Management Strategy Evaluation for South Australian Snapper

Richard McGarvey, Paul Burch and John E. Feenstra

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We thank Sean Sloan and Michelle Besley at PIRSA Fisheries who initiated this project to evaluate snapper management strategies. We are grateful to the South Australian marine scale fishers who provided all catch and effort data used in the model, and who requested that an assessment of the current November closure be undertaken. The Marine Fishers Association, led by Mike Fooks (Chair) and Peter Welch (Executive Officer) and Neil McDonald, together with Kelly Crosthwaite and Michelle Besley from PIRSA Fisheries, met to propose the specific set of fishery management strategies for South Australian snapper to evaluate in this model simulation study. Guidance and data were provided by the Subprogram Leader for Marine Scale Fisheries at SARDI Aquatics, Tony Fowler, who leads South Australian snapper research. Snapper sample data, were gathered in weekly trips to the SAFCOL auction fish market led by Bruce Jackson, and which included Mike Steer, Matt Lloyd, Graham Hooper and others. Richard Saunders' PhD work provided the basis for estimates of snapper fecundity versus body length, and for the December yearly timing of snapper spawning.

EXECUTIVE SUMMARY

- The commercial snapper fishery in South Australia is managed by a mix of input controls, including limited entry, a minimum size of 38 cm, no take by nets and fish traps, a 400-hook limit for longlines, 3-hook limit on handlines, the on-going marine scalefish licence amalgamation scheme, and a yearly closure to snapper fishing each November.

- This project was requested by PIRSA Fisheries and the Marine Fishers Association to evaluate the November closure and a range of alternative snapper management strategies.

- Management strategies evaluated include (1) the current (November yearly closure) baseline strategy, (2) removing the November closure, (3) extending the closure to 15 December, (4) setting yearly catch quotas of 110%, 100%, 90%, 80% and 70% of last year's (Oct 2007 – Sep 2008) commercial catch, (5) commercial trip limits of 250 kg, 500 kg, 750 kg and 1000 kg as maximum allowable catches per day, (6) an increase in the minimum size from 38 to 40 cm TL, and (7) reducing the maximum number of hooks to be fished by longlines from 400 to 300. Strategies (4) to (7) were run both with and without November closure, a total of 27 strategies in all.

- A management strategy evaluation simulation model ('SnapSim') was developed for South Australia snapper and run to compare the performance of these 27 strategies. The model generated estimates of egg production, yield, and economic performance under each strategy. These were quantified by long-term (23-year) time-average levels of egg-, yield-, and value per recruit.

- The current SnapEst fishery stock assessment model was used to provide the underlying dynamic model of snapper population change over time, to estimate population parameters for this fishery model, and to derive historical patterns of yearly recruitment used in the management simulation. These SnapEst mathematical algorithms and estimated parameters were incorporated to build the SnapSim management simulator.

- For each management strategy evaluated, the three performance indicators are given as a percentage above or below the levels estimated for the baseline. Scatterplots were generated showing the trade-off of enhanced egg production versus reduced (short-term) commercial catch for each strategy tested.

- Increases in future recruitment with higher production were not accounted for, because quantifying a stock-recruitment relationship was not statistically achievable. The results were therefore conservative in that the full benefits of strategies resulting from enhanced egg production (higher recruitment, higher biomass, and higher catch rates) were underestimated. It is possible, therefore, to describe the changes in catch as 'short-term' since medium-term increases due to higher recruitment were ignored.
- The principal observed trend in the resulting management strategy simulations, was the uniformly better performance of strategies that retained the November closure, by comparison with those same strategies where closure was removed.
- Apart from whether closure was added or removed, different categories of strategy, such as quota, trip limits or longline hook reduction, were not measurably different in terms of performance. These all fell along common grouping lines in scatterplots.
- The best performing strategy was one that extended closure to the middle of December.
- Supplementary simulation was undertaken to test one hypothesis for why strategies that retained closure yielded higher egg production, biomass, GVP, and catch rates, given any chosen (short-term) reduction in catch. The hypothesis was that when closure was removed, recreational catch became relatively unrestrained, but commercial catch was restrained by the alternative tested strategies (quota, trip limits, longline hook reduction). Simulations confirmed this hypothesis that higher mortality from recreationals erodes the egg production benefits of strategies applicable only to commercial harvest.
- This hypothesis was further supported by the observation that the one region, northern Spencer Gulf, where recreational catch is dominant, was also the region that showed a substantially greater advantage for strategies that retain the November closure.
- These simulations show that management strategies for snapper that proportionally constrain catch in both sectors offer a higher probability of achieving long-term sustainability, as higher egg production, biomass, and of optimising economic benefits as higher commercial catch rates and landed value, especially in regions where recreational fishing is an important component.

1 INTRODUCTION

1.1 Background

The snapper (*Pagrus auratus*) fishery in South Australia is the second largest among marine fish stocks in landed commercial value. Snapper have been subject to an increasing range of effort-based regulatory controls since the mid-1990's (Fowler et al. 2007). As with the highest-value finfish stock, King George whiting, both recreational and commercial sectors take important percentages of the yearly harvest.

Currently, snapper is managed in South Australian waters by a combination of input control measures (Fowler et al. 2007). These include, (1) a legal minimum size limit (as total length from tip to tail) of 38 cm, (2) a yearly temporal closure, in November each year, during which no snapper can be landed in South Australia, (3) an on-going licence reduction scheme which reduces the total number of fishing licences in the South Australian marine scale sector of which snapper is a principal species taken, (4) a prohibition on taking snapper by nets of any kind, and (5) an upper limit of 400 hooks for longliners.

Temporal closures were first implemented in 2000 in response to a sudden rapid decline in longline catches, effort and catch rates in the northern Spencer Gulf (NSG) in 1998/99 (Fowler and McGarvey 2006). Enhanced snapper management measures were also a response to the weak status of the snapper population in Gulf St. Vincent (GSV), where catches and catch rates had declined dramatically since the mid-1980's (Shanks 2000). After extensive discussions of the Snapper Fishery Working Group (Fowler and McGarvey 2006), two management strategies were considered for implementation: a yearly seasonal closure and a maximum size limit. A model was developed to assess these two options (McGarvey and Jones. 2000; McGarvey 2004) which suggested that both the maximum size limit and strategies of lowering fishing mortality by a reduction in days fished yielded similar estimated increases in eggs production, but that reducing fishing mortality could permit a higher long-term catch. Seasonal closure was the only method considered practical for reducing overall fishing pressure. These results were found to be robust under a range of assumed values for model inputs. Explicit accounting for release mortality (of snapper above a maximum size) strengthened the model outcomes favouring a policy of effort reduction.

Supplemental advantages of a seasonal closure were noted in Working Group discussions. (1) The closure applies to both fishery sectors, commercial and recreational; (2) it applies to the two main gear types, hand line and longline; (3) PIRSA Compliance preferred it as relatively straightforward and inexpensive to enforce; (4) it protects snapper stocks at a crucial time in their yearly reproductive cycle, as they are schooling tightly around aggregation points at the start of summer spawning; (5) by comparison with a legal minimum or maximum length, it avoids release mortality which can be substantial for snapper; (6) it does not permit fishing effort to shift geographically in response to controls that apply more strongly in some areas, such as shifts away from larger snapper in NSG under a maximum size.

In 2000, a snapper closure was implemented for 3 weeks in August and 3 weeks in November, sufficient to induce a reduction in yearly catch, and thus exploitation rate, of approximately or slightly higher than 10%. The August closure time was selected to coincide with the yearly time of lowest price to fishers, when snapper catches in Shark Bay WA were usually abundant in Australian markets. The decision in 2003 to drop the August closure and extend the November closure to a full month was undertaken after a mail poll to commercial fishers, who overwhelmingly favoured the continuation of the snapper closure, but of those, many recommended shifting the timing of the full closure period to November to protect spawners.

Detailed study of catches and effort in the days prior to and following the November closure by comparison with years when there was no closure (Fowler and McGarvey 2006) found that compensating behaviour (higher than average fishing intensity in the days before and after the closure period) constituted a relatively small impact.

Disadvantages of the November closure, which fishers have raised in recent years, include (1) lower prices in the time subsequent to closure as a result of higher landings in the first few days after closure, (2) a disruption in snapper supply during November, and (3) and concerns that a very high concentration of fishing effort in the first few days after reopening in December could disrupt snapper spawning behaviour and result in higher than average catch impacts.

The strategies to be analysed in this management strategy evaluation were proposed in meetings with PIRSA Fisheries and the Marine Fishers Association.

1.2 Objectives

The aim of this project, for PIRSA Fisheries and the Marine Fishers Association, is to examine the relative benefits to snapper sustainability and fishery production of the yearly November closure, and more generally to evaluate a range of management strategies, both in combination with, and as an alternative to the November closure. This evaluation of strategies will be undertaken using fishery population modelling tools developed for South Australian snapper stocks.

1.3 Management Strategies to Evaluate

Strategies evaluated in this study, as requested by PIRSA Fisheries and the Marine Fishers Association were:

1. Baseline strategy (current November closure)
2. Remove seasonal closure
3. Extended closure: 1 November to 15 December
4. Quota
    4.1. Use last year's (Oct 2007 – Sep 2008) catch as a default TAC.
    4.2. Run simulations with 110%, 100%, 90%, 80% and 70% of this default TAC.
5. Trip limits: 250 kg, 500 kg, 750 kg and 1000 kg as maximum allowable catches per day.
6. Size limit: 40 cm, increased from the current 38 cm.

November closure, being the status quo, is the baseline to which all other strategies will be compared. Being the historical reality from which data was obtained and to which the SnapEst stock assessment model was fitted, the percentage change in tested performance indicators were calculated relative to this baseline strategy.

It was also agreed that strategies 4-6 should be run for both closure scenarios, namely with and without the November closure.

In addition, fishers subsequently requested that we examine the effect of a reduction in the number of longline hooks from 400 to 300.

Some strategies apply only to the commercial sector. Recreational fishing is subject to the same regulation as commercial fishing under seasonal closures and increased legal size, but is unaffected by quota, commercial trip limits, and longline hook reductions.

2 METHODS

The performance of these management strategies was evaluated with the use of a South Australian snapper fishery management simulation model (SnapSim) designed and developed under this project. The underlying fishery population dynamics used in this simulator, and the model parameters were based directly on the existing estimation model SnapEst (McGarvey and Feenstra 2004) used for stock assessment of South Australian snapper and incrementally improved since the late 1990's (Fowler et al. 2007). In the next two subsections, we describe these two models, the stock assessment estimator and the management strategy simulator.

2.1 Snapper stock assessment estimation model, SnapEst

The SnapSim input model parameters were estimated using SnapEst, which has been extended for this project with data up to the end of September 2008. SnapEst yields population parameter estimates for the SA snapper stocks based on statistically rigorous fits (by maximum likelihood estimation) to the available data for this fishery, notably yearly catch and effort totals, and age and length (primarily SAFCOL market) samples of the landed catch. By fitting to fishery data, this model provides estimates of population parameters for northern and southern regions of Spencer Gulf (NSG and SSG) and for Gulf St. Vincent (GSV). SnapEst generates yearly biological performance indicators specified by the management plan, biomass, recruitment, exploitation rate and egg production, which are reported and compared with limit reference points in snapper stock assessments (Fowler et al. 2003; 2005; 2007).

The SnapEst stock assessment model is age- and length-based (McGarvey and Feenstra 2004). It is based on a 'slice partition' of each yearly age group of snapper (each cohort) into length bins (McGarvey et al. 2007). This slice-partition method models change in fish population numbers by age, and by length within each age of cohort, enhancing model realism, particularly for younger cohorts growing into legal size. Snapper have relatively wide growth variation. Faster-growing fish can reach legal size two or three years sooner than slow-growing fish from the same spawning year. By separating fish of legal size from sublegals as cohorts grow across legal minimum length, the gradual recruitment of a cohort to legal size, and the different rates of mortality that legal and sublegal fish incur, is quantified. Accounting for the presence of only legal fish in catch samples affords better model predictions of the numbers landed by age and by length in fitting to catch samples and generates a more accurate model prediction of the weight of landed snapper in fitting to catch log totals. The slice partition also permits more accurate growth estimates.

SnapEst runs on a half-yearly time step. The model year runs from October to September, with corresponding half-yearly time steps of October-March and April-September.

The parameters estimated by SnapEst include yearly recruit numbers by region, catchability by gear and region, length and age selectivity, and growth by region. Snapper have highly variable recruitment, with the majority of catch at any time mainly comprised of one or two large year classes (cohorts), such as 1979, 1991, and 1997 (Fowler et al. 2007). The model estimates year class strength based on fits to catch (conditioned on the effort required to harvest it) and to age and length samples from the catch (McGarvey and Feenstra 2004; Fowler et al. 2007).

2.2 Snapper management strategy simulation model, SnapSim

The simulation model (SnapSim) used to evaluate different snapper management strategies is based directly on SnapEst. The management strategy simulator incorporates the population equations describing recruitment, growth, catch and natural mortality used in the estimation model. It covers the same three regions of the snapper fishery in the two gulfs, and employs the same parameters. Both models are coded in the AD Model Builder model programming environment, and the parameter values are those estimated in SnapEst by maximum likelihood using AD Model Builder.

The strategy simulations all started with the 2003 model year, the first year of the exclusively November closure, and also the first year that daily data were mandated on catch return forms. Strategy simulations began in October 2003, and ran for 23 simulation years, ending in September 2026. The principal modification in converting the estimation model into a management strategy simulation was to construct a daily time step that runs over the days within each existing half-yearly model time step. For the first five simulation years, 2003-2007, the historical estimated levels of effort were applied. From 2008 (Oct 08 – Sep 09) onward, the same daily effort pattern from the last estimated year, namely the 2007 (Oct 07 – Sep 08) effort time series, under each strategy (except quota), was applied.

Strategies assuming no November closure from 2003 onward required that daily effort be predicted to simulate November fishing. Daily effort was reported prior to 2003, though it was voluntary. Fishing effort was approximated by a constant daily value, by region and for the two main effort types, across each simulated November open season. For 2003-2008, yearly changes in the total level of fishing effort were accounted for using reported effort in October and December of those first few simulation years for which data were available. A multiple regression method was used to predict the level of November fishing effort by year, based on the observed October and December effort in the years prior to closure, 1995-1999, by effort type and region. For all future simulation years, 2009 onward, the 2008 effort levels were used.

A daily time step permitted the simulation of all management strategies. Different strategies were simulated by adjusting commercial fishing effort as required on a daily basis through each model year. For example, temporal closure was simulated by setting fishing effort to zero for both commercial and recreational effort over the allotted time of closure (e.g. November, or November and the first half of December). Because the current November closure starts at midday on the 1st and ends on midday of the 30th, the closure simulations assume those two days were open to fishing.

Quota was modelled by checking after each simulation day whether each yearly catch quota had been exceeded, and if so, model effort for that effort type and region was set to zero for the remainder of the year. Individual quotas by licence cannot be simulated since the effort and catch of individual licence holders is not tracked in the model; but quotas were individual at the lowest modelled level of catch breakdown, namely for each combination of effort type and region. Total TACs were set as percentages (110% to 70%) of the reported catches by region and effort type in 2007 (Oct 07 – Sep 08), which was the year of second highest total statewide snapper catch on record.

Longline hook reductions were modelled as either the full 25% reduction (75% of prior) or a 15% reduction (85% of prior) in longline fishing effort, imposed to approximate a reduction from 400 to 300 in the number of longline hooks permitted.

A more complicated effort modification was required for daily trip limits, based on the observed histograms of catches (in kg) among reported fisher days, from catch logs. These histograms were used to estimate an overall reduced level of effort in each simulation day, to simulate the corresponding reduction that would have been achieved historically for 2003-2007 if trip limits of 1000 kg or less had been imposed.

Yearly recruit numbers for simulation years were based on past estimated historical levels. Simulation runs retained the existing estimated recruitment values for model years 2003 to 2005, after which estimates of snapper recruitment in the three regions are not available. For the remaining 20 management simulation years (2006-2025), we applied historical yearly snapper recruit numbers, by region, estimated for the 20 years prior to 2003. These were classified into two groups of 10 years, naming them 'high' and 'low'. The latter 10 years (1993-2002) were a higher-than-average recruitment time period, while the first 10 years (1983-1992) represent a period of lower mean recruitment, though it included the single biggest recruitment pulse (model year 1990, otherwise known as the 1991 year class). For the first set of runs (Figure 1a), we assumed 10 years of higher recruitment, then 10 years of lower recruitment for the 20 simulation years of 2006-2025. We also ran a low-then-low scenario for these 20 simulation years (Figure 1b).

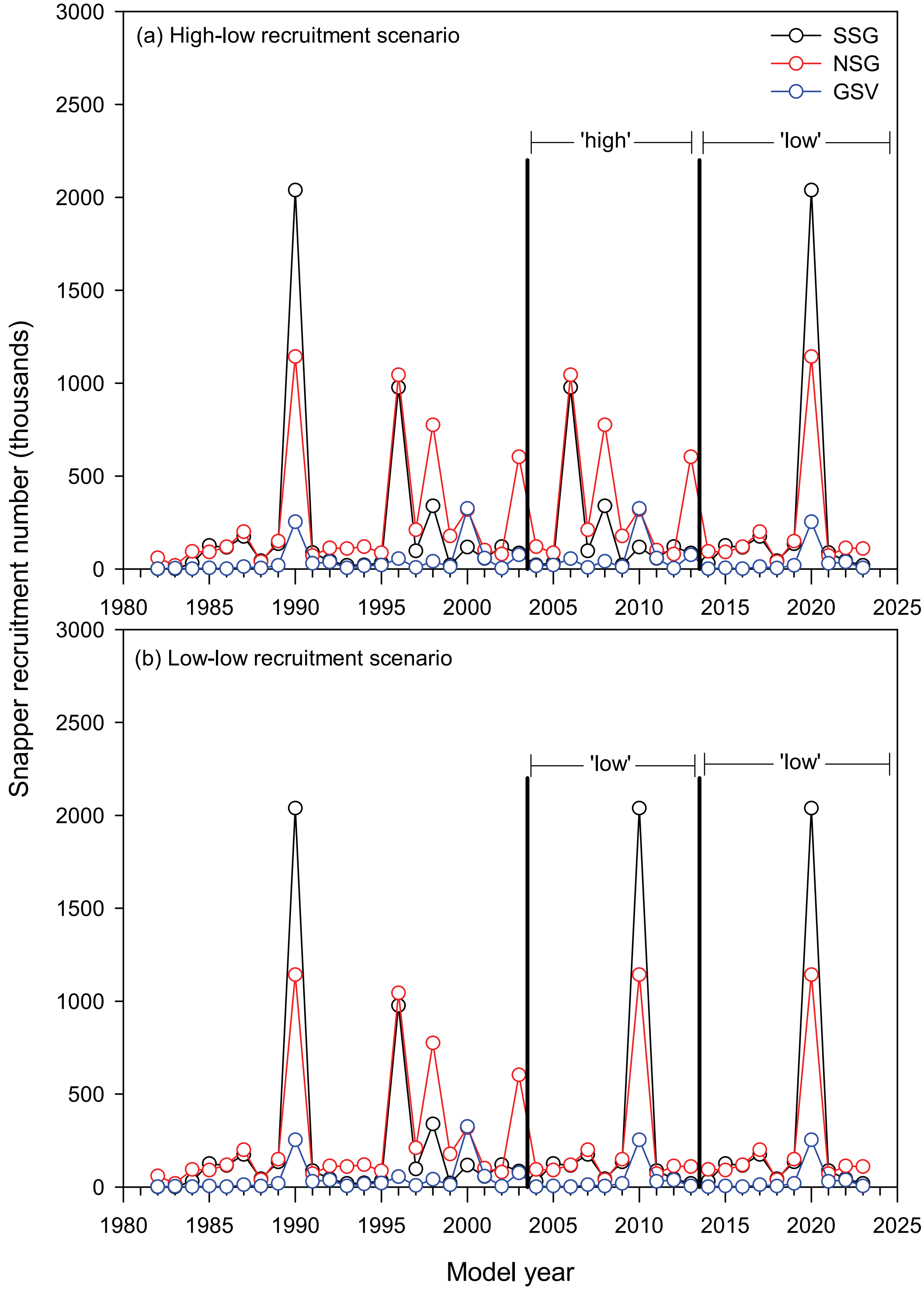

Figure 1. The assumed recruitment scenario time series (high-low and low-low) used in management evaluation. Historical estimated recruit numbers (1982-2003) were copied forward to generate future recruitment scenarios in each region, 'high' being the 10-year recruitment estimated for 1993-2002, and the 'low' being 1983-1992. Vertical bars show where future (post-2003) recruitment values are assumed in 10-year periods subsequent to 2003. See text above.

We then applied the same two sets of recruitment time series for all management strategies evaluated. We have not assumed a stock-recruitment relationship (see Discussion) because the nature of this relationship remains undetermined.

For calculating the performance indicator of value per recruit, we require the landed price of snapper. Total landed gross value of production (GVP) equals catch times price. The SARDI statistics branch record prices by species on a monthly basis. No breakdown by fish size is currently available. Price data for SA snapper are given in 5 regions, but only three of these regions cover the two gulfs. An average yearly landed value for snapper (Table 1) was computed by averaging catch times monthly price in each simulation month of each year, where prices are not differentiated by region.

Table 1. Snapper prices by month, used for all years in landed value and value-per-recruit performance indicators, taken from average reported snapper prices in three reporting regions which include the two gulfs, October 2007-September 2008.

Month	Snapper price ($)
October 2007	8.88
November 2007	7.56
December 2007	5.23
January 2008	6.27
February 2008	7.76
March 2008	8.33
April 2008	7.33
May 2008	6.86
June 2008	7.33
July 2008	8.64
August 2008	8.04
September 2008	8.64

Egg production is calculated as a relative quantity because the number of spawning events by female snapper per summer spawning season is unknown. But recent PhD work (Saunders 2009) has shown that most successful spawning occurs in December, and that effectively all fish of legal size (>38 cm) are mature. Maximum likelihood estimates of the batch fecundity (eggs released per spawning), as a function of total snapper body length from the data for northern and southern Spencer Gulf (A.J. Fowler, pers. comm.), yielded the following formula: $(Batch\ fecundity) = 0.0007201 \cdot (Total\ length)^3$. This formula was applied to all females (dividing legal snapper numbers by 2) each 15 December to compute a yearly relative index of total egg production in the three snapper regions.

A legal minimum length strategy requires methods to account for the release mortality and egg production of the 38-40 cm snapper which become excluded from the legal size range when the minimum size is increased. Release mortality is modelled assuming that 30% of captured snapper returned to the water die. In addition, we assumed that half as many snapper are captured in this 38-40 cm size range due to fishers changing fishing practices to avoid these sublegal snapper in the 38-40 cm size range. This contributes an added rate of mortality for 38-40 cm snapper which is 15% of fishing mortality, *F*, in addition to the assumed rate of natural mortality for all snapper of M = 0.05 (Gilbert et al 2006; GIlbert pers. comm.). The egg production from snapper in the 38-40 size range is computed by calculating the proportion of snapper that lie in this size range when minimum size is raised. That proportion is applied in all subsequent years to compute numbers of females falling in that size range. Batch fecundity of 39 cm snapper is then multiplied by female numbers in the 38-40 cm length bin to compute the eggs produced by 38-40 cm snapper.

3 RESULTS

The basic fishery performance indicators of commercial catch, egg production and revenue earned for the suite of management strategies evaluated are presented in two Results sections: (1) yearly time series, and (2) time averages, both for the 23-year simulated time frame from 2003 onward.

3.1 Time series outputs

The simulation model generates yearly predicted values for catch from the summed daily catches, biomass from the average of the two half-yearly values, and egg production from the 15 December yearly spawnings. The time series for one such run, namely NSG, under the high-low recruitment scenario are shown in Figure 2. Eight basic strategies are plotted.

We graph only commercial catch and egg production because catch and GVP track each other very closely. Likewise, biomass and egg production track very similarly by year.

The time series varied substantially depending on which future recruitment scenario is assumed (not shown). But it is the comparison among strategies, relative to the baseline, that is of importance in evaluating which strategies are preferable for managing South Australian snapper. While rich in detail, these time series are somewhat difficult to interpret, even with just a selection of 8 principal strategies among the 27 strategies evaluated. Subsequent results therefore focus on time averages of these time series performance measure outputs.

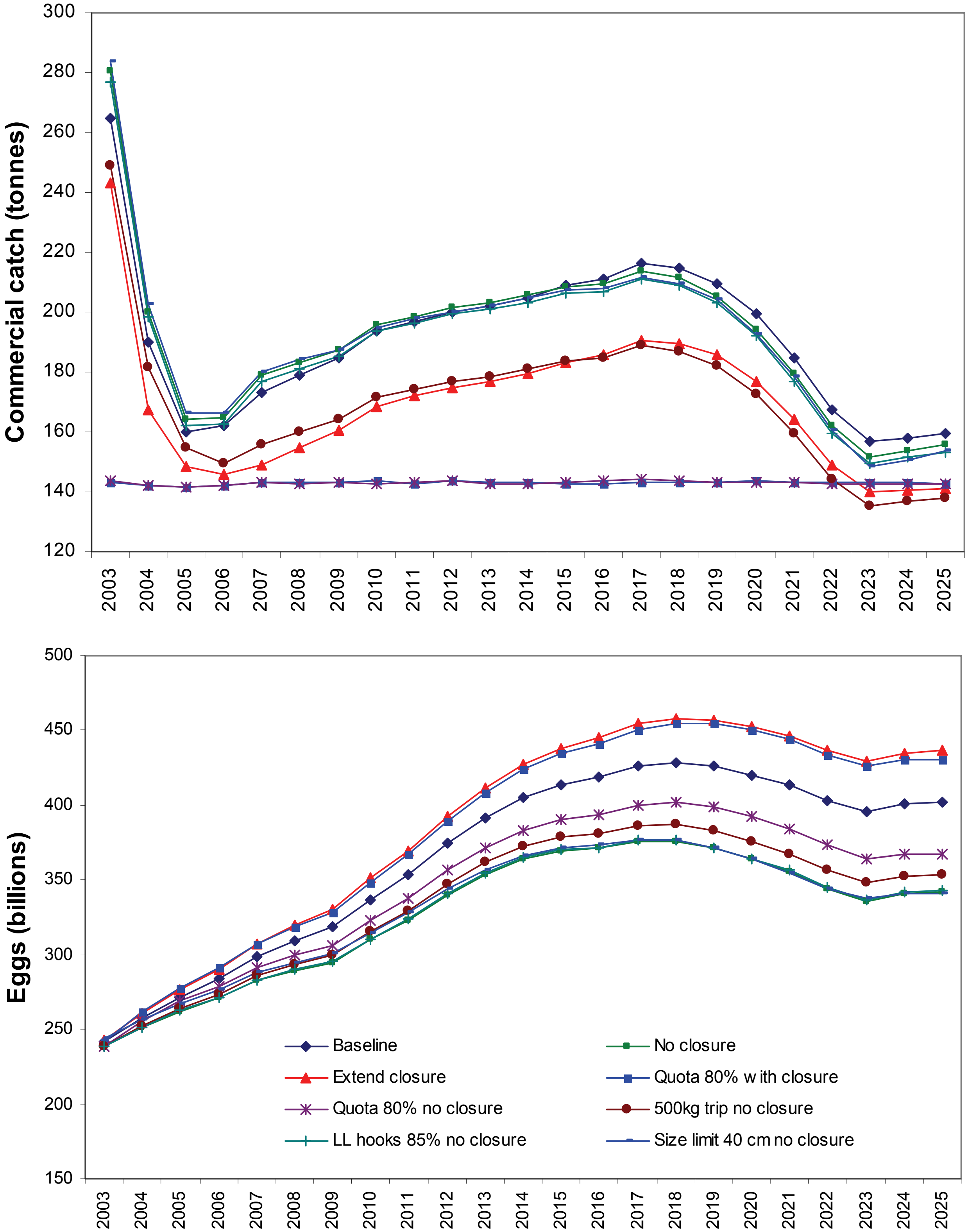

Figure 2. Yearly SnapSim outputs for catch and egg production for northern Spencer Gulf (NSG) under a range of tested strategies.

3.2 Time-average outputs

To summarise the comparison among different snapper management strategies evaluated, we have tabulated and plotted the three critical outputs of catch-per-recruit, egg-per-recruit and GVP-per recruit. These are presented for the two recruitment scenarios considered, namely high-low and low-low.

3.2.1 Tabulated results

Three ways of summarising these outputs render them more directly comparable among different strategies, and under the two recruitment scenarios. First, quantifying these as per-recruit measures means that variation in recruit numbers is compensated for. Second, we computed time averages over the 23 simulation years (2003/2004 to 2025/2026) to get a longer-term overall measure of these critical performance indicators. Third, we tabulated and plotted the percentage deviations in these per-recruit measures for each strategy relative to the baseline (status quo). Thus, for example, the value of 106% for eggs-per-recruit from the extended strategy in Table 2 indicates that strategy yielded a 23-year average in egg production which was 6% higher than the baseline. Table 2 gives the full set of time averages under the high-low recruitment scenario, and Table 3 under the low-low recruitment scenario. Each strategy evaluated is a row in these tables, and the three per-recruit output time-average percentage deviations from baseline (catch-, eggs- and GVP-per-recruit) are given for the four spatial breakdowns assessed, namely for all three regions, combined and individually.

Table 2. High-low recruitment results for all 27 management strategies tested, by spatial breakdown, overall and the 3 regions separately. Values shown specify percentage deviation of the 23-year time averages from the baseline (status quo) strategy. ‘Cw’ = catch in weight (kg), and ‘GVP’ = gross value of production, i.e. the value of landed snapper catch.

Strategy	3 regions combined			SSG			NSG			GSV		
	Cw	Eggs	GVP	Cw	Eggs	GVP	Cw	Eggs	GVP	Cw	Eggs	GVP
Baseline	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Remove November closure	102%	92%	104%	104%	96%	105%	100%	90%	103%	104%	96%	104%
Quota 110% of 2007-08 with closure	97%	101%	97%	99%	101%	99%	94%	101%	93%	100%	100%	100%
Quota 100% of 2007-08 with closure	95%	102%	94%	98%	101%	98%	89%	102%	88%	99%	100%	99%
Quota 90% of 2007-08 with closure	91%	103%	90%	98%	101%	97%	83%	103%	81%	95%	103%	95%
Quota 80% of 2007-08 with closure	86%	104%	85%	97%	102%	97%	75%	105%	72%	87%	108%	86%
Quota 70% of 2007-08 with closure	80%	106%	78%	96%	103%	95%	66%	107%	61%	78%	113%	77%
Quota 110% of 2007-08 no closure	99%	93%	101%	102%	97%	104%	94%	91%	96%	104%	96%	104%
Quota 100% of 2007-08 no closure	97%	94%	98%	102%	97%	103%	89%	92%	91%	102%	97%	102%
Quota 90% of 2007-08 no closure	93%	95%	94%	101%	97%	103%	83%	93%	84%	97%	101%	96%
Quota 80% of 2007-08 no closure	87%	96%	88%	101%	98%	102%	75%	95%	75%	88%	106%	87%
Quota 70% of 2007-08 no closure	81%	98%	80%	99%	99%	100%	65%	96%	64%	79%	112%	78%
Extended closure (2 Nov-15 Dec)	93%	106%	95%	94%	107%	97%	88%	106%	92%	99%	103%	100%
Trip limit 1000 kg with closure	97%	101%	97%	94%	104%	94%	98%	100%	98%	100%	100%	100%
Trip limit 750 kg with closure	94%	102%	94%	89%	106%	90%	95%	101%	95%	99%	101%	99%
Trip limit 500 kg with closure	87%	104%	88%	80%	110%	81%	89%	102%	89%	97%	102%	97%
Trip limit 250 kg with closure	70%	110%	71%	60%	120%	61%	70%	106%	71%	90%	108%	90%
Trip limit 1000 kg no closure	99%	93%	101%	97%	99%	99%	98%	90%	100%	103%	96%	103%
Trip limit 750 kg no closure	96%	94%	98%	93%	102%	95%	95%	91%	98%	103%	97%	103%
Trip limit 500 kg no closure	89%	96%	91%	84%	106%	86%	89%	92%	91%	101%	99%	101%
Trip limit 250 kg no closure	72%	101%	74%	63%	116%	65%	70%	95%	72%	93%	105%	93%
LL hooks 85% effort with closure	97%	101%	97%	95%	102%	95%	99%	100%	99%	96%	103%	97%
LL hooks 75% effort with closure	95%	101%	94%	92%	103%	91%	98%	100%	98%	94%	105%	94%
LL hooks 85% effort no closure	99%	93%	101%	99%	98%	100%	99%	90%	101%	100%	99%	100%
LL hooks 75% effort no closure	97%	93%	99%	96%	99%	97%	98%	90%	101%	98%	101%	98%
Size limit 40 cm with closure	100%	101%	100%	99%	102%	99%	100%	101%	100%	100%	101%	100%
Size limit 40 cm no closure	102%	93%	104%	103%	98%	105%	100%	90%	103%	103%	97%	103%

Table 3. Low-low recruitment results for all 27 management strategies tested, by spatial breakdown, overall and the 3 regions separately. Values shown specify percentage deviation of the 23-year time averages from the baseline (status quo) strategy

Strategy	3 regions combined			SSG			NSG			GSV		
	Cw	Eggs	GVP	Cw	Eggs	GVP	Cw	Eggs	GVP	Cw	Eggs	GVP
Baseline	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Remove November closure	103%	92%	104%	104%	96%	106%	100%	90%	103%	104%	96%	104%
Quota 110% of 2007-08 with closure	98%	101%	97%	99%	101%	99%	95%	101%	94%	100%	100%	100%
Quota 100% of 2007-08 with closure	97%	101%	97%	99%	101%	98%	93%	101%	93%	100%	100%	100%
Quota 90% of 2007-08 with closure	96%	102%	95%	98%	101%	98%	91%	102%	90%	100%	101%	99%
Quota 80% of 2007-08 with closure	94%	103%	93%	98%	102%	97%	87%	103%	85%	97%	103%	97%
Quota 70% of 2007-08 with closure	88%	105%	86%	95%	103%	94%	78%	105%	75%	89%	109%	88%
Quota 110% of 2007-08 no closure	100%	93%	102%	103%	97%	104%	95%	91%	97%	104%	96%	104%
Quota 100% of 2007-08 no closure	99%	93%	101%	102%	97%	104%	93%	91%	95%	104%	96%	104%
Quota 90% of 2007-08 no closure	98%	94%	99%	102%	97%	103%	90%	92%	92%	103%	97%	103%
Quota 80% of 2007-08 no closure	95%	95%	96%	101%	98%	103%	86%	93%	87%	99%	101%	98%
Quota 70% of 2007-08 no closure	89%	97%	89%	98%	99%	99%	78%	95%	78%	90%	107%	89%
Extended closure (2 Nov-15 Dec)	93%	106%	96%	94%	107%	97%	89%	106%	92%	99%	103%	100%
Trip limit 1000 kg with closure	96%	101%	96%	94%	104%	94%	98%	100%	98%	100%	100%	100%
Trip limit 750 kg with closure	93%	102%	93%	89%	106%	90%	95%	101%	95%	99%	101%	99%
Trip limit 500 kg with closure	86%	105%	87%	80%	110%	81%	89%	102%	89%	97%	102%	97%
Trip limit 250 kg with closure	69%	110%	70%	60%	120%	61%	70%	106%	71%	90%	108%	90%
Trip limit 1000 kg no closure	99%	93%	101%	97%	100%	99%	98%	90%	101%	103%	96%	103%
Trip limit 750 kg no closure	95%	94%	97%	93%	102%	95%	95%	91%	98%	103%	97%	103%
Trip limit 500 kg no closure	89%	97%	91%	83%	106%	85%	89%	92%	92%	101%	99%	101%
Trip limit 250 kg no closure	71%	102%	73%	63%	116%	65%	70%	95%	72%	94%	105%	93%
LL hooks 85% effort with closure	97%	101%	97%	96%	102%	95%	99%	100%	99%	96%	103%	96%
LL hooks 75% effort with closure	95%	102%	94%	93%	103%	92%	98%	100%	98%	94%	105%	94%
LL hooks 85% effort no closure	99%	93%	101%	99%	98%	101%	99%	90%	101%	100%	99%	100%
LL hooks 75% effort no closure	97%	94%	99%	96%	99%	98%	98%	90%	101%	98%	101%	98%
Size limit 40 cm with closure	99%	101%	100%	99%	102%	99%	100%	101%	100%	100%	101%	100%
Size limit 40 cm no closure	102%	93%	104%	102%	98%	104%	100%	91%	103%	104%	97%	104%

Several observations become apparent from these large tables, focusing on the 3 regions combined:

First, the increase in legal minimum length from 38 to 40 cm, while retaining closure, had a modest effect compared to most other strategies. When closure is retained along with the increase to 40 cm, catch, egg production and GVP vary by less than 2 percent under either high-low (Table 2) or low-low (Table 3) recruitment scenarios. This was observed for all spatial regions, and for the state overall.

Decreasing the number of longline hooks permitted (from 400 to 300, or to 75% of the prior effort level) has a modestly stronger impact, but with obvious lost short-term catch and only modest gains in egg production (Tables 2 and 3). This result is more sensitive to whether the November closure is retained or not, with increases in egg production only achieved when closure is retained. The assumed reduction in effective longline fishing effort (assumed to be either 85% of the prior catch per longline fisher-day, or the full 75% in catch per day, for this prescribed strategy of a reduction in longline hook number to 75% of its prior capture capability) yielded similar levels of egg production for closure retained and closure removed respectively.

The quota and trip limit strategies, for both recruitment scenarios, and for all 3 regions separately and combined, all showed the expected dependence in deviation from baseline of catch and egg production. That is, catch declined and egg production increased with increasing levels of protection. Thus, as the level of quota is reduced from 110% of the baseline year (2007) to 70% and trip limits are reduced from 1000 to 250 kg, catch declines and egg production increases.

GVP tracks catch very closely. GVP differs from catch, in % deviation from baseline, only due to variation in monthly price. To observe the relatively subtle difference between these two measures of fishery output, a graphical display was needed. Other trends in the comparisons among strategies are also more apparent when displayed graphically, which is done in the section to follow.

It is also clear (Tables 2 and 3), that within management strategies such as quota and trip limits, stronger conservation (e.g. 70% quota and 250 kg trip limits) yields greater egg production and lower short-term catches than less stringent versions (e.g. 110% quota and 1000 kg trip limits) of these strategies, as expected.

3.2.2 Scatterplot results

The catch and egg production outputs in Tables 2 and 3 were plotted to provide visual insight into which strategies perform more favourably. In particular, they can be plotted to illustrate the trade-off between sustainability (egg production) and shorter-term seafood yield (catch or GVP). One objective is to identify management strategies that permit the best outcome in this trade-off, i.e. more snapper egg production for the least amount of (short-term) catch constraint.

To this end, scatterplots of average egg production versus average catch (both quantified by % deviation from baseline, as in Tables 2 and 3) were generated for all 4 spatial breakdowns and both recruitment scenarios (Figures 3-6). Each point on these scatterplots represents the outcome for a specific management strategy, with 27 points in all. The baseline strategy (the status quo of November closure and 38 cm size limit, shown by the black star) by definition has (x=catch,y=eggs) values on all scatterplots of (100,100) meaning 100% of the baseline strategy. A value greater than 100 such as 102 implies a percentage (for eggs or catch), that was found to be greater than baseline by 2% in the average over the 23 simulation years.

The principal observation in the scatterplots for the 3 regions combined (Figure 3) is the clear separation into 3 general groups. Two of these visually evident groupings of strategies form downward sloping lines, which reflect a trend (observed in all 8 scatterplots) of decreasing egg production with increasing average catch.

Also evident in these two scatterplots (Figure 3a and 3b) is the fact that all of the strategies in the lower of the two line groupings have had closure removed, and all of the strategies in the upper line grouping retain the November closure. This implies that, for any given level of catch reduction (along the x-axis), the increase for egg production (and thus also biomass, catch rates and sustainability) is greater, in every instance, when the November closure is retained. Such clear and uniform separation, depending on whether closure was retained or removed, was an unexpected result, which we address in Discussion. In addition, we undertook additional simulations to test the hypothesis that this outcome results from the influence of recreational harvest with or without closure, presented in the last Results section below.

Within each linear grouping on these scatterplots, the individual strategies of quotas, trip limits or longline hook reductions, do not show any discernible difference in their position relative to each linear grouping. This suggests that there is no evident advantage or disadvantage for any specific method of reducing exploitation level, quotas, for example, compared with trip limits.

The only difference identified in these simulations, for observed performance of different management strategies, is whether closure is retained or removed.

A third group was also visually evident (red closed circle, Figure 3), despite being comprised of only a single point, insofar as this strategy appears to be located above the line of solid circles in the upper line grouping. That is, the extended closure strategy performed better than all other strategies, giving a still larger increase in egg production for the observed change in catch.

These three groupings are evident for both assumed recruitment scenarios (Figures 3a and 3b). Likewise, the position of all 27 strategies, and in particular, this separation of strategy performance into 3 groupings, is nearly identical when we generate these scatterplots using GVP on the x-axis in place of catch, notably for the 3 regions combined (Figure 4).

Considering these scatterplot results by subregion, we find that NSG (Figure 5) shows the same pattern of 3 groupings differentiated by closure status as for the state overall (Figure 4). In fact, the separation between the three groupings for NSG, particularly the two line groups, is noticeably wider, meaning that strategies retaining closure perform even better compared with those that do not in NSG.

However, in SSG (Figure 6) and GSV (Figure 7), the differentiation between these two groupings is much less evident. It is worth noting, that recreational snapper catch makes a much smaller proportion of the total in these two regions. This point is addressed in Discussion.

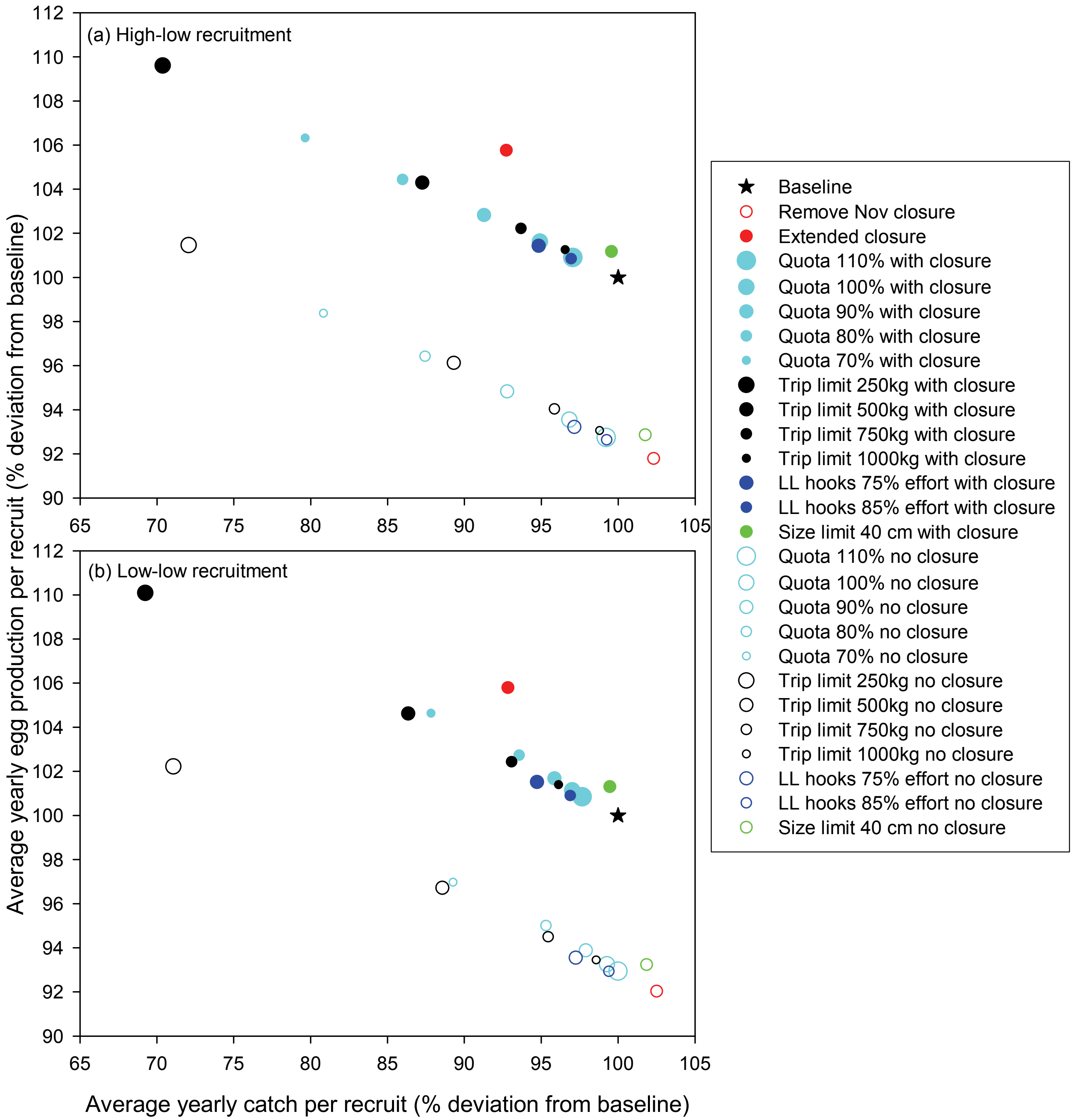

Figure 3. Three regions combined: commercial catch versus egg production. Each point represents a single strategy evaluation outcome, with the y-axis value for each strategy giving the percentage change in egg production compared to the baseline strategy, and the x-axis value giving the percentage change in commercial landings compared to baseline.

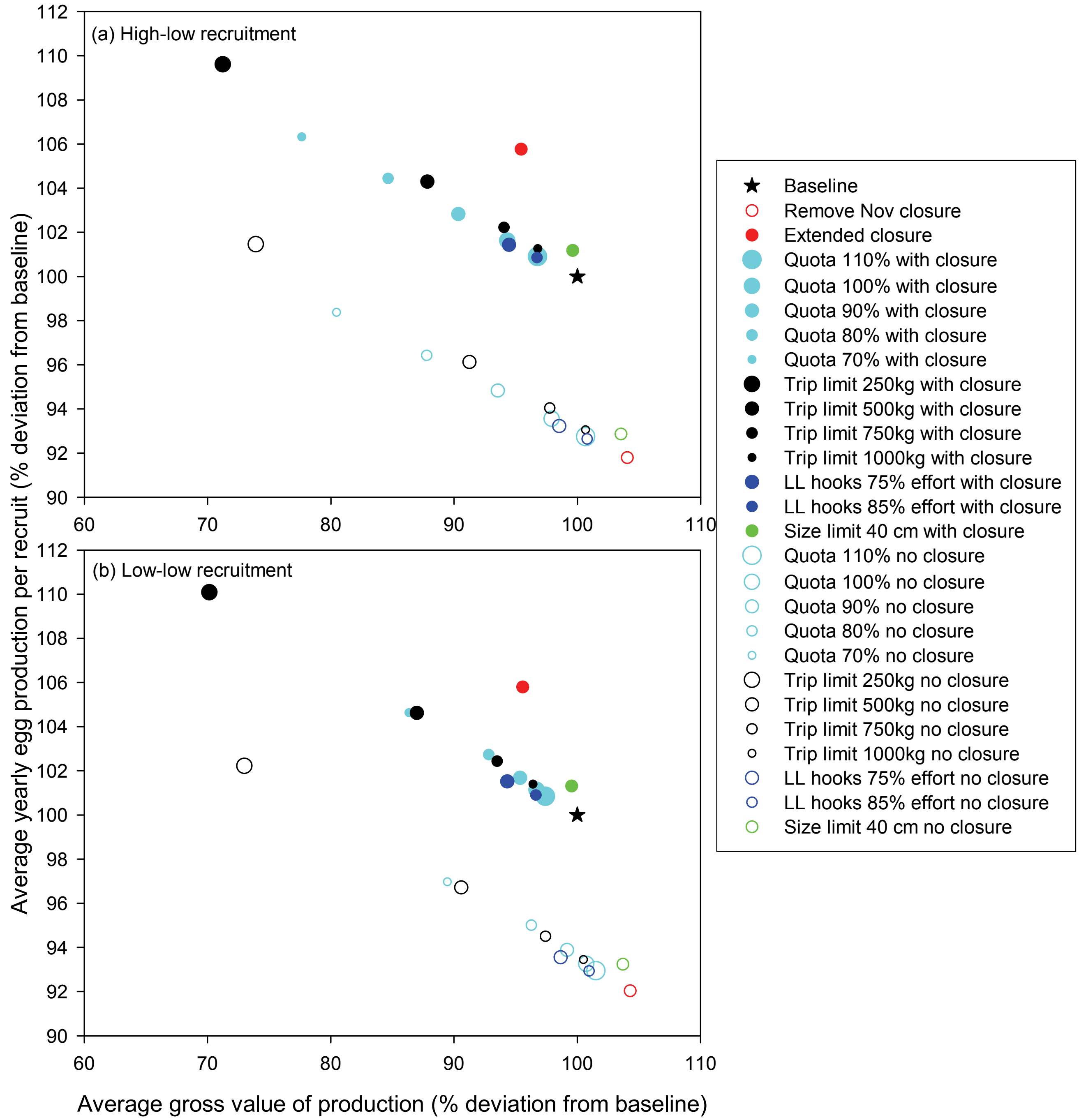

Figure 4. GVP versus egg production, three regions combined.

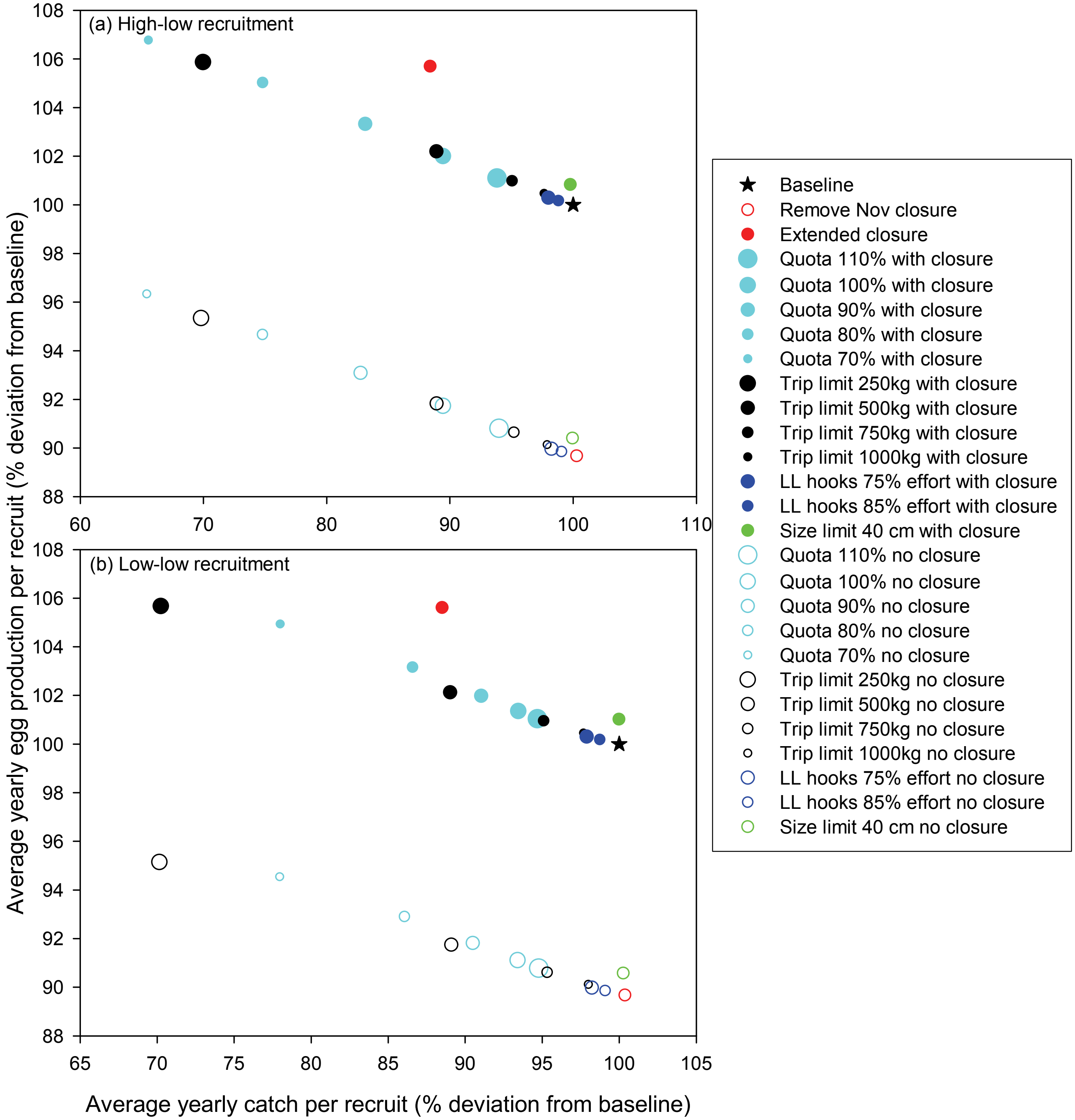

Figure 5. Commercial catch versus egg production, northern Spencer Gulf (NSG).

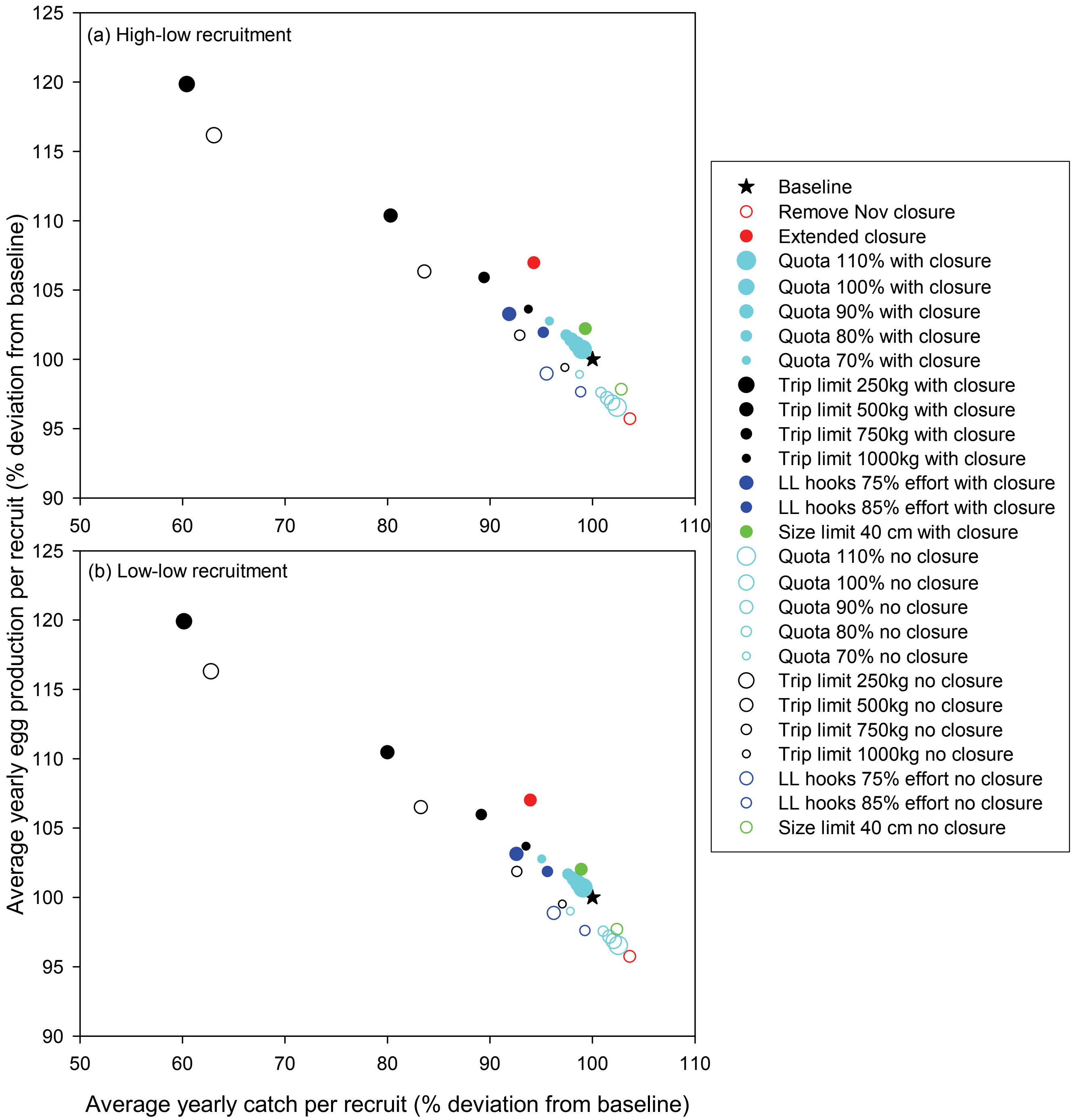

Figure 6. Commercial catch versus egg production, southern Spencer Gulf (SSG).

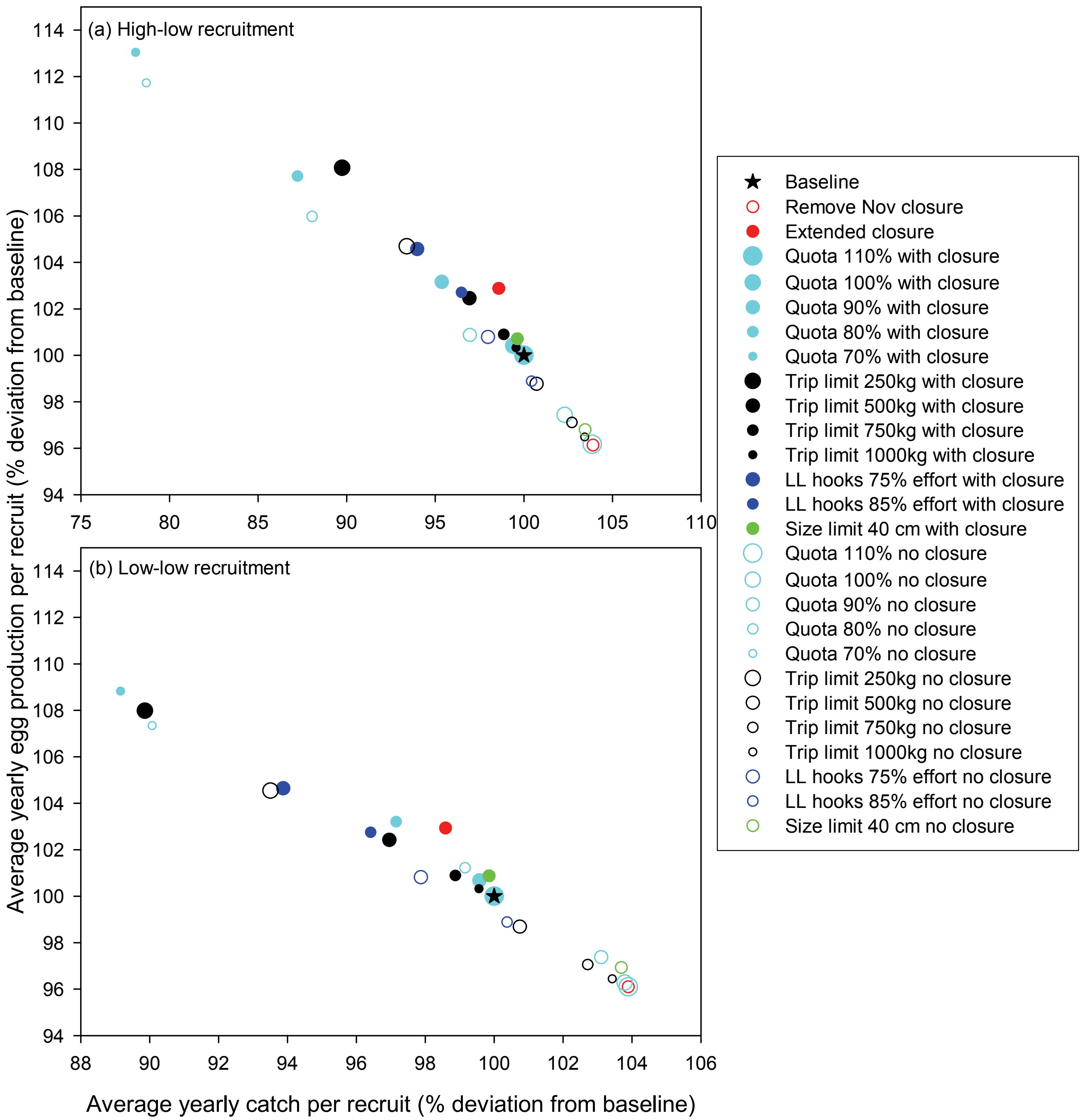

Figure 7. Commercial catch versus egg production, Gulf St Vincent (GSV).

3.2.3 Hypothesis test: Why closure strategies perform better

It is possible, with further simulation, to investigate why closure strategies performed uniformly better. One hypothesis is that non-closure strategies (quota, trip limits, longline hook reductions) remove the November closure for both recreational and commercial catch, while imposing alternative restraint on commercial catch only. In effect, this hypothesis proposes that the rise in recreational exploitation when closure is removed negates the conservation benefits to SA snapper of the alternative (non-closure) strategies tested.

Testing this hypothesis is relatively straightforward with the management simulator. In particular, we consider, for example, one category of commercial strategy, namely trip limits, for the 3 regions combined, under the high-low recruitment scenario. For this class of strategies, we assessed the impact of re-imposing November closure on recreationals. In particular, we compared two matched sets of strategies: (1) The set of 4 trip limit runs with no closure which were run above and which fell in the lower line grouping in Figures 3-5 and (2) the same trip limit runs as in (1), but with November closure reimposed for recreationals only.

The prediction of this hypothesis is that re-imposing closure on recreationals will permit South Australian snapper biomass, and thus egg production to be restored to the higher levels found in the upper line grouping. If egg production rises under this scenario to approximately the levels observed for strategies with closure, given the amount of catch taken, that would confirm this explanation for the observed difference in performance between closure and non-closure strategies.

The outcome of these supplementary simulation runs (Figure 8) showed that re-imposing the November closure for recreationals, while retaining trip limits on commercials, yields the much higher levels of egg production (and slightly higher commercial catches) as predicted. The levels observed for the open circles in Figure 8 do, in fact, fall right in line with those observed for the closure (upper line grouping) strategies in Figure 3a.

As a second test of this hypothesis, in further confirmation, adding closure to commercials only, leaving recreationals with no closure (blue star of Figure 8), drops the baseline strategy down from the upper-line group of better performing of strategies into the lower line of less well performing ones. This again implies that the imbalance in allocation of regulation, of no closure or other constraint on recreational catch, causes the closure strategies of Figures 3-5 to perform less well.

Thus, the prediction of this hypothesis is confirmed in Figure 8 for why closure strategies perform uniformly better, explaining the difference between the two line groupings of Figs 3-5. Moreover, this hypothesis would appear to fully explain the difference since the shift upward of the yellow circles in Figure 8 finds them positioned fully within the line of closure strategies, and the shift downward of the blue star finds it positioned fully in line with other non-closure strategies. This implies, within the assumptions of this simulator, that the less optimal performance of non-closure strategies is explained by the recreational uptake of catch foregone by the commercial sector under alternative strategies to closure (the lower line grouping of non-closure strategies) that restrain commercial catch only.

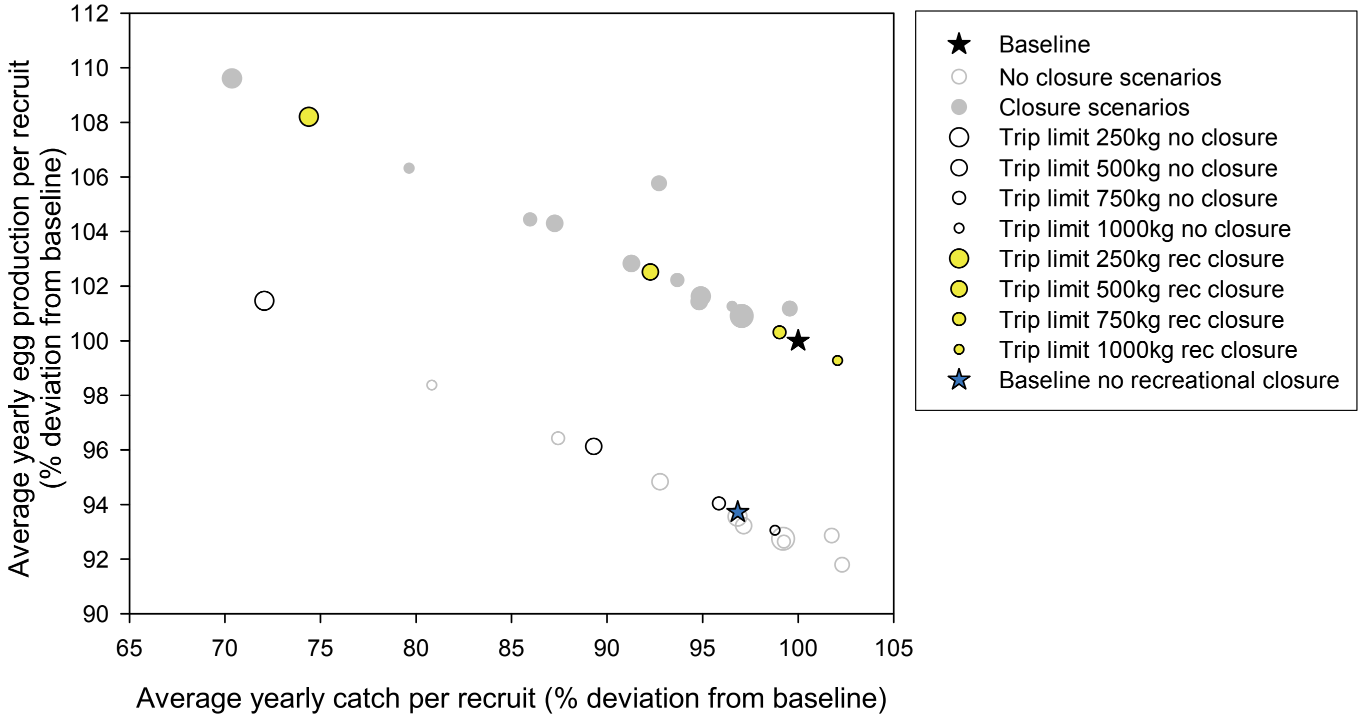

Figure 8. Testing the hypothesis for better performance of strategies that include closure, of recreationals having access in November when closure is removed while commercial catch is limited by other tested strategies. This is a modified version of Figure 3a, including 4 added and modified trip limit simulation runs in which the commercial sector has trip limits with no closure as in Figure 3a, but where the only recreational sector has November closure reimposed (black circles, shaded yellow). The same runs with trip limits restricting commercial catch, but no closure applying to either sector (open black circles) are replotted exactly as in Figure 3a. These example outputs are for the 3 regions combined, under the high-low recruitment scenario, for all 4 commercial trip limits (250, 500, 750, 1000 kg, from top left to bottom right in each line of scatterpoints). In addition, the reverse case was also tested (blue star), where November closure is retained for commercial harvest only.

4 DISCUSSION

A principal outcome of this management simulation study, is that strategies which remove closure leave the recreational catch unconstrained, thereby yielding less snapper sustainability benefit for the same reduction in commercial catch than strategies retaining the November closure. The closure applies to both sectors. This alone seems to explain the separation of strategies into three distinct groups, with closure strategies performing uniformly better for enhancing egg production given various levels of long-term commercial catch. This hypothesis is further supported by the observation that, among the three regions, only the region (NSG) where recreational catch dominates showed this performance advantage strongly for strategies retaining closure.

Simulated recreational catch, averaged over the 23 simulation years, comprised 74% of the total in NSG, 35% in SSG, and 23% in GSV, and 59% for the state overall under the high-low recruitment scenario. These recreational catch values were based on 2000/01, the year of the last reported (NRIFS) survey available for use in these simulations. The NRIFS estimated that 67% of the recreational catch was taken in NSG at that time (Fowler et al. 2007), but commercial snapper effort in NSG has declined considerably since then, increasing the proportion taken by recreationals.

Apart from this conclusion regarding closure and recreational harvest, the simulations did not differentiate an advantage for any particular alternative strategy, such as trip limits, quota or longline hook reductions. This suggests that choosing among these possible alternatives should be based on practical considerations, namely which strategy or strategies can reliably and feasibly constrain catch at a relatively low cost.

The best performance result for the extended closure suggests that lowering exploitation rate, by extended closure or other means that apply to both sectors can potentially offer sustainability benefits as higher egg production, for any estimated amount of short-term commercial catch reduction. But these benefits are relatively modest because exploitation rates estimated by SnapEst for SA snapper are unusually low (based on current fishing effort/catch and the presence of strong year classes in the fishery), and so further reductions are not as strongly suggested by these simulations, as would be the case of other, heavily exploited stocks, such as SA garfish.

The influence of higher egg production on higher future catches is not accounted for in these snapper fishery simulations. By assuming no stock-recruitment relationship, these simulations underestimate the benefit for future long-term catches of conserving snapper spawning stock in the short term. A stock-recruitment relationship is very difficult to reliably estimate, and more so for a resource like South Australian snapper which shows very high year-to-year recruitment variability. This yearly recruitment variability is almost certainly due to environmental variation from year to year. Differentiating this environmental noise from the influence on recruitment of the number of eggs produced is very difficult. With no stock-recruitment relationship assumed, predicted increases in future recruitment and thus future harvestable biomass with enhanced egg production of the spawning stock are left unquantified in the future estimates of biomass and catch. The simulated benefits to the resource of short-term reductions in catch are thus best understood as lower bound levels. Future biomass, catch rates, and catch will almost surely be greater, since some enhancement of recruitment with higher egg production is nearly certain. But because it is very difficult to estimate how much of this benefit would accrue, it has been omitted here.

A dominant feature of snapper fishery population dynamics in South Australia is the unusually low estimated level of mortality rate, and thus of fishing mortality. Low exploitation levels are reflected in the relatively modest percentage changes predicted under the majority of strategies in Tables 2 and 3, and in the scatterplots. These low levels of exploitation rate are inferred by SnapEst principally from age sampling, which show large cohorts remaining dominant up to ages well above 10 years, and with fishable abundances identifiable for cohorts above the age of 20 years. Such long lifespans in the fishable population imply low rates of total mortality. In addition, they probably reflect complex snapper migratory behaviour (Parsons et al. 2003; Fowler et al. 2005; Hamer et al. 2005), perhaps for some middle-aged life stages, away from the two gulfs where most exploitation occurs.

4.1 Future Research

We did not have data on snapper price by size. The size split for some species, such as garfish, snapper and lobster can sometimes be substantial, and different management strategies can potentially enhance the sustainability-yield trade-off by accounting for size-specific differences in landed price. On-going collection of size-specific price information could thereby enhance the precision and accuracy of estimates of economic yield for snapper (and other South Australian) fish stocks.

5 CONCLUSION

The strategies tested as alternatives to a yearly November closure, of quotas, trip limits, and longline hook reductions, restrain catch only for the commercial sector. For this reason, simulations which removed closure yielded a less beneficial outcome, as lower egg production (and biomass) given any chosen level of short-term commercial catch. Non-closure strategies also provided a lower economic return to the commercial sector. In the state overall, and particularly in northern Spencer Gulf, recreational catch dominates.

Strategies that restrain recreational catch with closure reimposed on recreationals only, with one of the tested alternatives (trip limits) retained to restrict commercial catch, did yield the desired benefits, as higher egg production, biomass, and thus catch rates for both sectors. Recreational catches could also be restrained using alternative strategies to the November closure. There is a diverse range of management strategies that can be used to restrain both commercial and recreational catches. Such strategies could be considered and implemented along with alternative commercial management strategies evaluated, such as spatial closures, quota (including tags) and trip limits, in order that management of snapper constrains catches of both sectors while also maintaining the allocation of shares to the resource between the sectors that is now required by the *Fisheries Management Act 2007* (SA).

The Western Australian Shark Bay Gulfs and Shark Bay Ocean snapper fisheries, where both recreational and commercial sectors operate, are managed by a range of overlapping regulatory constraints. For example, in the Freycinet Estuary at the bottom of one of the gulfs, snapper are managed by quota and upper and lower size limits. The quota is implemented through a tag system one fish taken per tag, with tags allocated to both commercial and recreational fishers (25%, 75% respectively) each year. The Shark Bay oceanic stock is managed by a combination of a lower size limit, and bag and boat limits for recreational fishers, with quota and size limits applied in the commercial fishery.

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