changes in the effective area of the fishing grounds incorporated into the TACs.

The proposal advanced here, and illustrated by the indicative figure 2, is to use the simple relationships between catch and effort observed in this fishery as the primary part of an Empirical Harvest Strategy for GS. The primary logic being that, if catch, effort and CPUE continue to conform to the observed relationship this indicates that the stable virgin level of recruitment giving rise to the relationships is continuing, in which case the current level of TAC can be safely continued. Conversely, any significant departure from this historic relationship will indicate change to the relationship, and that TAC levels should be changed incrementally to restore the relationship (Figure 2).

This proposal is to develop and extend this approach in the medium term (1-3 years) preparing for long-term implementation into the fishery. This process of development and implementation would begin with an MSE analysis (Punt 2006) of the proposed empirical harvest strategy rigorously testing the scientific basis of the approach, and in the process developing the algorithms that would be required eventually for implementation.

During 2010 SharkRAG supported preparation of a collaborative research proposal to this effect to begin in 2011 and COMFRAB has gave the proposal that was submitted for funding in 2011/12 a high priority for AFMA funding. Extension of the approach would involve establishing catch and catch rate targets which will have merit both as indicators of continuing stable recruitment, and as a measure of Optimal Economic Yield being the optimum level of effort required to take the chosen catch level. The harvest strategy would apply rules reflecting the type and magnitude of deviation from the target to make incremental changes to the TAC which would be designed through this MSE evaluation to push catch and effort levels back towards the target equilibrium level of catch, CPUE and profitability (Figure 2).

The use of size and/or age data in the harvest strategy

The sub-adult GS being fished are growing relatively rapidly as they move through the gauntlet of the fishery so that size composition of the catch can be expected to be, and anecdotally at least has been, a useful indicator of fishing pressure (F) as well as recruitment trends.

The incorporation of regional size composition data would probably greatly enhance the basic empirical Harvest Strategy proposed above by providing an independent index of regional fishing pressure (F), year class strength, and changes in yield due to changing yield per recruit. In figures 1 & 2 the annual level of effort is plotted along the x-axis, which like size composition in the catch provides an index of fishing pressure in the fishery. Combining these two independent estimators of regional F within some form of a decision tree format similar to that developed for the East Coast Tuna & Billfish Fishery (Anon 2007, Prince et al. 2010) would make the approach more robust by providing multiple indicators of fishing pressure, and possibly allow for graduated changes to the TAC should a recruitment decline ever be detected, or to reward the yield per recruit gains that recent moderate levels of fishing effort appear to be producing in the fishery.

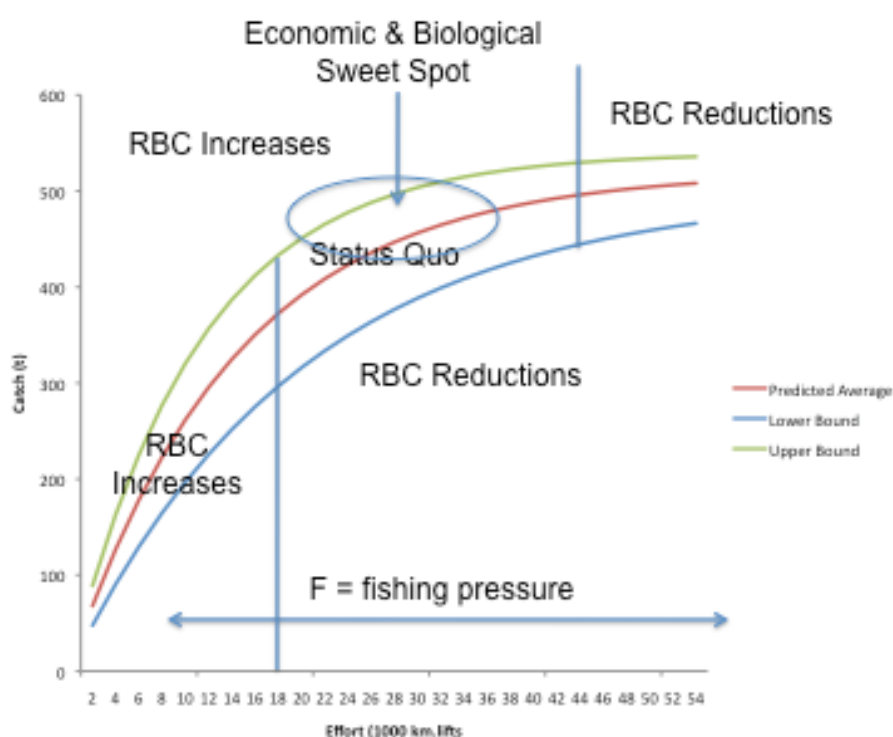


Figure 2. Schematic of a potential empirical harvest strategy for GS based on historic relationship between catch and effort. Potentially size or age structure could be incorporated into the harvest strategy providing an independent index of F and recruitment.

Regional Structure of the harvest strategy

Clear regional differences in the size and age of GS have always been a feature of the fishery, and this and other evidence suggests the GS stocks are strongly regionalized.

Long term implementation should be at a regional scale, probably an amalgamation of the statistical cells developed and used by SharkRAG, but based on mapped patterns in fishing effort and commensurate with the scale of GS movements (30-50km.yr⁻¹). In the interim an approach based on historical state landings as documented by Walker & Gason (2009) was used in 2010 because it is feasible within the resources and time available.

An Interim Approach to GS Harvest Strategy

Figure 2 illustrates the interim approach to TAC setting in the GS fishery suggested to SEMAC by this project (Appendix 5). The approach involves determining whether recent catch and effort data (2007, 2008 & 2009) conform to the historic (1971-2006) catch and effort relationship for Victorian and Tasmanian landings (combined) and for South Australia, figures 1a and 1b respectively.

The suggested decision making process for the interim was:

- If recent data continue to conform to the historic relationship determined by stable virgin levels of recruitment, or fall above the relationship, this will be taken to indicate that recruitment has continued to remain stable at pre-fished levels and the RBC should continue to be the current status quo.

or

- If the recent data fall below historic relationship the RBC should be reduced initially by 50% of the estimate Average Biomass of the effected region in the first year, and 25% of that amount for each subsequent year that Catch and Effort data for that region remain below the historic relationship.

Application of the Interim Gummy Shark Harvest Strategy

In December 2009 Mr Shanne Gaddes of AFMA provided the most recent three years of catch & effort data which were inserted into this analysis. Figure 3 A & B shows the same catch & effort relationship described above for the GS data 1971-2006, in this figure the most recent data (2007-2009) also plotted and identified for comparison. From this it can be seen that the most recent data conform with the trends observed since the inception of the fishery suggesting that recruitment to the fishery remains stable around virgin levels. Both the 2009 data points are low (i.e. low effort and low catch) presumably partly because at the time they were extracted (early December) they are still incomplete. Never the less, even incomplete it can be seen they fall within the range of the historic C&E relationship.

Interim TAC for 2010

The three most recent data points (2007-2009) lie within the historic catch & effort relationship indicating that recruitment continues to be stable around pre-fished levels and under this proposed interim Harvest Strategy for GS this justifies the RBC being maintained at the status quo TAC that has been applied to the fishery since 2002.

This advice was endorsed by SEMAC (January 2009) and COMFRAB (February 2009).

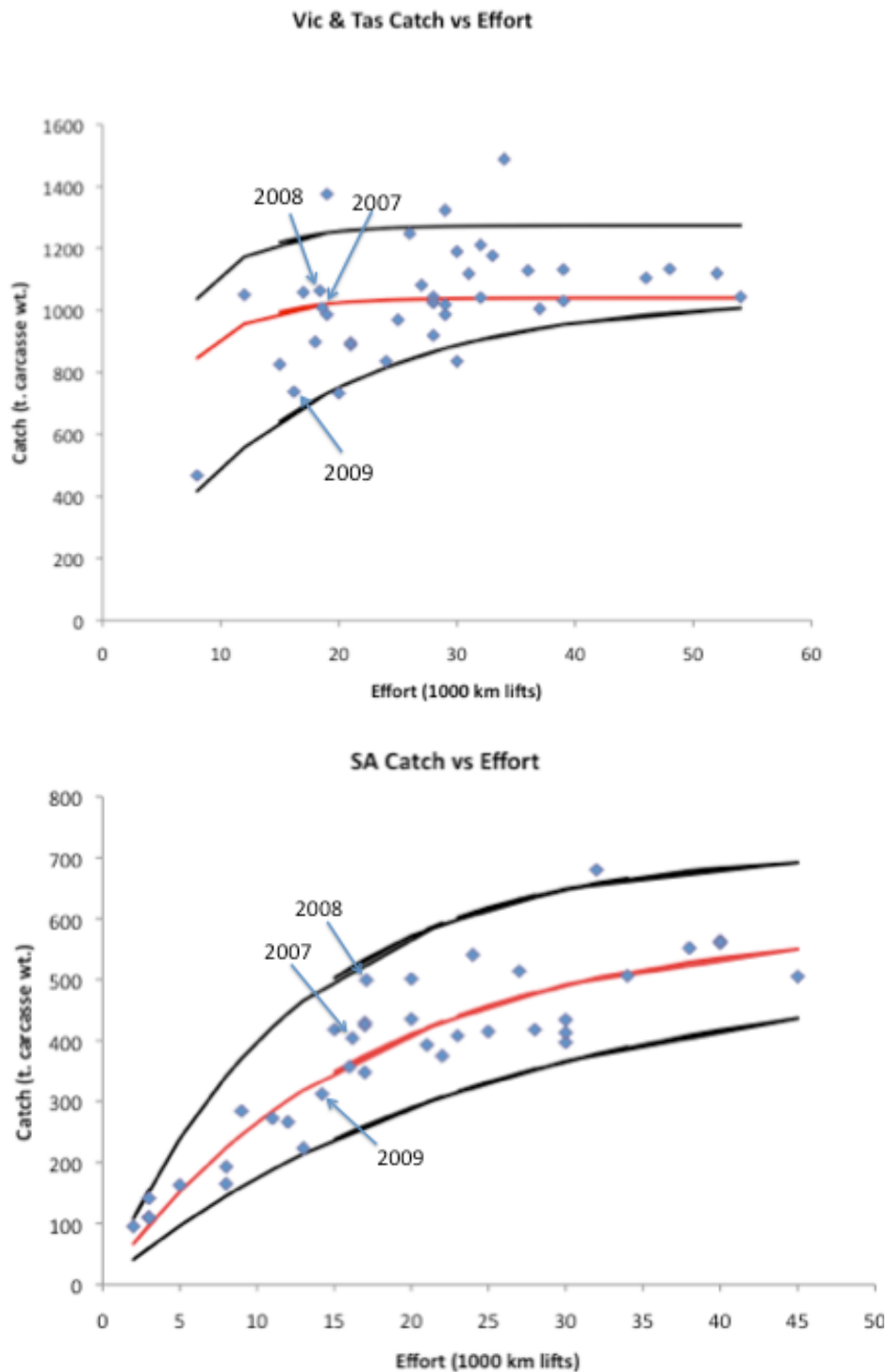


Figure 3 A & B. Plots of the historic relationship between GS catch and effort for (A) combined Victorian and Tasmanian landings and (B) South Australian landings, showing the relationship (red line) and estimated 95% confidence intervals (black line). It was proposed in the interim Harvest Strategy that the lower confidence interval should be used as the threshold for TAC reductions, as new data points below that level could be indicative of an unexpected decline in recruitment. The three most recent data points are plotted and indicated. Note that 2009 data points were incomplete at the time this figure was prepared.

Benefits

The long term benefits of this project will be more reliable, robust and cost-effective TAC setting for the Gummy Shark fishery and the direct beneficiaries of this will be stakeholders in the Gummy Shark fishery and SESSF fishery more generally, along with AFMA and its TAC setting process which will benefit from stability and less uncertainty.

Through 2009 and 2010 the output from this project used in both SharkRAG and SEMAC successfully demonstrated the proof of principle that simple empirical indicators can be used to set TAC levels by having the principal adopted in the interim for setting the 2011 Gummy Shark TAC.

An outcome of this project is that it is now understood by SharkRAG & COMFRAB that the Gummy Shark assessment's estimated trend in adult biomass is poorly informed by data, and does not provide a reliable basis for TAC setting. Industry, managers and scientists associated with the SESSF fishery now seem broadly aware of the need for a more robust basis for GS TAC setting as well as the potential cost savings from developing a simpler cheaper approach.

The beneficiaries of a successful and cost-effective new empirical harvest strategy will be the members of the SESSF industry for which Gummy Shark comprises 15-20% of the GVP. The benefit will be in the form of reducing the risk that arbitrarily large TAC increases or reductions will be driven by highly uncertain data poor modeled estimates of adult biomass, and in reducing the cost of setting Gummy Shark TACs, by using simple fisheries derived data, and reducing the reliance on annual or bi-annual quantitative assessments.

Further Development

Introduction

The basis for this section was a discussion document on the R&D needed to support further development and implementation of the empirical GS Harvest Strategy that was developed through discussion at SharkRAG November 2009, and then presented as a discussion document for SharkRAG April 2010 (Appendix 4). That content has been re-edited for this report in the light of subsequent SharkRAG discussions during 2010.

1. Assessment Modelling

Both Punt and Prince are agreed that the biomass trends estimated by the GS assessment model are determined by the nature of the assumed density dependence mechanism (DDM) and cannot be relied upon for reliably setting TACs. For SharkRAG's and SEMAC's process there was a need to update the existing assessment model in 2010. For the first time the assessment framework explicitly incorporated a plausible range of DDMs, rather than the previous single assumed DDM, and predictably the results showed that there are many plausible trajectories for adult biomass and the assessment is highly uncertain about current adult biomass levels (Punt and Thompson 2010).

This updated assessment model will provide a useful basis for developing the 'operating model' that will comprise part of the MSE model which is proposed for development. It is proposed that Robin Thompson (CSIRO) who worked with Andre Punt on the most recent GS assessment will work closely with Sally Wayte (CSIRO) who will develop the MSE framework that will be used to evaluate and develop the empirical indicators concept further.

2. Developing Empirical Indicators - Harvest Strategy Evaluation

Every new approach to Harvest Strategies should be quantitatively tested and developed through Management Strategy Evaluation (MSE) and SharkRAG emphatically recommended that this should be the next step for this proposal to develop empirical indicators for the GS fishery.

In the Management Strategy Evaluation approach the fishery is modeled by an 'operating model' which will incorporate GS biology and plausible population structure hypotheses, along with models of the fishery. Much of the operating model will be based on the core fisheries model developed by Punt & Thompson (2010) for the stock assessment. Within the MSE framework the operating model of the fishery is treated as if it were multiple alternative versions of the 'real' world, and then a computing framework is developed which allows the relative effectiveness of alternative forms of Harvest Rules to be evaluated, across the different possible versions of the real world we face. MSE can be used to evaluate the alternatives and examine how robust they are to our acknowledged uncertainties. Through this form of analysis an optimal set of robust rules can be developed and the efficacy documented for incorporation into the new empirical Harvest Strategy.

Once developed the MSE framework will also be used to evaluate and quantify the robustness of the proposed Harvest Strategy relative to the standards laid out by Commonwealth Policy.

Any important aspect of this project will be the development of techniques for informing the basic empirical indicator based on catch and effort data, with data on size in the GS catch data. From my own observation over time and the performance of the synthesis model in this regard it appears that size in the catch has been a reliable indicator of local fishing pressure. Likewise with only 4 main year classes in the fishery the size in the catch can be expected to be an effective indicator should recruitment to the fishery become unstable. Local size in the catch could be incorporated into an empirical GS harvest strategy adding value to the interpretation of basic catch and effort trends and potentially some level of proportionality to TAC changes should recruitment destabilize. The methodology for doing this would need to be developed. This methodology will need to be developed before Harvest Rules based around it can be evaluated through MSE evaluation. The MSE will also need to test for the effects of different plausible DDM and stock structure assumptions.

Through this project SharkRAG supported the development of a collaborative proposal for MSE evaluation of the proposed empirical indicators which is being supported by COMFRAB for AFMA funding in 2011.

3. Development of Systems for Collecting Regional size in the catch data

It is likely that regional patterns in size in the catch will be useful empirical indicators of regional stock trends. Local movement patterns of GS suggest these data need to be collected with high spatial resolution and so are better collected at sea before stowage rather than upon landing, so these data would ideally be collected by industry members at school under some form of industry data collection program. It is the recommendation of SharkRAG that the new Sustainable Shark Industry Association should be resourced with R&D funding so that some form of data collection at sea program can be re-developed and implemented with the intention of it eventually being taken up by a high percentage of the fleet.

Punt (2000a) produced evidence the size of GS varies between targeted and untargeted shots, and the former ‘first shot’ design trialed in the fishery may need to be reconsidered if the aim of the data collection becomes the size structure typical of the catch. It maybe that the former design needs modification, or the addition of a specific ‘targeted GS’ measuring protocol in addition the multi-species first shot measurements. These are all issues that an industry project could tease out in collaboration with SharkRAG.

4. Basic Biology supporting an Empirical Approach to Harvest Strategies

In today’s funding environment it is difficult to find funding for basic biology when all the biology essential for parameterizing stock assessments is already well documented.

However the course of modeling decided upon will inevitably raise a range of basic issues of Gummy Shark fisheries biology and ecology, and the rising political heat around the sustainability of elasmobranch fisheries suggests there will be growing expectations on the quality of the scientific justification underlying sustainable shark fisheries.

Fundamentally with GS the core fishery dynamics remains highly uncertain and almost unstudied in any formal sense. Core questions about the nature and extent of the fishing grounds, the nature of the aggregations being fished and the reasons GS aggregate on the fishing ground, all remain undocumented. Biological programs targeted at central features of the fisheries dynamics would allow a coherent scientific ‘story’ of the features underlying this fisheries sustainability, and so set SharkRAG for the defence of the fisheries sustainability.

Approaching from the modeling and assessment perspective, the 2010 assessment confirms that DDM assumptions determine the estimated trend in adult biomass. SharkRAG in September 2010 began discussing the plausibility of alternative DDMs which requires knowledge of juvenile – adult interactions, habitat partitioning and stock structure. Greater knowledge might allow alternative DDM hypotheses to be distinguished between.

Likewise the MSE will need to develop an operating model that can simulate a complete range of plausible DDM hypotheses to test for the effects of different plausible DDM and stock structure assumptions.

All these discussions will highlight the need for simple cost effective biological studies targeted at the key diagnostic issues for the fishery's dynamics.

Planned outcomes

During 2009 and 2010 this project supported SharkRAG initiating a process of developing empirical indicators for TAC setting in the Gummy Shark fishery. These discussion culminated in a decision by SEMAC to trial an interim empirical approach to TAC setting in January 2010, and in the development of collaborative COMFRAB supported proposal to develop further, test and evaluate the implementation of an empirical approach to TAC setting in the Gummy Shark fishery.

The output proposed for this project was:

1. The outline and scientific justification for a new harvest strategy for Gummy Shark based on simple empirical indicators derived directly from the fishery.
2. A series of documents that support SharkRAG:
 - A. Developing the new harvest strategy for implementation.
 - B. Developing robust scientific justification for the new harvest strategy.
 - C. Identifying critical gaps in knowledge needed for A and B.
 - D. Initiating the development of pre-proposals during 2010 aimed at filling those critical gaps.

The output of this project has been:

1. An outline and scientific justification for a new harvest strategy for Gummy Shark based on simple empirical indicators derived directly from the fishery.

An edited version of this is documented in the Results Section of this report. The original version of this document were prepared, through this project, for SharkRAG in November 2009 (Appendix 3) and SEMAC TAC Setting Meeting January 2010 (Appendix 4).

2. A series of documents that support SharkRAG:

- A. Developing the new harvest strategy for implementation (Appendix 3 & 4).*
- B. Developing scientific justification for harvest strategy (Appendix 3 & 4).*
- C. Identifying critical gaps in knowledge needed for A and B (Appendix 5).*

- Appendix 3 SharkRAG November 2009 Development of a robust assessment model for Gummy Shark.

- Appendix 4 SEMAC TAC Setting Meeting January 2010. An interim Approach to an Empirical Harvest Strategy for Gummy Shark
- Appendix 5 SharkRAG April 2010. Proposed R&D needs to Develop Empirical Indicators for GS.

D. Initiating the development of pre-proposals during 2010 aimed at filling those critical gaps.

- Pre-proposal for COMFRAB – June 2010
- Revised pre-proposal for COMFRAB – August 2010
- Full Proposal for COMFRAB – November 2010

The outputs of this project documenting the concept of empirical indicators for the Gummy Shark fishery allowed the members of SharkRAG and COMFRAB to envisage and discuss the concept. This discussion developed a unified body of support for developing the concept further through a structured Management Strategy Evaluation study.

A further output of this proposal has been a pre-proposal for the current funding round. COMFRAB has requested that the pre-proposal be developed into a full proposal and is giving it a high priority for AFMA funding in 2012. A full proposal is being prepared.

A further outcome of this project was that the Interim Harvest Strategy accepted by SEMAC allowed the TAC to be set for 2010/11 and established the principal of the empirical approach to harvest strategies.

Extension:

Phase 1. Interim Gummy Shark Harvest Strategy for 2010.

The first phase of the extension of this projects outputs occurred at the November 2009 SharkRAG meeting when the first draft outline and scientific rationale an empirical approach to TAC setting for Gummy Shark was presented (Appendix 3) by the proponent. On that basis an interim basis for deciding the Gummy Shark TAC for 2010/11 was agreed and implemented at SEMAC January 2010 (Appendix 4).

Phase 2. SharkRAG develops long term approach to Gummy Shark harvest strategies and identifies critical knowledge gaps.

In the second phase of extension during the first half of 2010 SharkRAG discussed the ideas and concepts raised by this project and agreed that the concepts outlined should be the subject of a Harvest Strategy Evaluation study aimed at testing and developing the concept with regard to implementation. SharkRAG supported the development of a collaborative pre-proposal for COMFRAB.

Dr Andre Punt attended the SharkRAG meetings in July and August 2010 and besides confirming that his analyses also indicated that model estimates of Gummy Shark adult biomass are poorly constrained by data, provided strong support for SharkRAG's proposals for developing the concept of empirical indicators for Gummy Shark further with Harvest Strategy Evaluation.

The Sustainable Shark Fishery Association which engages through SharkRAG in discussions about the approach also supports the approach being developed. See attached letter (Appendix 6)

Phase 3. Initiation of Pre-proposals for 2010/11 funding round

The third phase of extension of this project began with scoping documents prepared for SharkRAG's discussion (Appendix 5) identifying critical gaps in knowledge. Discussion with SharkRAG on critical knowledge gaps identified broad support from management, industry and researchers for evaluating the proposed empirical approach more closely and quantitatively. SharkRAG agreed that the concepts outlined should be the subject of a Harvest Strategy Evaluation study aimed at testing and developing the concept with regard to implementation.

SharkRAG supported a collaborative approach to developing a pre-proposal for COMFRAB in June 2010, which was well received by COMFRAB and eventually resulted in a full proposal being invited by COMFRAB for high priority funding by AFMA. A full proposal is being prepared.

Phase 4. The final phase

The final phase of extension will occur subsequent to this project and will involve the implementation of the permanent new empirically based harvest strategy for Gummy Shark. This will continue over 2-4 years and will involve SharkRAG working with AFMA, South East MAC, and the research projects initiated to fill critical knowledge gaps, to provide the scientific knowledge, technical detail and analyses needed to support the implementation process.

Conclusion

This project's original objects were:

1. Develop a new harvest strategy for Gummy Shark fishery based on empirical indicators.
2. Synthesize existing fisheries and biological data pertaining to the new harvest strategy and document the scientific rationale for the new harvest strategy.
3. Identify critical gaps in information needed to support the new approach and outline and scope the data collection systems, biological research and modelling studies needed to fill the critical gaps identified.

Through the documents prepared and presented by this project to SharkRAG and SEMAC during 2009/10 these objectives have all been met.

The scientific basis and rationale for a new simpler and cheaper empirical approach has been documented in this report, and in Appendices 3 & 4 which were presented to meetings of SharkRAG and SEMAC during 2009/10 supported by power point presentations.

Through discussion supported by this project SharkRAG agreed to give in principal support to the continued development and implementation of the empirical method of setting GS TACs proposed here. SharkRAG identified that the critical gap in knowledge in this case is quantitative evaluation of the concept and agreed to support a collaborative Management Strategy Evaluation (MSE) study to develop and quantitatively evaluate the concept with respect to its potential for implementation.

A collaborative pre-proposal was prepared and revised for COMFRAB on behalf of SharkRAG and involving Biospherics P/L and CSIRO as investigators. COMFRAB has invited a full proposal and allocated it a high priority for AFMA funding.

The principle outcomes of this project have been:

- It is now clearly understood by SharkRAG & COMFRAB members that while the Gummy Shark assessment framework reliably estimates the stable long term recruitment that characterizes the fishery, the trend in adult biomass it estimates is poorly informed by data, and does not provide a reliable basis for TAC setting.
- A new simpler and cheaper empirical approach to TAC setting for Gummy Shark has been documented and discussed with the aim of initiating its development and implementation for the Gummy Shark fishery.
- The 2011 TAC for Gummy Shark was set on an interim basis using the empirical based proposed for development providing proof of principle.
- SharkRAG identified that the critical gap in knowledge needed to continue developing this approach is quantitative evaluation with respect to its potential for implementation. SharkRAG agreed to support the development of collaborative MSE study aimed at developing and evaluating the concept with respect to potential for implementation.
- A collaborative pre-proposal has been prepared and revised for COMFRAB on behalf of SharkRAG and involving Biospherics P/L and CSIRO. COMFRAB has invited a full proposal and has allocated it a high priority for AFMA funding. A full proposal is being prepared.

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Appendix 1: Intellectual Property

The intellectual property developed through this project is for general publication.

Appendix 2: Staff

Dr Jeremy Prince was the principal researcher funded as a consultant by this project.

Appendix 3: Development of a robust assessment model for Gummy Shark. SharkRAG Nov. 2009

Prepared for SharkRAG 17-18 November 2009.

SharRAG Document # 2009-21

Development of a robust assessment model for gummy shark.

Jeremy Prince

Biospherics P/L

November 2009

TRF: JP-013

SharkRAG Document: 09-066

Introduction

This is a discussion paper written for the November 2009 meeting of SharkRAG, Its purpose is to provoke discussion into:

1. Why a new approach to determining Recommended Biological Catches (RBC) is needed, and
2. What that new approach to a gummy shark Harvest Strategy should be.

This document has been funded by Tactical Research Funding which was supported by COMFRAB 55, July 2009. The project aims to develop the outline for a new empirical Harvest Strategy for the gummy shark fishery through a series of documents, analyses and discussions with SharkRAG. This discussion paper being the first draft of document that is eventually intended to provide the rational underpinning of the approach.

It should be noted that the scope of this TRF project is limited to the desktop, drawing together the scattered information that underpin our knowledge and uncertainty about the gummy shark resource. It is anticipated that this issues and directions raised by this body of documentation and analysis will highlight the need for new research and development. It is easy to anticipate the need for both modeling and data analyses, as well as for some basic studies to better document fundamental aspects of fisheries biology. COMFRAB 55 stated that they recognized the importance of the issues raised by this proposal, and that they would use the report from this TRF project to evaluate the priority for further longer term R&D to support the process of implementation.

I have structured this document in a particular way. I am aware that several key issues of detail like; the need to abandon the current model and stock structure, are not resolved amongst SharkRAG members. However, I have removed these issues to appendices for what I intend will be more detailed discussion and analyses. My apologies that in this draft the so far mainly contain my rantings that have been easily culled from own archives. In future version I hope to redress the balance through wider research.

The main body of document uses the need and background sections of the TRF proposal to set the background, before moving directly into a simple analysis of the fishery from which a simple empirical fisheries model is developed. The paper ends by outlining how this model could be used as the basis of a harvest strategy for setting RBCs.

The reader is invited to understand and consider this new empirical model for setting RBCs, before returning to the detail of the various other ongoing discussions contained in the Appendices. All this material is for discussion by SharkRAG members and will be discussed over several SharkRAG meetings and through several drafts of the current document.

Need

The GVP of the gummy shark (GS) fishery is approximately \$13 million comprising 15-20% of the SESSF. The GS fishery has a history of stable catches which successive analyses have shown is due to recruitment remaining stable over time at pre-fishery levels. Little research has been conducted on gummy sharks because its stability has made it difficult to justify. However, the fishery displays a number of unusual, and poorly understood dynamics which conflict with standard stock assessment assumptions making estimates of adult biomass highly uncertain (see background & appendices). The adoption of the Commonwealth Harvest Strategy Policy (HSP) mandating managing to a default 48% of virgin biomass places the gummy shark fishery in a difficult position. Its formal assessment estimates adult biomass to be around 40%. So despite catch rates, effort and body size at 1970s levels, and all analyses showing stable virgin recruitment, applied literally to unreliable estimates of adult biomass, the HSP will necessitate a >30% reduction in the TAC and result in an unwarranted 5-7% loss of GVP to the SESSF. There is also growing public concern at the general unsustainability of most shark fisheries and it can be predicted that the gummy shark fishery will be subject to increasingly strident demands to prove its underlying

In this policy environment the existing stock assessment, with its acknowledged weaknesses is a liability. The need is to fundamentally redesign and redevelop the harvest strategy for gummy shark explicitly accounting for its unusual dynamics. This new approach needs to be based on empirical indicators of the fishery (catch, effort, cpue, size/age structure) which have allowed recruitment trends to be robustly estimated by successive stock assessment, rather than unreliably model interpolated trends in adult biomass. Importantly this new empirical approach needs to be robustly and scientifically justified so that this fishery can be distinguished from unsustainable shark fisheries.

Background

The gummy shark fishery has a GVP of approximately \$13 million comprising 15-20% of the value of the SESSF. The fishery has a long history of stable catches which successive analyses show is due to recruitment to the fishery having remained stable since the inception of the targeted fishery in the early 1970s. Historically a low priority has been placed upon studying and understanding the dynamics underlying the extraordinary

stability observed in this fishery. With the exception of the collection of basic data from the fishery, the original biological studies undertaken by Mr Terry Walker during the 1980s (Walker et al. 1983, Walker et al. 1989), and the development of an initial stock assessment in the late-1990s there has been little investment in research into this fishery's underlying dynamics, and significant questions remain unresolved.

The fishery displays a number of unusual, and poorly understood dynamics, which in some cases are incompatible with the standard stock assessment techniques being applied to the fishery. The attached appendices for sections expanding on the issues relating to how the actual fisheries dynamics interact with the stock assessment, only a brief overview is given here for context.

The key features of this fishery's dynamics include; a behavior driven dome shaped selectivity curve for the fishery that goes beyond the selectivity of the mandatory 6-6.5" mesh size, so that even within the fishing grounds adult age classes are not captured by the nets (Punt 2000). Within the fishing grounds the fishery acts like a gauntlet fishing on just four sub-adult and maturing year classes (4-7 year old), if the GS survive the gauntlet of the fishery they grow into the relatively unfished adult population. Because the fishery relies on this gauntlet of four year classes which move through the fishery rapidly its dynamics tracks recruitment closely, with the rate of recruitment directly capping catches. What is most unusual about GS is that recruitment has stayed stable at pre-fishing levels for 5-7 GS generation times. The mechanism for this stability is not clear since, at least within Bass Strait most analyses suggest that during the 1980s and early 1990s fishing was heavy enough to close off the gauntlet and prevent survival to adulthood for long enough to run down the parental biomass, placing the adult biomass into a decline it does not seem to be able to pull out of, despite successive iterations each suggesting in turn that incipient upturns might be beginning.

Whatever the mechanism is that provides constant recruitment to the fishery, the constant recruitment constrains the level of catch, so that since the 1970s, in Bass Strait, the catch has remained at the same level while effort has varied widely. This annual stability of the catch over a wide range of historic effort levels gives rise to a strong negative relationship between annual effort and annual catch rate which confounds the standard assumption that catch rate is an index of abundance. In this case the fishable biomass is remarkably stable being determined by annual recruitment, while CPUE is highly variable, more or less in proportion to the level of effort applied in each year.

During the late 1990s Dr Andre Punt as chairman of SharkRAG developed the synthesis stock assessment for gummy shark which is still being used. The assessment confirmed that recruitment remains stable at pre-fished levels, but estimated that adult biomass was declining to around 35-45% of pre-fished levels. At the time SharkRAG recognized that the actual dynamics of the fishery violated several fundamental assumptions of the model, and that consequently some aspects of its analyses are unreliable (see Appendix 4). Thus estimates of recruitment trends are robust, but the trend estimated for adult biomass levels are unreliable being a result of underlying assumptions of the model, which are poorly informed by data because the fishery does not fish adult age classes. At that time (late-1990s) relatively little importance was attached to resolving the latter aspect of the assessment because of the underlying stability of recruitment.

Cognizant of the actual dynamics of the fishery (see below), and to some extent ignoring the stock assessment's results which suggest higher catches are possible, in 2001

SharkRAG and GHATMAC recommended that the TAC for gummy shark be set at the level of the long term average catch, and the TAC was reduced to 1700t from the level of 2100t that had been set in 2000. The stated aim being to drive catch rates higher and effort lower. This measure has been successful; effort, catch rates and body sizes have returned to levels last observed in the late 1970s and recent economic analyses of the SESSF suggest this sector of the fishery is the best performing sector.

The adoption of Harvest Strategy Policy which mandates managing to a default of 48% of virgin biomass has placed the gummy shark fishery in a difficult position because its formal assessment estimates, albeit arbitrarily (see Appendix 4), that adult biomass is around 40% of virgin levels. Despite catch rates, effort and body size having returned to the high levels recorded at the inception of the fishery, and all analyses of the fishery showing that it enjoys stable recruitment at virgin levels, the Harvest Strategy Policy if applied literally to the unreliable estimates of gummy shark adult biomass produced by the 2000 assessment framework, will necessitate a >30% reduction in the TAC which will result in an unwarranted 5-7% loss of GVP to the SESSF.

Over and above the need for an accurate stock assessment created by the Harvest Strategy Policy there is growing public concern at the general unsustainability of most shark fisheries. To date this is being reflected in DEWHA placing increasingly stringent WTO conditions on the shark fisheries managed by the states, and calls by NGOs (such as the AMC) for the closure of all shark fisheries. In this policy climate it can be predicted that the gummy shark fishery will be subject to increasingly strident demands to prove its underlying sustainability, and that it faces a very real threat of being closed down or limited by the blanket push to increasingly restrict all shark fisheries.

In this environment the existing stock assessment, with its acknowledged weaknesses (Appendix 4) has become a liability. To protect this valuable sector of the SESSF an accurate, and well documented stock assessment is needed to reliable and stably set RBCs within the SESSF Harvest Strategy approach.

The unusual facets of this fishery's dynamics means that the current assessment cannot be simply by turning the handle on the annual stock assessment process. A new data driven empirical approach is needed, based on a better documented understanding of the underlying fisheries ecology of the stocks, and simple informative fisheries data.

Towards A Harvest Strategy for Gummy Shark

Gummy Shark Fisheries Dynamics

The following figures presented on the basis of data aggregated by state are taken from Walker and Gason (2009) and illustrate the basic dynamics of the fishery. Figure 1 shows the annual aggregate data (1970-2006) for the gummy shark fishery in the three states, Victoria, Tasmania and South Australia. I choose to use these data at this point of the analysis for the sake of simplicity in discussing the issue. It does not imply that this scale of aggregation should be implemented permanently. The dynamics that I describe here will be found to apply with less noise if applied at a regional scale commensurate to the scale of the fishing grounds and gummy shark movement. The broad trend data shown in figure 1 are relatively uninformative simply showing that after an initial expansion of fishing effort catches have stabilized in each state and remained stable over some period of time, considering the 4-8 year old profile of the catch. In each state effort levels have declined 50-70% since the peak levels recorded during the 1980s and early 1990s.

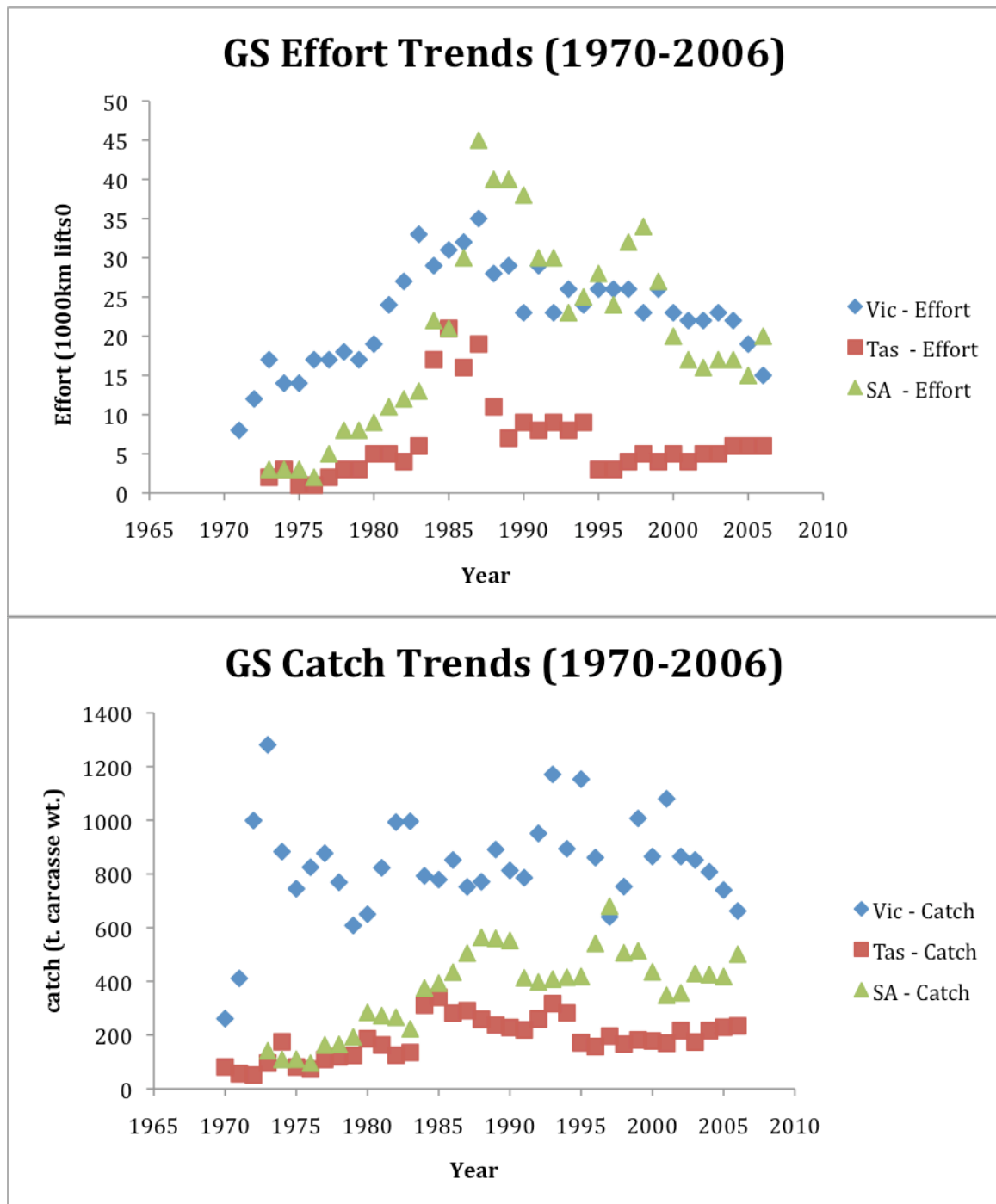


Figure 1. Gummy shark effort (1000 km.lifts) and catch (tonnes carcasse wt.) for each state by year(1970-2006) of landing. Data from Walker & Gason 2009).

A more interesting view of these same data are given by looking at the relationship between effort and catch in these fisheries figure 2. In these plots the catch of each year (tonnes carcass wt.) is plotted as a function of the effort reported (1000km.lifts). This figure has the last data point in the time series (2006) indicated to provide reference. In these figures at low effort levels catches at first increase as the level of annual effort increases, but at a certain level effort catches plateau and then remain relatively constant despite increases in effort. In the case of the Victorian data the time series begins soon after the inception of the gummy shark fishery through Bass Strait and so the data do not record the first years of very low effort.

The noteworthy features of these figures are:

1. The same pattern is replicated in each area of the fishery. It is my observation that this is because individual fishing grounds in the fishery display the same pattern, so this is a composite of the smaller scale pattern.
2. How flat catch becomes above a certain threshold of effort i.e. catch is very predictable.

It is this second feature of these catch and effort data (figure 2), the flat relationship between catch and effort, that makes CPUE uninformative as an index of stock abundance in the current, or for that matter, any other CPUE based assessment.

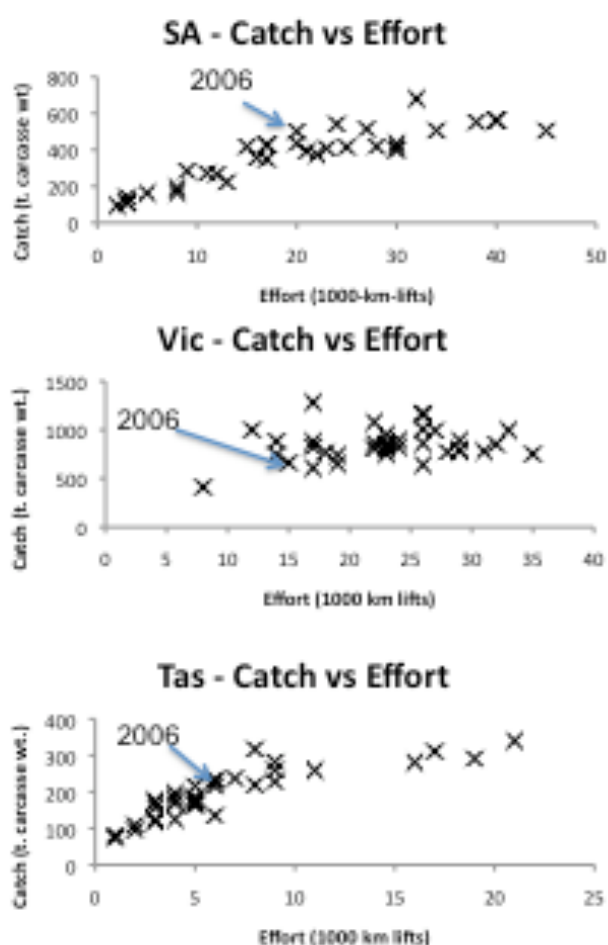


Figure 2. Annual GS catch (tonnes carcasse wt.) and effort (1000 km.lifts) data from South Australia, Victoria and Tasmania 1970-2006. Catch is plotted as a function of effort. The 2006 data point (the last in this time series) is indicated as a reference point. Data from Walker & Gason 2009).

Immediate Implications of the Stable Recruitment Based Fishery

The two most immediately relevant implications of this dynamic involving fishing on stable recruitment are:

1. The fishery is very responsive to changes in recruitment and changes in fishing pressure. The level of recruitment drives the level of catch in the fishery and any weak year class by affecting roughly 25% of the fished stock can be quickly perceived in catch rates, catches and age structure of the catch. Likewise my qualitative observation is that patterns in fishing pressure are accurately reflected in the size structure and catch of the stock in each region, probably because growth is relatively linear through these age classes and so both length and weight give a clear indication of age. This to me suggests they offer opportunity for developing indicators for use within a harvest strategy.
2. In this context the other major implication of this dynamic and the powerful proof it gives of stable recruitment is that the model uses this estimate of recruitment to derive its estimate of the adult biomass before fishing (see Appendix 4). Without any other information on the size of the original biomass the size of the recruitment, is combined with model assumptions about DDM, rates of natural mortality and data on growth and fecundity to derive estimates of the virgin adult biomass needed to produce the proven level of recruitment.

Through the computed time series the model estimates how many of the recruited year classes survive the gauntlet of fishing and top-up the adult year classes, and also how many of each years adults survive through to the next year. Repeating this process 39 times the model eventually derives an estimate of current adult biomass that is unsullied by any recent adult population abundance data.

In other words:

The model first estimates virgin biomass on the basis of the proven level of recruitment.

It then computes that heavy fishing on the sub-adults has run down the adult stock to a point where it cannot be reversed without major reduction of the fishery.

But the estimate of current biomass is based entirely on back calculation to the estimate of initial biomass based on estimated recruitment. There are no recent data that can inform this estimate because the model discounts CPUE as an index of abundance, and besides the catch contains few adults to inform the model anyway. These estimates of adult biomass are extreme extrapolations un-anchored by any recent data.

Thus the first implication is that the simple data available from the fishery are actually highly informative about the current status of the fishery, however, the second implication of this dynamic is to make the current assessment's estimates of adult biomass too approximate in its prediction of reality to be reliably used for setting RBCs.

Developing a Reliable Harvest Strategy for Gummy Shark

Accepting that there is an issue that prevents the current assessment reliably estimating adult biomass the question becomes what to do about a harvest strategy for gummy shark.

There are essentially two alternatives;

- 3.

4. Solve the uncertainty about stock size and definition, collect data on the abundance of adult gummy shark and rework an integrated quantitative model to produce reliable estimates of biomass.
5. Use the simple but informative data available from the fishery to develop an empirical based harvest strategy for GS.

Early discussions about this initiative between Jeremy Prince (Chair SharkRAG) and, Tony Smith and Geoff Tuck (CSIRO), and later by phone Shane Gaddes and Beth Gibson (AFMA) discussed which approach to take to the issue. The first course of action involves the risk of biological research proving inconclusive with respect the main issues, along with the long term expense of biomass surveys. The decision was made that the direction should be the latter, to develop an empirical based model for setting TACs that uses simple data collected from the fishery and that robust to biological uncertainties, because it has been planned around them.

A parallel model is being developed in the ECTBF using catch rate target and size structure to incrementally adjust TACs.

Harvest Strategy Outline

Basic Premises

- Use the data and assume the least
- The fishery targets several year classes of sub-adults.
- Very young juveniles and larger adults are not fished.
- The fishery has a history of stable recruitment over many generation times of the stock, established by the stability of catches and age structure, over four decades and the wide range of fishing pressure that has been applied.
- The fishery apparently fishes a mosaic of stocks which while linked to some extent genetically have varying biological parameters, and show local impacts of fishing (Appendix 3).
- It is not established whether or not the stable recruitment enjoyed by the fishery is entirely produced by the adult biomass within the area of the fishery (Appendix 3 & 4).

A Simple Fisheries Model

At this point of the analysis, for the sake of simplicity in discussing the issue, I choose to use the data aggregated by state collated by Walker & Gason (2009). In a longer term implementation it would be more sensible follow this approach for component fishing grounds defined on the basis of mapped fishing effort and known movement characteristics of GS.

Each of these state fisheries, and I am sure each of the regional fisheries within the states conform surprisingly well to a very simple model of catch and effort described by Beverton and Holt (1957), which describes a fishery competing for shares of an annual fishery with an average annual fishable biomass. My expectation is that the dynamic described here will be evident in the data for component fishing grounds, and the relationships observed will be even tighter because regional differences in effort will have been taken into account through regionalization of the data.

The model is described with the equation.

$$\text{Catch} = \text{Av. Biomass} \times (1 - e^{-(A \times \text{effort})})$$

This equation simply means that the fishery gets a proportion of the annual Average Biomass proportional to the amount of effort applied, accept that at higher levels each additional unit of effort is less and less effective, contributing more to a general decline in catch rates than to increasing the total catch. As applied here I have fitted this simple model to the catch and effort data from each state by minimizing a sum of squares to estimate the parameter A, which scales how flat and abrupt, or smooth and curved the relationship between effort and catch is, and Average Biomass in each year, which in this setting is a proxy for the annual available biomass in the fishery.

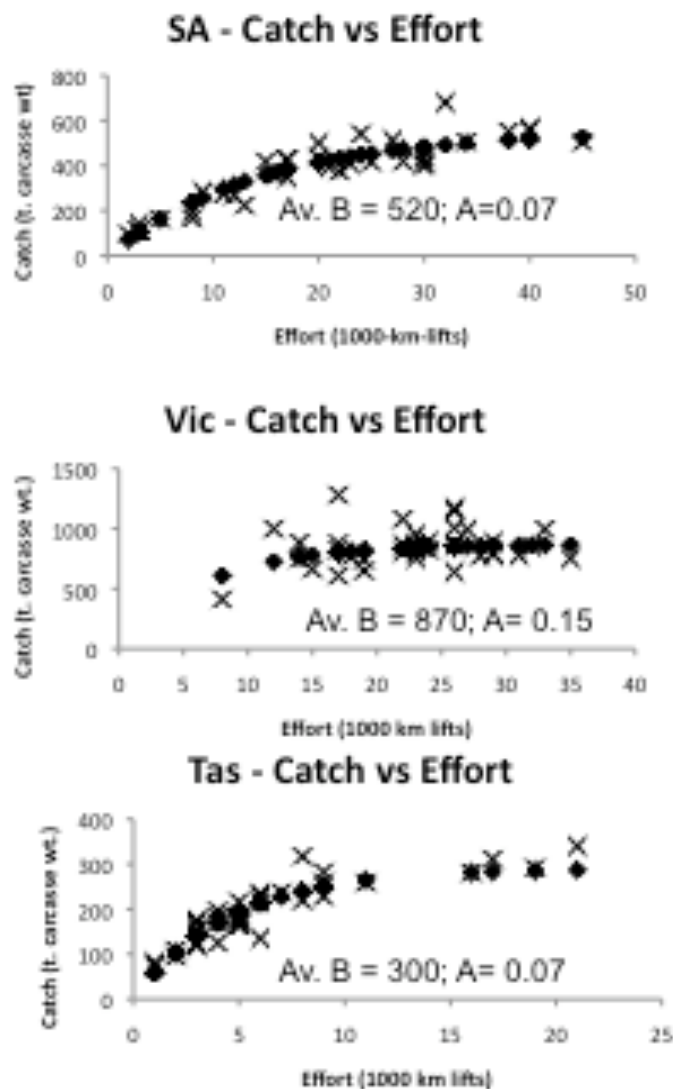


Figure 3. Plots of catch vs effort in each year (crosses) for each state with the model expected values plotted in solid diamonds.

However, the fact that catch rate is an inverse product of annual effort while the biomass stays constant, when combined with the knowledge that the age composition is stable and young is still extremely informative for a fisheries biologist (Appendix 2). These data allow us to be very certain about the annual level of recruitment levels and its long term trend. So while CPUE may not be a useful index abundance of abundance, there is other highly informative data about recruitment that could be used empirically within a harvest strategy designed to determine RBCs.

The fitted models can be seen to describe quite accurately the way effort catch and CPUE have varied over time. On the basis of this experience with the fishery we can predict that future values for catch, effort and CPUE should lie around this observed relationship and if they do that is an indication that the historically stable virgin level of recruitment is continuing. In fact since SharkRAG September 2001 argued that the current TAC level should be set at the level of the long term average catch, the gummy shark fishery has been implicitly managed using these relationships. The proposal here is to extend this approach, to formalize it and add additional rigor.

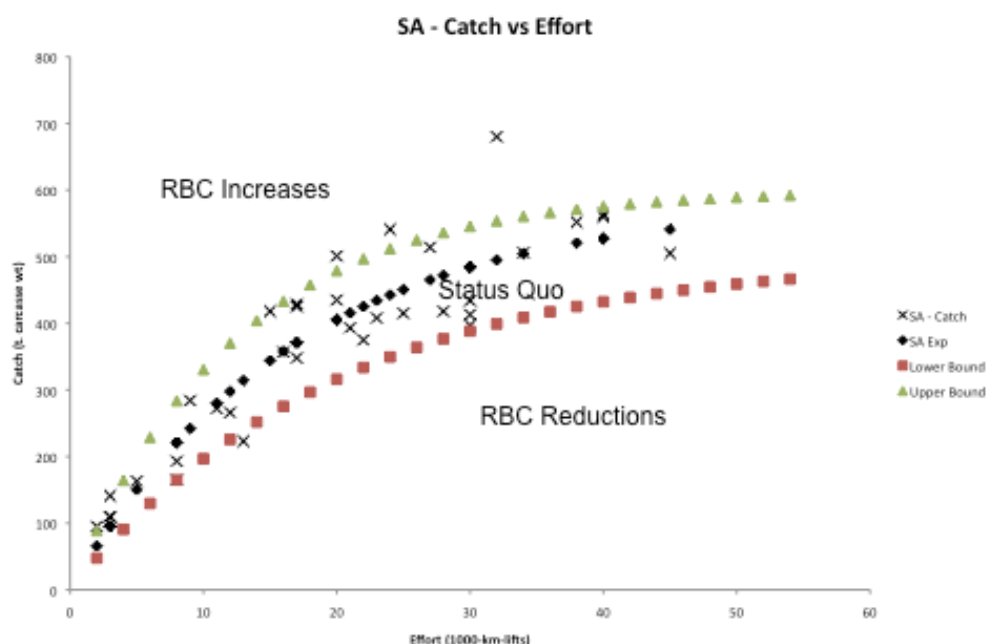


Figure 4. Indicative plot of the modeled relationship between catch and effort with indicative upper (triangles) and lower (squares) probability bounds of the relationship plotted. The labels indicate three broad regions over which a harvest strategy should vary from RBC reductions, maintaining the status quo, and increasing RBCs.

Extending this approach a little further some simple boot-strapping can be used to estimate the statistical confidence intervals around each estimated relationship as illustrated in figure 4, indicating the probability of new data points falling close to, or far away from the described relationships.

NB: figure 4 is illustrative at this stage and not actual. My intention is to have actual fittings for SharkRAG 16-17 November, 2009. At this stage the confidence intervals shown in figure

4 are illustrative of the fact that confidence intervals can be established around these relationships. The idea being that the probability of annual data points falling outside the described relationship under normal conditions of stable recruitment can be quantified, and data points falling outside the upper and lower probability bounds regarded as outside normal variability. So a line could be established as the cut-off point between normal variability, and a signal that something has changed.

Figure 4 is an indicative plot of a modeled relationship between catch and effort with indicative upper and lower probability bounds. The labels indicate three broad regions around this relation which are relevant to developing a harvest strategy. Between the upper and lower probability bounds a region where the fishery is conforming with historically observed behavior and this should justify the status quo continuing. Below the lower bound is a region where if new data fell it would indicate some level of recruitment decline has occurred and RBC reductions become necessary. While on the upper side left hand side of the curve where if data continual fall some level of higher RBC should be trialled as this would indicate that YPR has increased or the ecosystem has become more productive for gummy shark.

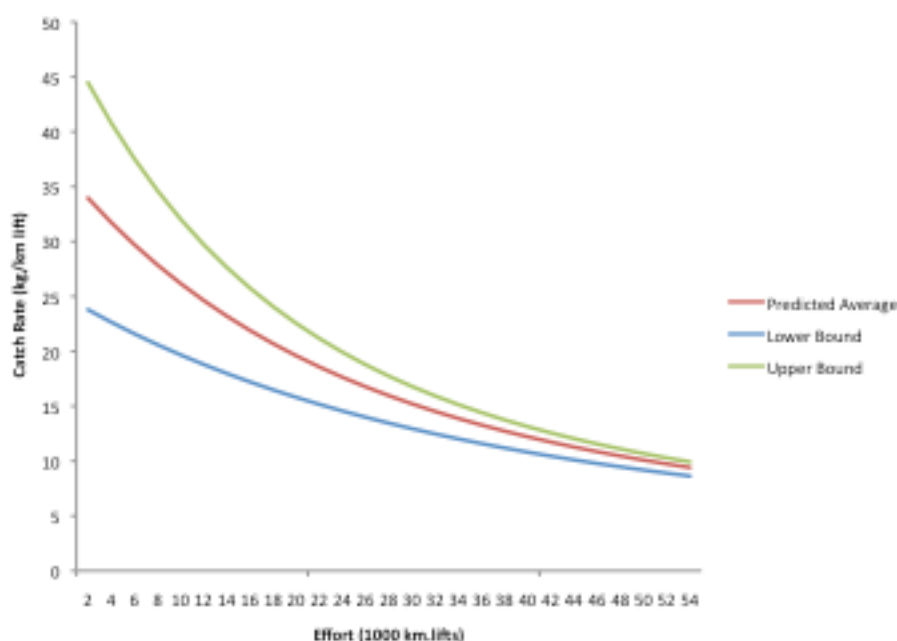


Figure 5 Output from the same models as presented in figure 4, but this time plotting the relationship between effort (km.lift) and catch (kg/km.lift)

Clearly some elaboration on this initial coarse scheme is foreseeable. For the sake of simplicity on this first outing only two likely elaborations are mentioned.

One elaboration would be to incorporate catch rate targets based on economic targets for the fishery (Figure 5) explicitly into the harvest strategy so that incremental changes in RBC pushed effort and catch levels towards selected CPUE and profitability targets for the fishery (Figure 6).

Size data could also be applied as well to provide an additional independent stream of information which potentially could inform the Harvest Strategy about deviations around this relationship due to YPR gains and recruitment change. With size or age trend data, in the

case of the unexpected decline in recruitment, it would be possible to make the RBC change proportional to the decline observed.

The use of size composition data could provide a Harvest Strategy with an independent estimate of regional fishing pressure (F), as well a year class strength. Fishing pressure increases as effort increases and yield per recruit and CPUE also decline. Conceivably F might be used as both a regional target and annual indicator in a future development of an empirical Harvest Strategy for GS. Target levels for F might be used to ensure minimum levels of survival through the fisheries gauntlet, and to optimize yield per recruit from the fishery.

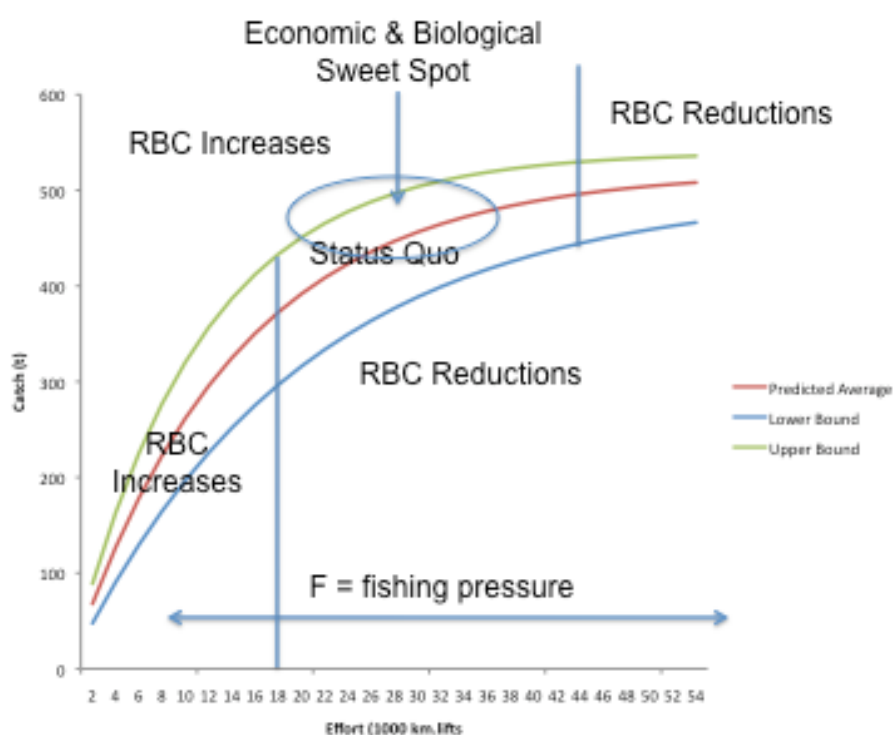


Figure 6. Schematic of a potential empirical harvest strategy for GS based on historic relationship between catch and effort. Potentially size or age structure could be incorporated into the harvest strategy providing an independent index of F and recruitment.

Principles of the Empirical GS Harvest Strategy:

1. Assume the observed levels of stable recruitment continue, and
2. Monitor and manage for variation in historic relationships observed in regional patterns catch, effort, CPUE and body size.

Design the harvest strategy to renew long term catch levels unless declines in recruitment are detected, and to reward yield per recruit gains, and recognize if new fishing grounds being added to the fishery.

Guard against unexpected recruitment decline

The harvest strategy should detect deviations below accepted trends in CPUE, effort, catch and body size which will indicate recruitment below previously observed levels. Because this is not a forward looking indicator the response to such an unexpected perturbation would need to be immediate and strong. But particularly if we developed the use of size or age data in time we could be quantitative about the declines we have observed and cut TACs proportionately.

In the interim our logic would need to be cruder. Probably something like:

There are four main year classes in the fishery, if we see a negative perturbation that will indicate that a weak year class has entered the fishery. So an initial 25% cut of TAC would have conserved the weak year class, that unfortunately has already been fished. But we have no information about following year classes, however, 2 x 25% cuts applied in the year the decline was first detected would give the weak year class already recruited but fished, greatly reduced fishing pressure, and provide a precautionary reduction against further weak recruitment. During that year of the 50% TAC reduction trends in catch, effort, CPUE and age/size age structure could be used to determine whether the recruitment decline was a single or multiple cohorts, and the future TAC direction decided accordingly.

The idea of immediate 50% TAC reductions when a recruitment decline is observed may sound draconian. However, the context for this must be remembered:

- A. A recruitment decline has never been observed, but if it were to occur strong proportional cuts as outlined would be precautionary.
- B. At this stage of discussions, the examples being used are on a state, dividing the SESSF TAC into three proportions. I recommend in implementing this system that we disaggregate the data into smaller fishing grounds commensurate with what we know about the movement of gummy shark and the distribution of fishery. In this way the assessments would be done on 6-10 sub-units in the fishery. So these large pre-emptive cuts would most probably only ever being applied to one or several sub-components which add up into the fisheries RBC.

Reward yield per recruit gains

In the long term the system needs to be able to reward yield gains expected because with lower effort levels the recruited year classes are being caught on average at an older age and larger body size. Prince (1991) collected anecdotal evidence that the original body weight in the early fishery was around 4kg, and in some areas of the fishery it declined to around 2.2kg in the early 1990s. With current low effort levels we should expect body weight to move back towards an average of about 4kg. We already seem to be observing this in the fishery.

In an empirical system such as this, movement above the trend line or targets for (CPUE, catch, effort, body size) should be rewarded with small incremental TAC increases. These experimental upward steps should be cautious and only periodically, so that the impact of the previous step can be clearly seen in the fisheries statistics before the net step is taken.

For simplicity sake, I would be proposing not to build such a feature into the Interim Harvest Strategy, so that in the interim the Harvest Strategy only has capacity to re-act to unexpected bad news, not to expected good news.

Recognize new fishing grounds

The context of this conceptualization of the fishery is that the productivity being harvested is thrown up and supported by a dispersed population. It follows that in the lightly exploited extremes of the fishery (southern Tasmania, and western South Australia) there will be some capacity for similar fishing grounds still to be developed. Under this system if the catches from these areas became significantly more important than at present, the statistics and catches from these grounds should be treated independently with the Harvest Strategy, and assessments for those areas completed for addition into the fishery wide RBC.

Regional Structure of the harvest strategy

Despite attempting to demonstrate a principal with the state scale data. I think long term implementation should be at a more regional scale, probably something like, or an amalgamation of SharkRAGs statistical cells, but based on mapped fishing patterns and the scale of GS movements.

The use of size and/or age data in the harvest strategy

At the present time I am not certain what can be done with existing size and age data because at the moment I am not clear enough of on the details of their collection. I believe they are more than sufficient to demonstrate the approach outlined here. I also think that going into the future the collection of size data to support the catch and effort data could greatly strengthen the quantitative basis of this empirical harvest strategy.

It should be noted that the GS are growing relatively rapidly or linearly as they move through the gauntlet of the fishery. It is only having survived the fishery that their growth will really slow and the size classes will pile up on each other and become indistinct in size data. So the size data from the fishery measured in terms of length or weight seems to produce a good indicator of age structure. Long term it will probably be most cost effective to monitor using size data, initially while doing the research needed to support implementation of this new harvest strategy, analysis of historic age profiles of the catch might be useful.

My observation is that the change in body size regionally tracks fishing pressure very closely. I was struck by the regional difference and so carefully noted regional average carcase weights when I first became involved with this fishery in 1991. Since that time it is my strong impression that it has provided an accurate index of regional fishing pressures. I believe it could powerfully augment the simple interpretation of regional recruitment trends.

For example, if it were ever necessary to rapidly reduce RBCs trends in size composition should make it possible to estimate the shortfall in recruitment and on that basis make the RBC reductions proportional to the observed reduction in recruitment. Likewise Yield Per Recruit (YPR) should become evident in the size indicators as well, allowing estimated increases in RBC, rather than periodic trial RBC increases. For long term implementation I recommend we incorporate regional size composition based indicators into the empirical Harvest Strategy.

Further development, MSE and implementation

Implementation and the research needed to support further development and implementation of this approach.

Still drafting

MSE testing & Data analysis:

Clearly there is a need to engage these ideas with the data and develop more rigorous ways of estimating the upper and lower thresholds around the observed relationship.

MSE testing should be extremely useful in matching expected changes in catch/effort/catch rate and levels of recruitment decline to levels of RBC reduction. I am sure a little MSE testing will immediately confirm that measuring

Still drafting

Basic Biology:

Much of the rationale outlined above and in the appendices are poorly documented, based on unpublished anecdotal accounts, my own qualitative observations, supported by scattered research observations by T. Walker.

Studies are needed to scientifically test and document claims and deductions advanced here.

Still drafting

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Appendices

Appendix 1. Gummy Shark Feeding

Walker et al. (1989) Southern shark assessment project final FIRTA report: March 1989. Victorian Dept. Conservation, Forests and Lands, Fish. Div. Internal. Rep. pp. 175.

Diet by Wt of gut contents: 36% cephalopods; 25% crustaceans; 11% bony fish

“Within constraints of their flat plate like teeth they are non-selective feeders opportunistically taking epi-benthic organisms which it encounters on sandy and to a lesser extent rocky bottoms. Their diet converts away from smaller crustaceans towards larger cephalopods (octopi) and benthic crustaceans (stone crabs & lobster). Larger specimens in the study have some ability to feed semi-pelagically.”

Prince (1991) recorded qualitative observations made aboard GS vessels. Noting that when the fishermen had found areas of high catch rate, both the catch was of a very uniform size, but also the stomach contents were very uniform, within and between individuals. Upon interviewing fishermen I discovered this characteristic applied to all the main gummy shark grounds. The prey item on each ground varied but all the prey items feed benthic-pelagically. At that time I also observed that all the fisheries occurred in areas of high tidal flows which were subject to seasonal upwelling and enrichment. Prince (1991) hypothesised that the enrichment of these areas and creates opportunities for benthic-pelagic feeding by 4-8 year gummy sharks because they are still agile enough to chase down smaller prey in the water column, and that the diet change in older animals towards larger solitary benthic prey reflected a loss in benthic-pelagic agility. I hypothesize that it is the aggregation to feed on shoaling benthic-pelagic prey and the agility of the GS in the mid-water above the bottom that makes them especially catchable on the fishing grounds, and so creates the opportunity for the fishery.

Prince (1991) also hypothesised that these feeding grounds are not the only GS feeding grounds, only a concentrated source in some parts of their range, and that other more dispersed benthic sources of food support lower density populations through the broader GS range beyond the fishery.

Appendix 2 Stable young age structure of catch

The first published account of the age structure of the gummy shark catch by Walker et al. (1989) observed the Bass Strait gummy shark fishery to be 80% < 5 year old animals In 1986-87. In the early 1990s when BRS proposed the Southern Shark Fishery should be closed for 15 years this was seen as supporting the assessment that extreme recruitment overfishing was going on, because recruitment was declining at 20% per annum.

Prince (1991) reported from interviews with fishermen were telling him that the 1986-87 age structure was typical of the catch composition since mid-1970s, and observed aboard vessels how older age-classes became under-represented when vessels found

high catch rate areas to fish. Based on the uniform benthopelagic diets of the sharks in the high catch areas Prince (1991) hypothesized that catchability is linked to benthopelagic feeding by several sub-adult year classes.

Prince (1991) noted that if both the stability of the catch history, and the long term young age structure “are accepted the conclusion has to be drawn that this fishery is based on continuing recruitment rather than the removal of accumulated biomass.” “It would appear that some relatively secure level of breeding stock must exist to generate the recruitment sustaining the Bass St. Fishery. Based on modeling of the fisheries trends Prince (1991) went on to estimate the level of recruitment that sustained EBS, WBS, SESA and CSA

Prince (1991 & 1992) pointed out that the un-regionalized stock assessment of gummy shark could not be correct in its estimation that recruitment was declining at 20% per annum, because the young age structure (around 5 y.o.) had been sustained over several generations, and catches had remained stable while catch rates vary inversely to effort. Prince (1994) went on to emphasize this point by regionally modeling GS catch and effort data showing that the best fitting model assumed constant recruitment independent of adult trends within the fishery.

Every quantitative assessment of the GS resource since this time has come to the same conclusion, that the fishery enjoys stable recruitment at pre-fishing levels.

SharkRAG May 2000 Gummy Shark Assessment Report: ‘The assessment indicates relative stability of gummy shark recruitment over the last 30 years.’

To test Prince (1991) claims that there is a behavioral element to selectivity, beyond net selectivity, Punt (2000) used the data collected during scientific shark surveys in 1986/87 and 1998 to model the selectivity observed at low and high catch rates. He concluded that his results support the hypothesis that high catch rate (“aggregated”) shots lead to tighter length-frequency distributions.

Appendix 3 Gummy Shark Distribution & Movement

Gummy shark are distributed widely through southeastern Australian waters, they do not have well defined shallow water nurseries, unlike school shark (Walker et al. 1989).

Catches from the fishery are highly localized and something like 80% of the catch has come from the same 20% of the fishing grounds. The highly productive areas are located in known areas of elevated marine productivity, including the plankton blooms that the benthopelagic feeding prey are presumably feeding on.

The question is how do GS in each of these scattered fishing grounds connect to each other, and to the dispersed GS population that is also known to occur outside the fishing grounds?

Walker et al. (1983) presented data collected from tagging studies 1973-1976. Of the 1525 released 375 were recaptured by the end of 1982. The longest period at liberty was 2944 days (distance moved 110km) and the longest distance moved was 1003 km (272 days at liberty). However, overall for an average time at liberty of 636 days (s.e. = 28 days) the average distance moved was only 78.2 km. Females showed some

tendency towards being more mobile (102.2 km & 640 days) than males (62.2 km & 628 days).

These data, which I believe have been supported by the more recent tagging project, show relatively low rates of movement which would suggest that measured at those rates the main fishing grounds are separated by distances of 2-8 years movement apart. These scales suggest that the recruitment the fishery is based upon is likely to be drawn from a limited area of catchment zone around each fishing ground. The scale is such that east and west of Bass Strait are likely to be functionally separate, but some mixing may occur around Flinders island, and the Northwest corner of Tasmania and King Island.

The broader area of the shelf and shoreline throughout the region support some level of GS population of all ages, but the feeding aggregations fished are either not observed or cannot be fished because the reef is too heavy. The bigger question is whether and how these larger unfished areas of population relate to the population being fished within the fishery.

Question:

Do all sub-adult gummy sharks pass through the fishery in a closed system?

Or

Are the GS fisheries just a commercial outcropping of a larger more widely dispersed biomass?

In my view:

1. The localization of fishing around peak productivity areas where benthopelagic feeding occurs,
2. The extensive distribution of the all age classes of the population outside fishing grounds
3. The low movement rates

Combine to suggest the fishery in each area is cropping off recruitment that is being supplied from catchment area around the fishing grounds. I presume the recruitment is drawn to the fishing grounds by the enhanced feeding opportunities presented by the elevated productivity in these areas and the presence of shoaling benthopelagic prey.

I presume the recruitment is drawn out of a surrounding catchment into the more limited feeding / breeding grounds. Given the tag results and the age structure of the fishery it is reasonable to assume catchment areas might extend out 100-150km around each fishing ground. It is probably the adult population in these broader catchment areas that determine the stability and level of recruitment to each region.

Thus the recruitment in each region is probably capped by the local productivity of a broader area of adults, which in turn are linked to GS populations even further removed from the fishing grounds.

If the scale of the broader habitat and range of the species, and the scale of fishing grounds are admitted into the discussion along with the scale of gummy shark movement it becomes evident the GS fisheries are simply a part of a broader network

of GS populations some (many?) of which are not fished. In this context it is by no means certain that the fisheries are not the closed systems being modeled. It is quite likely that adult stocks within a fisheries catchment area can be sustained by immigration from more outlying areas, should survival through the gauntlet of the fishery fail to support local adult biomass.

Could it be that the adult population within the catchment of the fishery can be supported over multi-year and decadal time periods by immigration rates from unfished parts of the stock sufficient to prevent this fishery observe the impact of closing off the gauntlet in its fishery for a prolonged period of time.

Appendix 4. Tier 1 Gummy Shark Assessment

During the late 1990s Dr Andre Punt as chairman of SharkRAG developed the synthesis stock assessment for gummy shark which is still the Tier 1 assessment for gummy shark. From the outset in the 2000 assessment it once again confirmed that recruitment remains stable at pre-fished levels, but estimated that adult biomass was declining. In the 2001 SharkRAG agreed estimates of tagging mortality should be incorporated into the model and from that time the assessment began estimating adult depletion to be around 35-45% of pre-fishing levels. At the time of the first assessment using the current model SharkRAG recognized that the actual dynamics of the fishery violated several fundamental assumptions of the model, and that consequently some aspects of its analyses were unreliable.

SharkRAG Gummy Shark Assessment 2000

“6. Major Uncertainties. The assessment is based on almost all of the available data and attempts to capture key spatial aspects of the fishery. However, several uncertainties remain:

3. Based on comparing catch rates at different levels of catch, it was decided that the assessment should include a component that models gear competition. However, the method used does not fit the data particularly well. One reason for this is that catch rate appears to increase when effort decreases and vice versa. However, error in modeling this relationship does not substantially impact on final outcomes of the assessment (e.g. leaving out the catch rate data has little impact of the estimates of depletion See Table1).”

At the time the problems this raises were discounted because “*leaving out the catch rate data has little impact on the estimates of depletion.*”

But at this point in time it is pertinent to ask; if the catch rates of gummy shark do not drive the estimated depletion of modeled adult biomass, what does?

The fishery catches sub-adults and there are no surveys of adult numbers, so the assessment has virtually no information with which to estimate adult biomass. So how is it doing this?

The answer is that the adult trend, last estimated to be just below 40% and still declining is driven by the various assumptions in the model, rather than data.

At the core of the gummy shark assessment it is an accounting exercise track numbers of sharks through successive year classes and years assuming the gummy shark fishery is a closed system, and all the young sharks in each year classes are exposed to impact of fishing effort. This is the normal assessment and is made implicitly in all assessments.

The solid piece of information the assessment model has and that it cannot escape is the magnitude and trend of recruitment. So given GS breeding biology, estimates of natural mortality and assumptions about Density Dependence Mechanisms (DDM) the model back calculates the level of original breeding biomass required to produce that level of recruitment to the fishery. Having established the size of the original biomass the model then annually diminished the estimated adult biomass by the rate of natural mortality, and adds whatever survives the gauntlet of the fishery.

The current problem only arises because fishing pressure rose very high during the 1980s and closed off the gauntlet for long enough that the adult biomass should have run down. Walker et al. (1987) estimated >80% of the catch from Bass Strait was <5 years old. This implies there were long periods in the fishery when none of the recruiting year classes were surviving the BS gauntlet to top up the breeding biomass as an unfished 9 year old. Models for Bass Strait inevitably estimates that fishing pressure rose high enough in the 1980s and continued high long enough into the 1990s to close off the supply of sub-adults to the breeding stock and so run down the breeding biomass. Any logical closed-system population model will produce the same result this was the point of Prince (1994) when he noted constant recruitment models fitted the data better than models that assumed recruitment was linked to the adult biomass within the modeled fishery.

The current assessment model only manages to produce the one data driven result, that of stable virgin recruitment, by precisely matching in each year the decline in adult biomass and pup production, with a precisely balancing increase in pup and juvenile survival. The match between these two apparently independent parameters is too precise to be believable as a model dynamic. Even if that can be explained, why should the fishery be stable around the pre-fished level of recruitment? why no surplus-yield gain from fishing down the initial biomass?, and why did it not decline after sustained very high fishing pressure?

By the standards of Occam's razor this is not believable behavior in a fisheries model.

Thus estimates of recruitment trends are robust, but the trend estimated for adult biomass levels are unreliable being a result of underlying assumptions of the model, which are poorly informed by data because the fishery does not fish adult age classes. At that time (late-1990s) relatively little importance was attached to resolving the latter aspect of the assessment because of the underlying stability of recruitment.

Cognizant of the actual dynamics of the fishery, and to some extent ignoring the stock assessment's results which suggest higher catches are possible, in 2001 SharkRAG and GHATMAC recommended that the TAC for gummy shark be set at the level of the long term average catch, and the TAC was reduced to 1700t from the level of 2100t that had been set in 2000. The stated aim being to drive catch rates higher and effort lower. This measure has been successful; effort, catch rates and body sizes have returned to levels

last observed in the late 1970s and recent economic analyses of the SESSF suggest this sector of the fishery is the best performing sector.

The adoption of Harvest Strategy Policy which mandates managing to a default of 48% of virgin biomass has placed the gummy shark fishery in a difficult position because its formal assessment estimates, albeit arbitrarily, that adult biomass is around 40% of virgin levels. Despite catch rates, effort and body size having returned to the high levels recorded at the inception of the fishery, and all analyses of the fishery showing that it enjoys stable recruitment at virgin levels, the Harvest Strategy Policy if applied literally to the unreliable estimates of gummy shark adult biomass produced by the 2000 assessment framework, would necessitate a >30% reduction in the TAC which will result in an unwarranted 5-7% loss of GVP to the SESSF.

Why Not Just Update the Assessment?

At this point in this discussion, when it runs in SharkRAG, and the comment gets made; “Well, with all the more recent positive data why not just update the assessment, the estimate of adult biomass may well have increased above 48% by the positive data of the last few years. After all the new data should eventually reveal to the model that sufficient adult biomass survived through the heavy fishing period to sustain recent catch levels.”

This logical suggestion is not easily answered as the chair in open forum. So here is my chance.

1. The basic point is that the assessment's adult biomass is not reliable and so should not be used to set an RBCs. Whether it produces an 'acceptable' number or not, its basis for determining that number is arbitrary and not science based.
2. Given the immense pressure will be brought to bare to use any adult biomass estimate produced if a re-assessment is done, no update should be conducted until it has been agreed that the adult biomass estimates produced are not to be used for RBC determination. This has to be decided first. To update the assessment and then hold the discussion about using the estimates, will open up allegations of arguing for one or the other desired outcome. The process here is everything. The issue of how the result can be used must be resolved before the current assessment is updated.
3. The model is not responsive to new catch and effort data. Remember SharkRAG 2000 *“leaving out the catch rate data has little impact on the estimates of depletion.”* As catch rates increase the model estimates the fishery is not competing heavily with each other any more, but still estimates survival is too low to reverse the long term decline in biomass. With little survival to the adults each year, the model keeps estimating natural mortality keeps on eroding the adult biomass. In my opinion the model is not being provided with any data that will suggest to it that adult stocks are building and so has no means, or need, to change its estimated trend. Logically one would expect that at some low biomass point the flexibility of the DDM mechanism will be exhausted and although all the pups and juveniles will survive there will not be enough to support

recruitment to the fishery. At that point further declines in adult biomass will produce model expectations of recruitment decline. I am not willing to gamble on when that will occur and what that will do to the models expectation of adult biomass when it does occur. Certainly there has never been much exploration of the current models likely behavior in this regard. I still will have no faith that it has any resemblance to reality.

Questioning the Closed System Assumption

In contrast to the various aspects of the model related to catch rates being an index of abundance and estimating current biomass, the estimated recruitment trend are solidly based in the fisheries record of a stable catch of 3-7 year old sub-adults since the 1970s (Appendix 1). The same finding has been derived by every assessment applied the GS fisheries data (Appendix 2).

The problem for gummy shark in the current formulation of Tier 1 is that tier's focus on adult biomass estimates and linking those directly to TAC levels. This is because the model derived estimates of adult gummy shark biomass, and estimates of pup production based upon them, are not scientifically safe and cannot be relied upon to set TACs for this fishery.

In my opinion the main problem is the standard stock assessment assumption that all of the GS stock's recruitment passes through the gauntlet of the fishery. Gummy shark movement rates are relatively limited (Appendix 4)

As a fisheries scientist to dare to pose the idea that a 'cryptic biomass' might support the productivity of a fishery is something akin to heresy and risk one's personal credibility. Because, of course, the 'cryptic biomass' argument is the resort of every rabid fishing industry group trying to avoid much needed management restrictions. So I do not make this suggestion lightly, but after 15+ years working with the fishery.

But in the case of gummy shark it needs to be taken seriously.

Appendix 4: An Interim Approach to an Empirical Harvest Strategy for Gummy Shark. SharkRAG Dec. 2009

Prepared for Discussion by:

SharkRAG 11 December 2009 & 7 January 2010.

And by SEMAC 28-29 January 2010

Dr Jeremy Prince, Biospherics P/L

3 December 2009

Introduction

This document has been prepared as a part of the TRF project 2009-066 which has the aim of developing an empirically based Harvest Strategy (HS) for the gummy shark (GS) fishery, and supporting the 2010 TAC setting process with an interim Harvest Strategy. This particular document is aimed directly at supporting the 2010 TAC setting process by suggesting an interim empirical approach to recommending an Recommended Biological Catch (RBC) for GS for use until a permanent approach can be developed and implemented for the fishery. The background and contextual material contained in this document is a summary of material discussed in more detail in a discussion paper presented to the November 2009 SharkRAG meeting and readers are directed to that document for that detail. This broader material will continue to be the focus of further documents that will be prepared for, and discussed by SharkRAG, during the remainder of TRF 2009-066.

For the record, the most recent GS data (2007-2009) which are evaluated in the final sections of this document, in relations to the suggested interim HS, were only received from AFMA after the body of this document was developed and drafted.

Background

The gummy shark fishery has a GVP of approximately \$13 million and now comprises 15-20% of the value of the SESSF. The GS fishery displays a number of unusual, and poorly understood dynamics, which in some cases are incompatible with the standard stock assessment techniques being applied to the fishery. The underlying thesis of this TRF project is that while the mechanisms that give rise to the fisheries dynamics are poorly understood the dynamic of the fishery has remained very stable since the fishery's inception in the late 1960s and so are extremely predictable. Furthermore the thesis presented here is that we should explicitly use this predictability in TAC setting and avoid having untested assumptions at the core of our TAC setting mechanism.

The GS fishery has a long history of stable catches which successive analyses (e.g. Prince 1994, Punt 200a, SharkFAG 2000, Punt et al. 2004a&b, Walker 2009) all show is due to

recruitment to the fishery having remained stable since the inception of the targeted fishery in the early 1970s.

The key feature of this fishery's dynamics include:

- The fishery is concentrated within a limited area of the species range (approximately <10-15%).
- Limited dispersal rates within the species range (approximately 35-50km/y)
- A behavior driven dome shaped selectivity curve for the fishery that goes beyond the selectivity of the mandatory 6-6.5" mesh size, so that even within the fishing grounds adult age classes are not captured by the nets (Punt 2000b). So that within the fishing grounds the fishery acts like a gauntlet fishing on just four sub-adult and maturing year classes (4-7 year old), if the GS survive the gauntlet of the fishery they grow into the relatively unfished adult population.

Because the fishery relies on fishing just four sub-adult year classes, which grow rapidly through the fishery the dynamic of the fishery closely tracks the trend in recruitment, with the level of recruitment to the fishing grounds directly limiting catches. What is most unusual about GS is that recruitment has stayed remained at pre-fishing levels for 5-7 GS generations (35 years). This remarkable stability of recruitment has caused catches to remain extremely stable over time despite a three-fold range in effort levels and it is this dynamic along with the relatively stable age and size structure of the catch which invariably causes stock assessments to conclude recruitment has remained stable at virgin levels.

The mechanism for this stability is not clear since, at least within Bass Strait most analyses suggest that during the 1980s and early 1990s fishing was heavy enough to close off the gauntlet and reduce survival to adulthood for long enough to run down the parental biomass. The exception being Walker (2009) which estimates that the 1980s depletion cannot have been so extreme, presumably because recruitment has remained high and stable. Whatever, the mechanism is that provides constant recruitment to the fishery, the constant recruitment constrains the level of catch, so that since the 1970s, in Bass Strait, the catch has remained at the same level while effort has varied widely.

This annual stability of the catch over a wide range of historic effort levels gives rise to a strong negative relationship between annual effort and annual catch rate which confounds the standard assumption that catch rate is an index of abundance. In this case the fishable biomass is remarkably stable being determined by annual recruitment, while CPUE is highly variable, being basically an inverse linear function of the effort applied in each year.

Implications of the Stable Recruitment Based Fishery

In this context the main implication of these dynamics for the synthesis stock assessment models which have been used in this fishery is that catch rates contain little information about the abundance of the fished year classes (SharkRAG 2000), and because the adult biomass is not fished the assessments contain no trend data for adult biomass. The result of this is that estimates of current adult biomass which are critical to application Tier 1 Harvest Strategies are highly unsafe as they are not fitted to any trend data.

If this is the case, what in fact are they based upon?

The synthesis models are in fact extrapolating over 35 years of the fishery from the adult biomass it estimates must have been necessary to supply the virgin level of recruitment. Having estimated the original adult biomass on the basis of the assumed Density Dependence

Mechanism (DDM) in the virgin state, the model for each year subtracts recorded catches and the rate of natural mortality, while adding the estimated survival through the fishery each year. The model repeats this extrapolation process 35 times to derive an estimate of current adult biomass which is unconstrained by any index of adult abundance. In fact the extrapolated estimate of adult biomass is only loosely constrained by the assumed form of the DDM, estimated rates of natural mortality, and the need to match the virgin level of recruitment observed in the fishery.

Thus the model's estimate of current biomass is based upon:

- The estimated virgin recruitment levels,
- Estimates of natural mortality from tagging studies,
- Untested assumptions about the nature of the DDM in the virgin stock,
- The 35 year time series of catch at size, and
- Extrapolation of the effect extracting catches over 35 years of fishing.

Note that these models contain no data on adult abundance trends to inform the extrapolation of adult abundance over the 35 years of fishing. So the extrapolated estimate of current adult biomass is very poorly informed and is heavily influenced by the assumptions used to formulate the model.

In this context the main implication of this fisheries' dynamics is that estimates of adult biomass are highly uncertain and do not provide a reliable basis for setting RBCs in a Tier 1 Framework.

Developing a Reliable Harvest Strategy for Gummy Shark

Accepting that there is an issue that prevents the current assessment reliably estimating adult biomass the question becomes what to do about a harvest strategy for gummy shark?

There are essentially two alternatives;

6. Solve the fundamental uncertainties about the fisheries dynamics, stock size and structure by collecting data on the abundance of adult gummy shark and rework an integrated quantitative model to produce reliable estimates of biomass.
7. Use the simple but informative data available from the fishery to develop an empirical based harvest strategy for GS.

The first alternative is problematic, expensive and will take some period, probably 5-10 years, if it is successful at all. Even with an accurate survey of the current adult biomass comparisons back to pre-fished levels will rely on assumptions about DDM and stock structure, and there is no guarantee that an expensive program of research will resolve those issues. Early discussions about this initiative between Jeremy Prince (Chair SharkRAG), Tony Smith and Geoff Tuck (CSIRO), and Shane Gaddes and Beth Gibson (AFMA) decided that the first course of action involves the risk of biological research proving inconclusive with respect the main issues, along with the long term expense of biomass surveys. Consequently the decision was made that the direction should be to develop an empirical based model for setting TACs using the aspects of the data collected from the fishery which have proved informative to the assessment process, and to apply them in a manner which is robust to biological uncertainties, by planning around the acknowledged uncertainties.

A parallel model of an empirical Harvest Strategy is being developed in the ECTBF using catch rate target and size structure to incrementally adjust TACs, and is accepted within the Commonwealth Harvest Strategy Policy (Anon 2007).

Harvest Strategy Outline

Basic Premises

- Use the data and assume the least
- The fishery exploits several year classes of sub-adults.
- Very young juveniles and larger adults are not fished.
- The fishery has a history of stable recruitment over many generation times of the stock, established by the stability of catches and age structure, over four decades (5-7 generations) and the wide range of fishing pressure that has been applied.
- The fishery apparently fishes a mosaic of stocks which while linked to some extent genetically have varying biological parameters, and show local impacts of fishing.
- It is not established whether or not the stable recruitment enjoyed by the fishery is entirely produced by the adult biomass within the geographically limited fishing area.

A Simple Fisheries Model as the Basis for an Empirical Gummy Shark HS

The dynamics of the GS fishery conform to a very simple model of catch and effort described by Beverton and Holt (1957), which describes a fishery competing for shares of an annual fishery with an average annual fishable biomass.

The model is described with the equation.

$$\text{Catch} = \text{Av. Biomass} \times (1 - e^{(-A \times \text{effort})})$$

This equation simply implies that the fishery gets a proportion of the annual Average Biomass that is basically proportional to the amount of effort applied, except that at higher levels each additional unit of effort becomes progressively less effective, contributing more to a general decline in catch rates than to increasing the total catch.

At this stage this simple catch and effort model has been fitted to the catch and effort data (1971 – 2006) taken from Walker & Gason (2009). The landings data for Victoria and Tasmania combined because the fishing fleets landing into each state principally fish the same fishing grounds in and around Bass Strait. The South Australian fishery is treated separately because their fishing grounds are distinct between distributed between Robe and the Eyre Peninsula (Figure 1a & b). Relationships have been fitted to each of these two broad areas of the fishery using Excel Solver to minimize negative log-likelihood functions, as described by Hilborn & Mangel (1997), to estimate the parameter A, which scales how flat and abrupt, or smooth and curved is the relationship between catch and effort, and the Average Biomass (t. carcasse wt.) in the fishery. Confidence intervals ($\pm 95\%$) around these parameters have been estimated using the techniques described by Hilborn & Mangels (1997) which involve plotting the negative likelihood function against fixed values of the parameter around the best fitted value.

The parameters ($\pm 95\%$) fitted to the Victorian and Tasmanian C&E data were:

$$\text{Av. Biomass} = 1134, (1040-1275)$$

$$A = 0.100, (0.064-0.21)$$

The parameters ($\pm 95\%$) fitted to the South Australian C&E data were:

$$Av. \text{ Biomass} = 591, (518-710)$$

$$A = 0.059, (0.041-0.082)$$

The fitted models are shown in figure 1a&b. Confidence intervals ($\pm 95\%$) around these relationships have also been estimated on the basis of the variation of the negative likelihood function around the fitted relationship, also as described by Hilborn & Mangel (1997).

These relationships can be used to predict future levels of catch, effort and CPUE in the fishery, and to detect departures from these observed relationship. In fact SharkRAG has been implicitly using this approach to recommend TACs since September 2001 it argued that the current TAC level should be set at the level of the long term average catch (1700t for the gillnet sector), rather than the 2100t initially set using the synthesis model. This implicit approach has successfully managed the fishery back from high to moderate effort levels under a stable TAC, and the sustained period of moderate effort levels is now apparently fostering a yield per recruit increase for the fishery.

The factors underlying any departures from these relationships should be indicated by where the new data points fall relative to the historic relationship:

1. Because the fishery depends principally on just four year classes of sub-adults a decline in recruitment in any year will produce a rapid decline in catches and catch rates, and probably a concurrent increase in effort as quota holders struggle to fish up to the TAC under more difficult circumstances. In this case new data points will fall below the historic relationship which has been determined by the history of constant virgin recruitment.
2. Alternatively because the fishery has not previously fished stably for any period of time at the current moderate to low effort levels an increase in yield per recruit from the fishery might be expected, and this should cause new data points to begin falling outside the observed relationships in the top left hand side of the plots,
3. Another alternative is that the development of previously unfished areas in the far west of South Australia, or off the eastern, southern or western coasts of Tasmania could cause data points to fall above the relationship, most probably in line with the initial linear part of the curve.

This proposal, illustrated by the indicative figure 2, is to use these simple relationships as a primary part of an Empirical Harvest Strategy for GS. The primary logic being if catch, effort and CPUE continue to conform to the observed relationship this indicates that the stable virgin level of recruitment that gives rise to these relationships is continuing, in which case the current level of TAC can be safely continued. Conversely, any significant departure from this historic relationship will indicate change to the relationship, and that TAC levels should be changed incrementally (Figure 2).

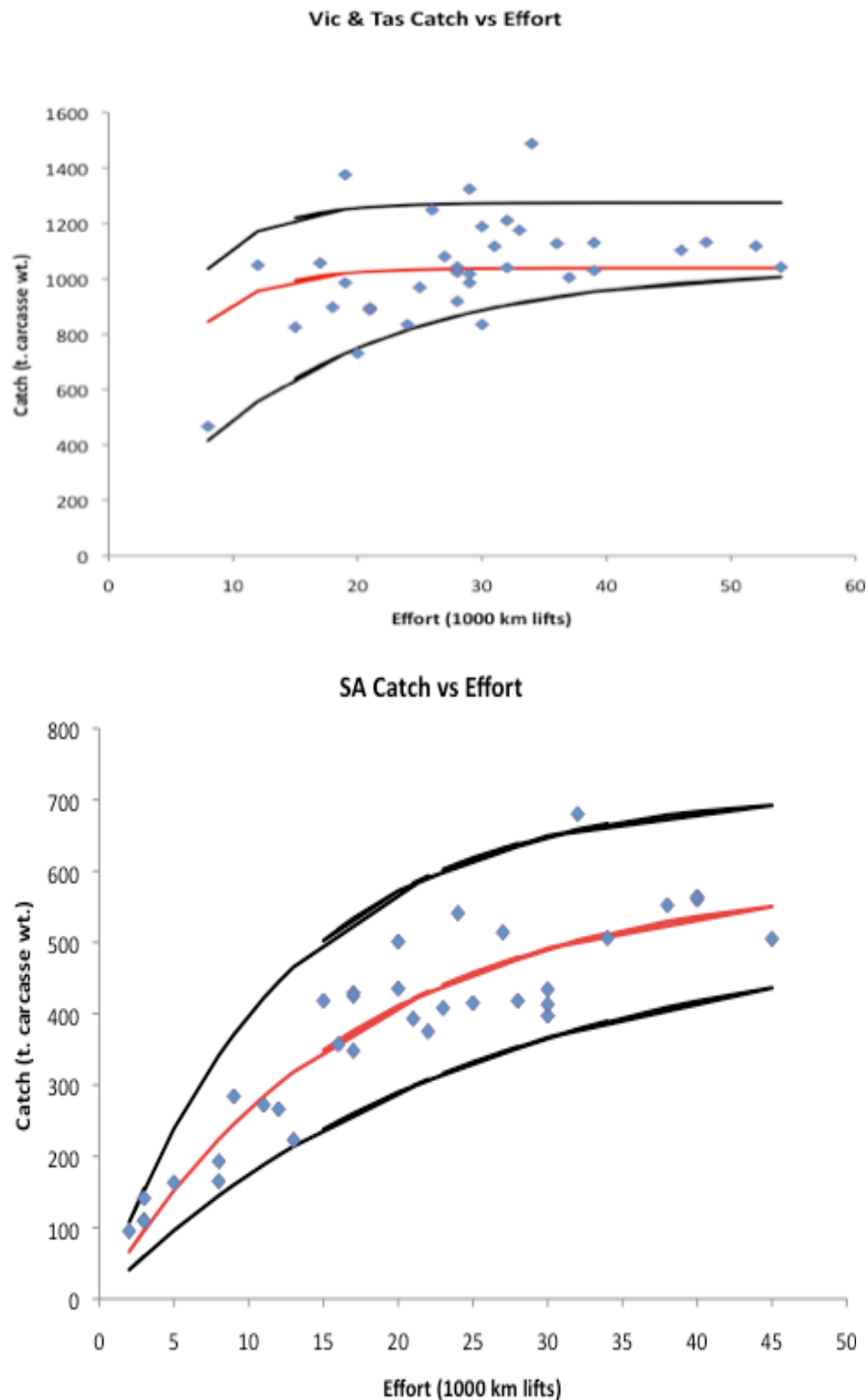


Figure 1 (a & b). Plots of the relationship between annual catch (t. carcase wt.) and annual effort (thousand km. lifts) for Gummy Shark from 1971 to 2006 for catch landed into (A.) Victorian and Tasmanian ports (combined) and (B.) South Australia. The fitted relationship, as described above is shown by the red line with the upper and lower 95% confidence intervals shown by the black lines. Data source Walker and Gason (2009).

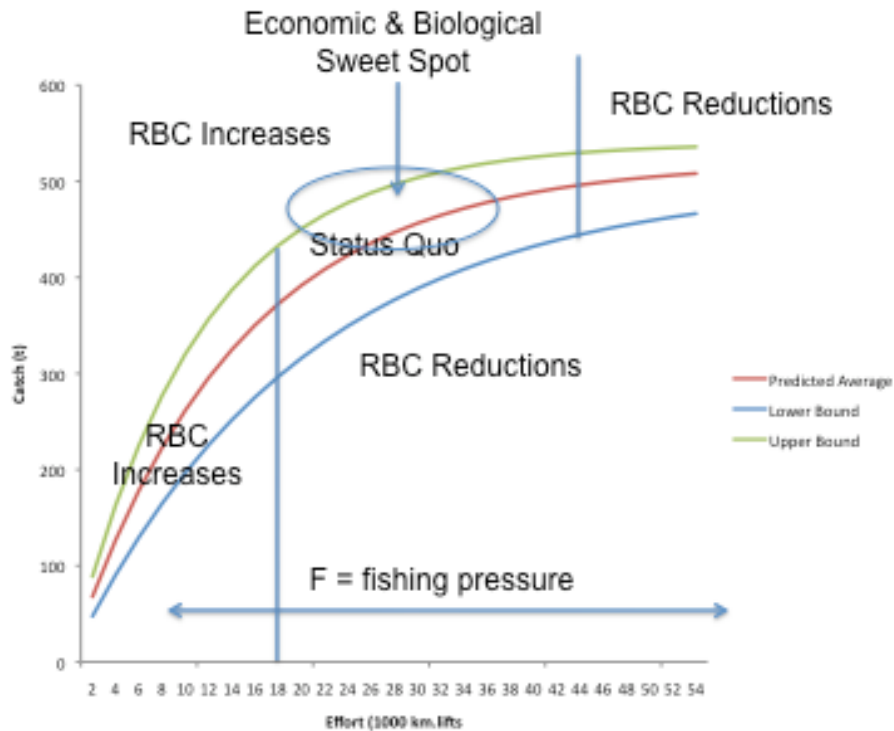


Figure 2. Schematic of a potential empirical harvest strategy for GS based on historic relationship between catch and effort. Potentially size or age structure could be incorporated into the harvest strategy providing and independent index of F and recruitment.

This proposal is to build on and extend this approach in the medium term (1-3 years) for long term implementation. Further development should involve formalizing and rigorously testing the approach using MSE modeling, and adding additional rigor by explicitly incorporating size data as a second indicator of fishing pressure and yield per recruit. Extension of the approach should also incorporate establishing catch rate targets based on economic targets for the fishery explicitly into the harvest strategy so that incremental changes in RBC can push catch and effort levels towards selected CPUE and profitability targets for the fishery (Figure 2). The incorporation of size composition data could also provide a Harvest Strategy with a second and independent estimate of regional fishing pressure (F), year class strength, and changes in yield due to changing yield per recruit. These elaborations to the approach would make the approach more robust by providing multiple indicators of fishing pressure, and allow for graduated changes to the TAC should a recruitment decline being detected, or to reward the yield per recruit gains that recent moderate levels of fishing effort appear to be producing in the fishery.

Regional Structure of the harvest strategy

Long term the implementation should be at a regional scale, probably an amalgamation of the statistical cells developed and used by SharkRAG, but based on mapped patterns in fishing effort and commensurate with the scale of GS movements. In the interim an approach based on historical state landings as documented by Walker & Gason (2009) has been used because it is feasible within the resources and time available.

The use of size and/or age data in the harvest strategy

The sub-adult GS being fished are growing relatively rapidly as they move through the gauntlet of the fishery so that size composition of the catch can be expected to be, and anecdotally at least has been, a useful indicator of fishing pressure and recruitment trends. In the long term incorporation of catch at size data into the HS would allow a second independent indicator of fishing pressure, recruitment strength and yield per recruit to be incorporated in this HS approach. This is not possible within the time and resources needed to develop an interim approach.

Principles Underlying an Empirical GS Harvest Strategy:

1. Assume the observed levels of stable recruitment continue, and
2. Monitor and manage for a break down in the observed relationships in regional patterns catch, effort, CPUE and body size, which may indicate (a) recruitment has declined unexpectedly, (b) yield per recruit has increased, or (c) the extent of the fishing ground have changed.

A. Guard against unexpected recruitment decline

The harvest strategy will detect significant deviations below the historic relationship between CPUE, effort, catch and body size, which have historically been determined by recruitment being stable at virgin levels. Deviation below the relationship will indicate recruitment below previously observed levels. Because this would not be a leading indicator of future recruitment but a backward looking indicator of recruitment that has already been fished, the response to an unexpected recruitment decline would need to be immediate and strong. With the development and incorporation of a second indicator based on size or age data it will be possible to be quantitative about any decline in recruitment observed and cut TACs proportionately.

However, in the interim, while the simple catch and effort relationship is being used unsupported by size data, the logic underpinning the HS will by necessity be cruder.

There are four main year classes in the fishery, if we see a negative perturbation that will indicate that a weak year class has already entered the fishery and been fished for a year. An initial 25% cut of TAC would have conserved the weak year class that in the mean time would have already been fished. At that stage we will have no information about following year classes, so, 2 x 25% TAC cuts applied in the year the decline is first detected would greatly reduced the fishing pressure on the year class that is known to be weak but which has already been fished for a year, and it would also provide a precautionary reduction against the next year class being weak as well. During that year of the 50% TAC reduction trends in catch, effort, CPUE and age/size age structure could be used to determine whether the recruitment decline was a single or multiple cohorts, and the future TAC direction decided accordingly.

The idea of immediate 50% TAC reductions when a recruitment decline is observed may sound draconian. However, the context for this must be remembered:

- C. A recruitment decline has never been observed, but if it were to occur strong proportional cuts as outlined would be precautionary.
- D. At this stage of discussions, the examples being used are on the basis of the state of landing, dividing the SESSF TAC into two broad regions. In implementing such a system permanently the multiple fishing grounds fished by the fleet in each

state would be disaggregated into smaller fishing grounds commensurate with knowledge about gummy shark movement rates and the distribution of fishery. In this way the assessments would be done on 6-10 sub-units within the fishery, and any large pre-emptive cuts would most probably only ever being applied to one or several sub-components which add up into the fisheries RBC.

B. Reward yield per recruit gains

In the long term the system needs to be able to reward yield gains expected because with lower effort levels the recruited year classes are being caught on average at an older age and larger body size. Prince (1991) collected anecdotal evidence that the original body weight in the early fishery was around 4kg even prior to gillnets when some of the fishing grounds were fished with unselective hooks, and in some fishing grounds had declined to around 2.2kg by the early 1990s. With current low effort levels we should expect body weight to move back towards an average of about 4kg. We already seem to be observing this in the fishery. In an empirical system such as this, movement above the trend line or targets for (CPUE, catch, effort, body size) should be rewarded with small incremental TAC increases. These experimental upward steps should be cautious and only implemented periodically, so that the impact of the previous step can be clearly seen in the fisheries statistics before the next step is taken.

To implement such a graduated approach Management Strategy Evaluation (MSE) will be needed to calibrate the scale and timing of TAC increases so that they are proportional to gummy shark fisheries biology, and programs to collect, analyse and incorporate size data will need to be developed and implemented. This will require additional funding and time.

In the interim this Harvest Strategy will not have the capacity to capture potential yield per recruit effects by increasing TACs.

C. Changing Extent of Fishing Grounds

In the lightly exploited extremities of the fishery (southern Tasmania, and western South Australia) there may be some future capacity to develop new fishing grounds which due to the limited rate of GS movement can be expected to contain distinct lightly exploited, or unexploited GS populations. Under a permanent implementation of this HS, were catches from areas currently outside the established fishing grounds to become significant, the statistics and catches from these grounds should be treated independently within this Harvest Strategy, and new assessments for those areas should be developed for addition into the fishery wide RBC. Alternatively, negotiations currently commencing about managing the incidental catch of Australian sea lions may lead to a loss of GS fishing grounds, and if this occurs the loss of fishing grounds will need to be recognised by a commensurate reduction in the TAC and a recalibration of the HS approach.

In the interim this Harvest Strategy will assume the area of the fishery remains stable.

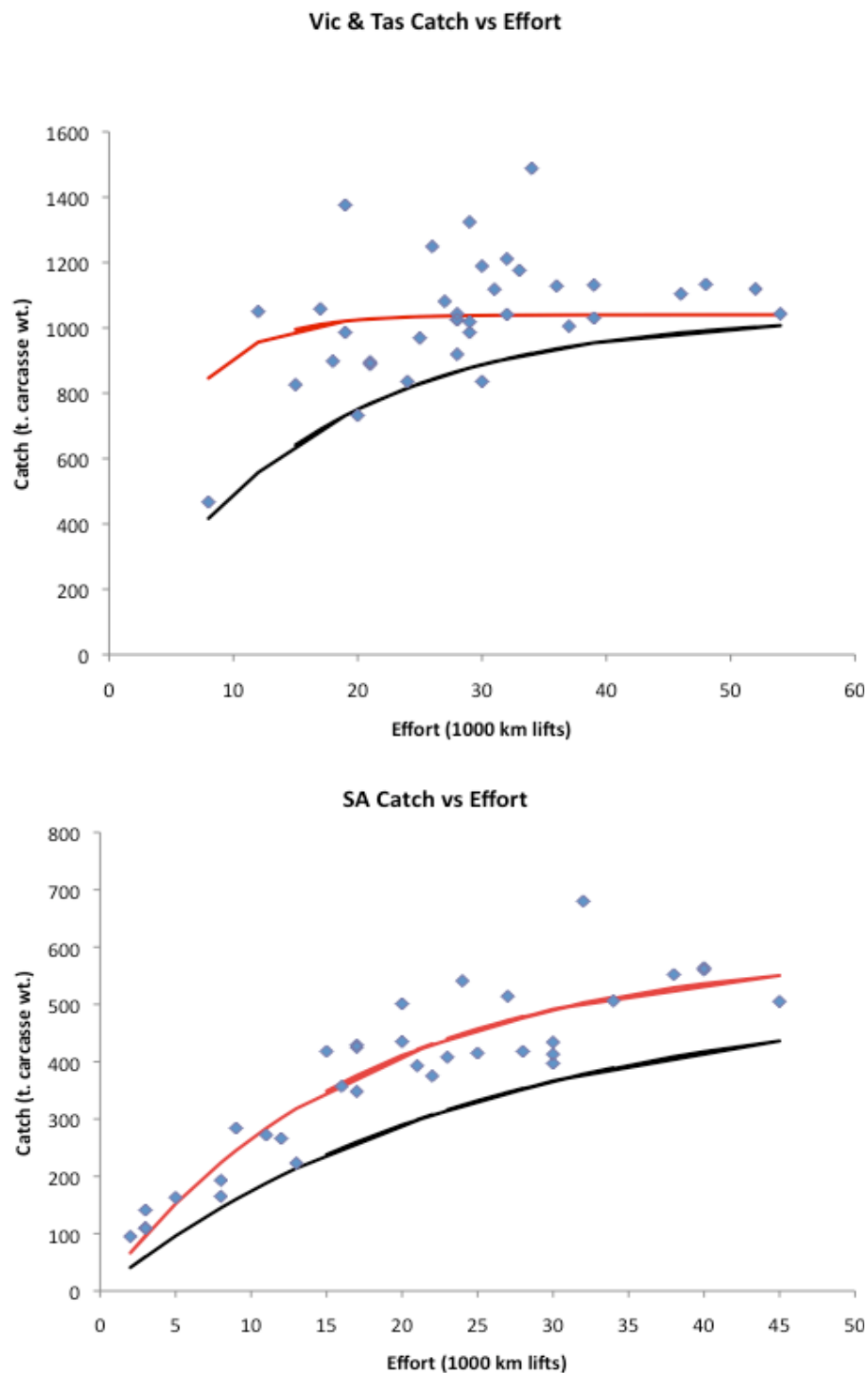


Figure 3a & b. Plots of the historic relationship between GS catch and effort for (a) combined Victorian and Tasmanian landings and (b) South Australian landings, showing the estimated relationship (red line) and the estimated lower 95% confidence interval which is proposed in an interim Harvest Strategy should be the threshold for TAC reductions, as new data points below that level could be indicative of an unexpected decline in recruitment.

An Interim Approach to GS Harvest Strategy

Figure 3(a & b) illustrates the suggested interim approach to TAC setting in the GS fishery. The approach would involve determining whether recent catch and effort data (2007, 2008 & 2009) conform to the historic (1971-2006) catch and effort relationship for Victorian and Tasmanian landings (combined) and for South Australia, figures 1a and 1b respectively.

The suggested decision making process for the interim is:

- If recent data continue to conform to the historic relationship determined by stable virgin levels of recruitment, or fall above the relationship, this will be taken to indicate that recruitment has continued to remain stable at pre-fished levels and the RBC should continue to be the current status quo.

or

- If the recent data fall below historic relationship the RBC should be reduced initially by 50% of the estimate Average Biomass of the effected region in the first year, and 25% of that amount for each subsequent year that Catch and Effort data for that region remain below the historic relationship.

Dealing with Uncertainty and Risk

The Commonwealth Fisheries Harvest Strategy Policy (Anon. 2007, p.41) mandates that a Harvest Strategy must maintain a stock above the biomass limit reference point at least 90% of the time. In the context of the GS fishery only having robust indices of recruitment and no indices of adult biomass, and in the time frame available to develop this interim approach to a GS Harvest Strategy for GS it is will not be possible to categorically demonstrate compliance with this mandate.

However, using first principles there seems no likelihood that this policy will be breached. The approach being followed here is to set TAC levels around maintaining stable virgin recruitment. Shark fecundity is determinate meaning the number of surviving young produced by each female is not highly variable like it is for most species bony fish and crustaceans. So while the various GS stock assessments demonstrate that the assumed form of DDM influences the estimated level of adult biomass required to produce virgin levels of recruitment it seems highly unlikely that virgin levels of recruitment could be generated from a biomass less than 20% of unfished levels (the default biomass limit reference point). Furthermore account must also be taken of the fact that the adult biomass remains unfished and so even in the absence of all recruitment, the adult biomass will only decline at the rate of natural mortality (0.1 – Walker 2009). Thus within the short term context the interim HS, and the stability of recruitment around pre-fished levels, for the previous 35 years of the fishery's history, there is virtually no possibility that adult biomass will fall below 20% of unfished levels.

In the longer term compliance with this mandate will need to be demonstrated through MSE evaluation. The development of fishery independent surveys to index adult abundance will not help in this respect because there is no way of comparing current adult biomass with pre-fished levels. The more amenable approach will be to compare

a range of alternative plausible DDMs and determine what level of adult biomass is necessary to maintain virgin recruitment levels. It is to be hoped that this proves virgin recruitment levels cannot be maintained at 20% of pre-fished adult biomass. In which case a HS strategy that maintains recruitment at virgin levels, and can rapidly restore recruitment to virgin levels, will comply with Commonwealth Harvest Strategy Policy (HSP). Using MSE studies the magnitude of TAC reductions, should a recruitment decline be detected, could also be calibrated to ensure that this policy mandate is complied with.

Should modeling studies suggest that GS recruitment can be maintained at virgin levels by <20% of the pre-fished adult biomass this issue will become more problematic as there are no data on the pre-fished level of adult biomass. In this case some more novel approach to conforming with the standard of the HSP will need to be developed specifically for the GS fishery.

On a separate but related issue, the interim approach to the HS outlined above, proposes using the estimated lower 95% confidence interval for the observed C&E relationship (1971-2006) as the indicator of a decline in recruitment and the trigger for large pre-emptive TAC reductions (figure 3&b). In both cases these confidence intervals bound almost all the observed data, and so intuitively provide a reasonable threshold to distinguish normal variability from an unexpected decline in recruitment. Strictly speaking however, these confidence intervals estimate the probability that the actual C&E relationship lies within these bounds, rather than the probability of an individual 'normal' data point falling within these bounds. The probability of an individual data points falling close to the estimated relationship will be a direct function of the observed variance around the relationship, while the confidence intervals I have estimated are a function of both the variance in the data and the number of data points. The difference can be illustrated by the fact that if there are a great many data points (100s-1,000s) the confidence intervals around the relationship could be tight, even if the data are highly variable around the relationship.

The net result of this difference will probably be to make the threshold for TAC reductions suggested here higher than a threshold based on simply on the observed variance around the estimated relationship. i.e. the approach suggested here is more conservative and has a higher probability of producing a reduction of the RBC, than a more strictly correct approach based simply on observed variance around the relationship. In this context it should be noted that two out of the thirty five Victorian and Tasmanian data points fall just below the estimated lower threshold. So historically the interim approach would have suggested an RBC reduction in two out of 35 years even though recruitment has subsequently been proved by the fishery to have continued around virgin levels.

The published fisheries science available to me at this point of time, concentrates on determining the significance of observed differences between relationships, rather than the likelihood of additional points conforming with previously described relationships. Resolving this issue will require a level of statistical expertise beyond my own, and a time line longer than that available to me at the current time in the run-up to Christmas 2009. This issue will have to be resolved within the framework of this TRF in the New Year.

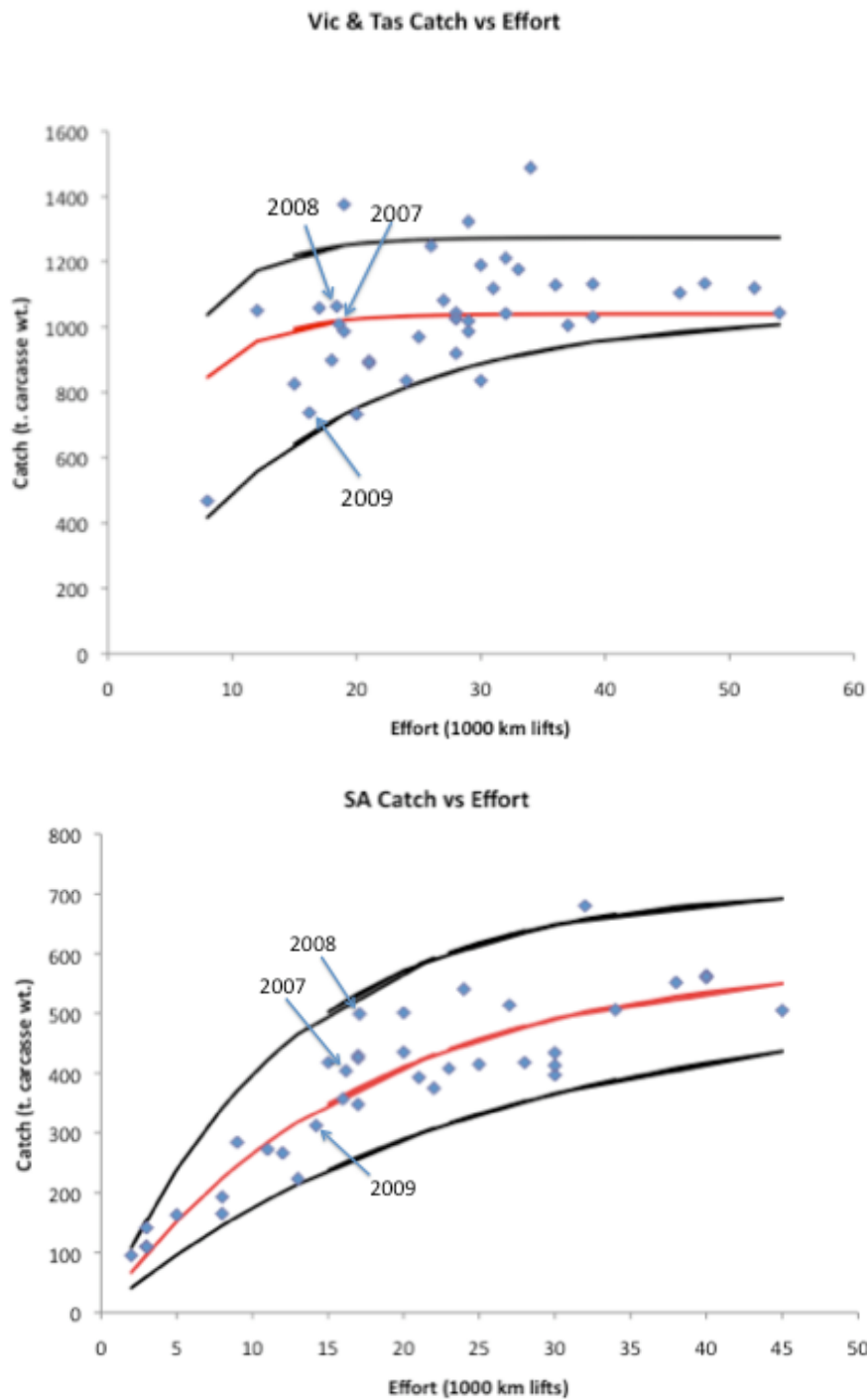


Figure 4a& b Plots of the historic relationship between GS catch and effort for (a) combined Victorian and Tasmanian landings and (b) South Australian landings, showing the estimated relationship (red line) and the estimated 95% confidence intervals (black line). It is proposed that in the interim Harvest Strategy the lower confidence interval should be used as the threshold for TAC reductions, as new data points below that level could be indicative of an unexpected decline in recruitment. The three most recent data points are plotted and indicated and in both regions fall above the threshold. Note that the data points for the 2009 calendar year are incomplete at the time of writing.

Without having fitted the new data points (2007-2009) it is my judgment that this issue will remain entirely academic within the context of recommending an RBC for 2010, since anecdotal accounts from the fishery suggest the most recent data points will fall close to, or above the estimated C&E relationship, and well above the suggested lower threshold, indicating that the fishery continues to enjoy stable virgin levels of recruitment. In this case this issue can be resolved over the coming year with appropriate statistical advice and within the context of developing a long term empirical HS for the fishery.

Application of the Interim Gummy Shark Harvest Strategy

Figure 4 a&b show the C&E relationship described above for the GS data 1971-2006, this time with most recent (2007-2009) plotted. From this it can be seen that the most recent data conform with the trends observed since the inception of the fishery indicating that recruitment to the fishery remains stable around virgin levels.

Both the 2009 data points are low (i.e. low effort and low catch) presumably partly because at the time they were extracted (early December) they are still incomplete. Never the less, even incomplete it can be seen they fall within the range of the historic C&E relationship.

Conclusion

The three most recent data points (2007-2009) lie within the historic C&E relationship indicating that recruitment continues to be stable around pre-fished levels and under this proposed interim Harvest Strategy for GS this justifies the RBC being to maintain the status quo TAC that has been applied to the fishery since 2002.

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Appendix 5: Proposed R&D need to develop Empirical Indicators for GS. SharkRAG April 2010

Document prepared for SharkRAG 15-16 April 2010.

Jeremy Prince
8 April 2010

Introduction

The TRF on Empirical Indicators for GS is required to scope out for COMFRAB the types of research needed to support their further development and implementation into the fishery.

On the basis of previous discussions I have drafted up an outline of R&D projects which I think will be necessary at some stage. If SharkRAG, in my absence, could discuss and recommend what ever changes they think best, I could then use the records of the meeting to redraft something for inclusion in the draft report of the TRF.

It would be expected that all projects liaise closely with SharkRAG during the terms of their projects (i.e. attend SharkRAG regularly)

1. Assessment Modelling

Both Punt and Prince are asserting that the biomass trends estimated by the GS assessment model are determined by the nature of the assumed density dependence mechanism (DDM) and so cannot be relied upon for setting TACs. For SharkRAG's process there is a need to update the existing assessment model with modern data and use it to perform a series of sensitivity tests of the assertions of Punt and Prince. In this way SharkRAG will formally establish the need to develop an alternative harvest strategy for GS.

2. Developing Empirical Indicators - Harvest Strategy Evaluation

Every new approach to Harvest Strategies should be tested and developed through Harvest Strategy Evaluation (HSE) modeling. In this approach the operating model will incorporate GS biology and plausible population structure hypotheses, along with models of the fishery. The modeling study will evaluate how the operating model responds to alternative forms of Harvest Rules and so allow an optimal set of rules to be developed into the Harvest Strategy. The operating model will then be used to evaluate the robustness of the proposed Harvest Strategy relative to the standards laid out by Commonwealth Policy.

Any important aspect of this project will be the development techniques for informing empirical indicators with size in the GS catch data. It appears that size in the catch has been a reliable indicator of local fishing pressure in the GS fishery. Likewise with only 4 main year classes in the fishery the size in the catch can be expected to be an

effective indicator should recruitment to the fishery become unstable. Prince is proposing that local size in the catch could be incorporated into an empirical GS harvest strategy adding value to the interpretation of basic catch and effort trends. The methodology for doing this needs to be developed. This methodology will need to be developed before Harvest Rules based around it can be evaluated. However the operating model developed for the HSE analysis will also provide the ideal test bed for developing size based analyses of GS data.

3. Development of Systems for Collecting Regional size in the catch data

We can predict that regional patterns in size in the catch data will be useful empirical indicators of stock trends. Local movement patterns of GS suggest these data need to be collected with high spatial resolution and so are better collected at sea before stowage rather than upon landing. With this project the new Sustainable Shark Industry Association should be resourced so that some form of data collection at sea program can be re-developed and implemented with the intention that it will be taken up by a high percentage of the fleet.

Punt produced evidence the size of GS varies between targeted and untargeted shots. In this case the former ‘first shot’ design trialed in the fishery may not provide the data needed to support the harvest strategy. It maybe that the former design needs modification, or the addition of a specific ‘targeted GS’ measuring protocol in addition the multi-species first shot measurements. These are all issues that this project could tease out in collaboration with SharkRAG and project 2 (above).

4. Basic Biology supporting an Empirical Approach to Harvest Strategies

In today’s funding environment it is difficult to find funding for basic biology when all the biology essential for parameterizing stock assessments is already well documented. Especially when the current state of the fishery suggests management over the last decade has been highly successful using what we already know. However in this situation several lines of logic lead us towards prioritizing some further research into the way GS biology and behaviour interact with the fishery to produce the distinctive dynamics that have been observed since fisheries inception in the early 1970s.

The rising political heat around the sustainability of elasmobranch fisheries leads us to expect that the quality of the scientific justification underlying sustainable shark fisheries will need to be of a very high quality. With GS much of the understanding of its core fishery dynamics remains uncertain and unstudied in any formal sense. Core questions about the nature and extent of the fishing grounds, the nature of the aggregations being fished and the reasons for the GS to aggregate, all remain undocumented. Biological programs targeted at central features of the fisheries dynamics would allow a coherent scientific ‘story’ of the features underlying this fisheries sustainability, and so set SharkRAG for the defence of the fisheries sustainability.

Approaching from the modeling and assessment perspective, it can be expected that further modeling and analysis will confirm the assumptions of Punt and Prince that

DDM assumptions determine the modeled biomass trend, and that this will lead to discussion of the likely DDM for the fishery. Likewise for the HSE studies the operating model being developed will need to be able to test for the effects of different plausible DDM and stock structure assumptions. All these discussions will highlight the need for simple cost effective biological studies targeted at the key features of the fisheries dynamics.

My suggestion would be to involve the new Sustainable Shark Industry Association with this project, at least for the development of structured sampling at sea, if not for the entire biological study as well, perhaps in collaboration with one of the established shark researchers.

Appendix 6: Letter of Support from The Sustainable Shark Fishery Association.

Sustainable Shark Fishing Inc.

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Dear CoMFRAB Members.

**Support for future research into the development of Gummy Shark
empirical indicators.**

The southern shark fishery's industry association (Sustainable Shark Fishing Inc) has been working closely with Dr. Jeremy Prince and SharkRAG on the future management of our industries prime target species, Gummy Shark.

The preliminary outcomes of Dr. Prince TRF funded project (TRF 2009-066) have been vital in the development of management strategies for both Gummy and School shark resources in this fishery and the proposed project "Development of Empirical Indicators for Assessing Gummy Shark" (application JP018) will contribute greatly to upcoming stock assessments.

As outlined in the project proposals, the gummy shark fishery displays a number of unusual and poorly understood dynamics despite being one of the most stable of all commonwealth fisheries. This stability conflicts with the current traditional stock assessment assumptions, which are estimating adult biomass with high uncertainty.

The majority industry association, Sustainable Shark Fishing Inc, would like to lend its support to this proposal and ask that it be considered for funding in the coming round.

The outcomes and methods employed in the proposed project will provide a

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strong complement to industry initiated research projects that are currently in prep' for presentation to FRDC. Also the use of empirical indicators offers an extremely cost effective way of managing a valuable SESSF species. This falls in line with AFMA and SESSRAG's move to longer term TACs and lower management costs.

The Shark Industry strongly supports this proposal to undertake empirical assessments of Gummy Shark.

Should you require any further information regarding this matter, please contact Mr. Brian Bailey, Chairman - Sustainable Shark Fishing Inc on (03) 62442775 or anurasci@gmail.com



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