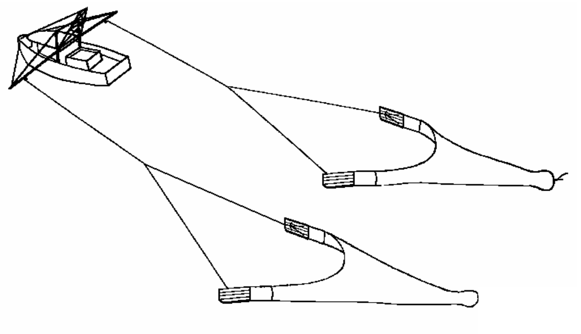
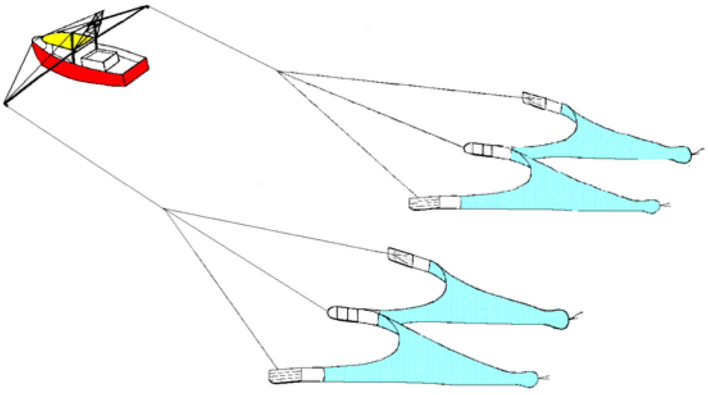
Australian Government
Australian Fisheries Management Authority

R04/1076 | 19/11/2005

The introduction of Quad rig in the NPF – seeking an effort neutral transition, and implications for TED/BRD performance.

FINAL REPORT





DAVID STERLING - STERLING TRAWL GEAR SERVICES
JOHN WAKEFORD AND STEVE EAYRS – AUSTRALIAN MARITIME COLLEGE
WADE WHITELAW – AUSTRALIAN FISHERIES MANAGEMENT AUTHORITY

STERLING TRAWL GEAR SERVICES

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NOTATION

1p2b 1p3b 1p4b	Specification of body taper in trawl net. 1p2b stands for one point two bar. More bars per point is a steeper cut and results in a shorter net possessing less netting.
DELX:Y	Displacement vector for variable X from X given Y
erf	Parameter determining the effective headline height based on actual headline height
EGPF	Exmouth Gulf Prawn Fishery
Hh	Headline height (m)
Hl, HL	Headline length (m)
K	Parameter determining catch efficiency based on headline height
NPF	Northern Prawn Fishery
PTPM	Prawn trawling performance model
RFP	Relative fishing power
SAR	Swept area rate (m^2/sec)
SAR*	Swept area rate x Catch efficiency (m^2/sec)
SR	Spread ratio
SRFP	Static relative fishing power (estimated by 3-year average)
STD_X	Standardised transform of variable X, obtained by subtracting the average (or median) and dividing by the standard deviation
SVR	Swept volume rate (m^3/sec)
SVR*	Swept area rate x effective height; effective Swept volume rate (m^3/sec)
X_DIFF	Displacement vector of variable X from the average (or median)

DEFINITIONS

Catch efficiency	Proportion of prawns in the path of the trawl that are captured
Swept area rate	Effective fishing span of net x trawl speed over the ground
Swept volume rate	Effective fishing span of net x trawl speed over the ground x headline height

NON-TECHNICAL SUMMARY

Since 1987 the Northern Prawn Fishery (NPF) fleet has towed double rigs (two nets). Prior to this most trawlers towed quad rig (four nets). To improve economic efficiency in the fishery there is great interest to again allow the use of quad rig.

This work has two objectives:

- *Establish conversion factors to ensure effort neutrality between double gear and quad gear.*
- *Produce a short document listing issues connecting the question of TED/BRD specification and performance with respect to a transition from double rig to quad rig.*

Since 2000 the NPF has been managed under a gear units system. During this time there have been a number of gear unit reductions (SFR devaluations) applied to assist with stock recovery and recently to improve economic efficiency.

Derivation of effort neutral translation formulae

The derivation of effort neutral translation formulae is a two-step process. The first step was to evaluate the proportional increase in catch performance when a vessel converts from double to quad rig, and the second was to identify appropriate effort neutral translation formulae.

Assessing the performance benefit of quad rig

To assess the performance advantage of quad rig we need to predict catch and also assume characteristics for the boat and gear before and after conversion to quad rig.

For each current NPF trawler, the catch benefit of converting to quad rig was estimated using the Prawn Trawling Performance Model (PTPM) ver. 3 (Sterling, 2005). The PTPM primarily estimates of swept area of the trawl gear per second as an index of catch performance. The PTPM can also account for the effect of increased headline height on taking a greater proportion of prawns in the path of the net. The data used was for the 2004 NPF fleet and included specification details for each vessel on the propulsion system and the trawl gear, and operation details for the main engine. The PTPM also estimates trawl speed and the degree to which the nets are stretched (spread ratio).

A variety of quad rig systems were investigated for each vessel. The main series had the same headline length as the original double rig, but had different trawl board specifications according to a plausible path for adoption and subsequent refinement of quad gear. In the first instance the ***same trawl boards*** as used in double rig were assumed, being the low cost option for operators. Quad rig refinements investigated were; ensuring the ***same angle of attack*** of the trawl board as double rig, using the size of ***traditional trawl boards*** from prior to 1987 (the period when quad gear was used in the fishery), and using ***optimum trawl boards***, as determined by the PTPM.

In estimating the performance for each scenario, both the gear characteristics and operator behaviour were considered. For the latter, two assumptions define the range of possibilities; **Constant Engine Power** and **Constant Trawl Speed**.

This analysis found that the median catch benefit of quad rig, assuming constant engine power, increased with refinement from 15% to a range of 19.2% to 26% for the traditional trawl boards scenario depending on the catch performance index used e.g. Swept Area Rate or the version accounting for prawn loss over the headline. The lower value for the traditional trawl boards scenario (19.2%) reflects the correction for catch loss due to lower headline height, which reduces the predicted benefit of quad rig. The estimated median catch benefits of quad rig for the optimum trawl board scenario were similar. Assuming constant trawl speed, the catch benefit of quad rig is reduced to a range of 10% to 16%.

An evaluation of the sensitivity of the results to the configuration of double rig used on each boat, as specified for 2004, showed that the performance benefit of quad rig is lower for vessels that towed smaller double rig nets. This is consistent with what was found in studies conducted after the banning of quad rig in 1987 (Robbins and Somers, 1993). The decrease in benefit for smaller boats is about 2%, in absolute terms (eg decrease from 22.5% to 20.5%), as the headline length on each side of the vessel decreases by 3m. The results also indicate that the application of gear cuts in the double rig fleet, such as that occurring during 2005, further erode the catch benefit of converting to quad rig if a lack of gear trading causes trawl speed and trawl spread ratio for vessels to increase. The ultimate result of large gear reductions, where there is limited fleet restructure, is a situation where the fleet tow smaller nets that are stretched to the same degree as quad gear and at very high trawl speed. Here the catch advantage of quad gear, assuming constant engine power will be small and under the constant trawl speed assumption will be zero. This situation, where the catch per unit of headline does not change when quad rig is introduced can be called a **Constant Trawl Utilisation** condition. There is strong industry opinion that the fleet has reached this condition, particularly since the latest gear reduction of 25% in 2005.

Analysis of configuration data for the 2005 double rig fleet may be able to establish whether or not the constant gear utilisation condition for the fleet has been reached. A component of the constant gear utilisation condition is the condition of constant trawl speed. VMS measurements of trawl speed would be very helpful in analysing the situation because they are more accurate and more procurable than predictions from the PTPM (Dichmont et al., 2003).

Translation formulae

What is an appropriate translation formula to ensure effort neutrality, given an assumed catch benefit for quad rig over double? The current gear units system does not provide a management environment where a distinct formula can be determined except for particular circumstances e.g. where constant trawl utilisation applies. At an individual boat level, modifying the headline length can result in range of possible responses. The type of response at the vessel and fleet level affects the fishing capacity of the vessel and fleet to varying degrees. Reducing gear size reduces the technical efficiency of the operation (area trawled per litre of fuel used), because it pushes operators to higher spread ratio and speed; further away from optimum values. This evokes an incentive to buy SFR units. Trading of SFR units, if it occurs, tends to maintain a lower trawl speed across the fleet by allowing over-powered vessels to increase gear size rather than operate at high speed and/or reduced power.

If the efficiency of the trawl fleet has been driven down to a point where trading occurs readily, then the limits to high spread ratio and trawl speed may have been reached (assuming the industry is economically viable). Under these circumstances constant trawl utilisation might be assumed and determining an effort neutral formula for any situation is straightforward. The appropriate SFR devaluation simply needs to directly offset the catch enhancement from conversion to quad rig.

On the other hand if an increase in spread ratio and/or trawl speed is possible and no trading occurs for an individual, the PTPM can be used to calculate gear reductions (SFR devaluations) required to ensure effort neutrality for both constant engine power and constant trawl speed circumstances.

Where trading occurs the amount of gear units purchased needs to be known in order to derive the correct effort neutral SFR devaluation.

Final recommendations and conclusions

The following table provides a summary of effort neutral formulae (SFR devaluations) for the degree of catch benefit reported above for quad rig conversion and the different circumstances and assumptions that can apply.

CATCH BENEFIT PERCENTAGE FOR QUAD RIG OF SAME SIZE		
CONVERSION ASSUMPTION		
Constant Engine Power	Constant Trawl Speed	Constant Trawl Utilisation
19.2% - 26%	10% - 16%	0%

EFFORT NEUTRAL SFR DEVALUATION FOR DOUBLE TO QUAD CONVERSION			FISHER AND FLEET RESPONSE
0.839 - 0.794	0.909 – 0.862	1	Constant Trawl Utilisation Assumption
unknown	unknown	1	No Constant Trawl Utilisation Assumption SFR Trading Occurs
NA	0.90 - 0.82	NA	No SFR Trading Occurs Constant Trawl Speed Assumption
0.68 - 0.49	NA	NA	No SFR Trading Occurs Constant Engine Power Assumption

A range is given for each situation due to uncertainties in estimating the effect of headline height on the catching performance of the gears.

The catch benefit of quad rig could be made more accurate with the integration of catch comparison data from field trials on trawl gear to establish the effect of speed, headline height and leadahead on the proportion caught of prawns in the path of the trawl.

The extent to which the application of gear unit reductions since 2000 have made it appropriate to assume constant trawl utilisation rather than constant engine power could be clarified if vessel speed data from the VMS system and gear configuration information for 2005 is analysed.

The uncertainty in an appropriate SFR translation formula is mainly a result of uncertainty in the degree to which the current engineering status of NPF trawl gear can be considered “constant trawl utilisation” as apposed to “constant engine power”, and uncertainty in the amount of SFR trading that will occur when an effort neutral translation formula is applied. In respect to the latter an economic understanding of the situation needs to be considered.

Impact of quad rig conversion on TEDs and BRDs

While the existing TED and BRD specifications should continue to be effective as fishers adopt quad-rig, the use of very small nets, increased spread ratio and increased towing speed has the potential to compromise the performance of these devices. The use of very small nets is perhaps the greatest risk to effective TED performance and protection of turtles and may also reduce BRD performance through limiting the size and location of the device, and the number of escape openings available for bycatch to escape. Higher towing speed will reduce the ability of small fish to swim through the escape openings of a BRD. It should be noted that AFMA is legislating minimum TED and escape opening dimensions for the fishery in 2006. This should ensure the continued escapement of turtles and large marine organisms.

EXECUTIVE SUMMARY

Introduction

Background

For the Northern Prawn Fishery (NPF) an initiative to again allow the use of quad gear, nearly 20 years after it was banned in 1987, is being investigated. The driving force for the initiative is the economic viability of the NPF, which has been substantially eroded recently by high fuel prices, depressed prawn prices and effort reduction measures. The use of quad rig could improve the economic efficiency of the NPF because it is a more fuel-efficient trawl system than the double rig that is currently used.

Meanwhile, in the NPF a tiger prawn stock rebuilding strategy is ongoing and any potential increase in fishing effort due to the transition to quad rig needs to be effectively mitigated. A crucial part of the initiative therefore, is to apply translation formulas to the units of Statutory Fishing Rights (SFRs) held by the operators choosing to use quad rig so that the change in gear configuration is effort neutral with respect to the tiger prawn fishery.

Also, a Bycatch Action Plan was introduced to the NPF in 1998 which resulted in the successful introduction of Turtle Exclusion Devices (TEDs) and Bycatch Reduction Devices (BRDs) in 2000. There has been substantial work aimed at improving the efficacy of these devices; the end result being that such devices used in the NPF are recognized as performing very well for the particular conditions experienced by NPF operators and are viewed highly in terms of standards promoted by international agencies. Given that the transition to quad gear will potentially involve changes to the configuration of the gear, particularly in the area where bycatch reduction devices are fitted, and that the operating characteristic (spread ratio and speed) of the gear will also change, it is important to consider the implications of the gear transition to the performance and specification of TEDs and BRDs.

The re-introduction of quad-rig over double rig has the potential to increase the amount of seabed swept by the fleet each night unless an effective effort neutral translation formula is introduced. This would be achieved because quad-rig generally uses four half sized nets and smaller otter boards, compared to double rig; connected in a way that allows an increase in swept width (spread ratio) and towing speed.

Fundamental to the development of an effort neutral strategy for the reintroduction of quad rig is the need for a reliable estimation of the relative catching performance of quad rig compared to double rig. Apart from being a complex technical question, the catch benefit of using quad rig changes across the wide range of different vessel/gear configurations occurring in the NPF fleet and also the wide variety of quad rig configuration options.

This project is a short-term desktop study designed to scope the range of factors affecting the issues identified above so as to provide a base for future decisions and a framework for debate within the management process.

The experience of the Exmouth Gulf fishery, in Western Australia, which has recently undertaken a complete transition of the fleet from double rig to quad rig is relevant to this desktop study. For an interim period both quad rig and double rig were present in that fishery and efforts were made to detect the effect of the transition on the fishing power and efficiency of individual trawlers. A review of the information collected by industry and the WA fisheries department in relation to these exercises is relevant for seeking corroboration with the findings of this desktop study.

Objectives

Based on the perceived needs the following objectives were identified for this project:

1. Establish conversion factors to ensure effort neutrality between double gear and quad gear.
    - 1.1 Use the PTPM ver3 to estimate the benefit of quad rig over double rig for a NPF – 2005 context
    - 1.2 Compare knowledge gained in WA from the recent introduction of quad rig into their double rig fisheries with the PTPM ver3 predictions.
    - 1.3 Produce a final recommendation for an appropriate translation formula for a transition to quad rig in the NPF.
2. Produce a short document listing issues connecting the question of TED/BRD specification and performance with respect to a transition from double rig to quad rig.

Project scope

For each objective, the project is scoped by a pre-planned strategy for data collection and analysis.

To date, numerical engineering models have produced performance predictions for prawn trawling based on Swept Area Rate (SAR). In this investigation alternative indicators of performance are considered, including Swept Volume Rate (SVR), Effective Swept Volume Rate (SV*R) and Swept Area Rate x Catch Efficiency (SAR*). Here SV*R and SAR* attempt to account for the diminishing advantage to catching performance of increased headline height, given that tiger prawns are acknowledged to be naturally very close to the seabed, while nevertheless recognising that headline height helps to capture those prawns that can swim faster than the gear over short distances.

Given that SV*R and SAR* are new concepts that introduce relatively unknown prawn biology/behaviour assumptions into the engineering model, the associated predictions of catch gain are somewhat unsubstantiated at this stage. However, the engineering of the trawl gear alone could not always model the characteristics of the gear in sufficient detail to predict and portray subtle, but important, issues with the configuration of the gear and its performance. In these crucial instances it was necessary to use the new performance indicators that are based on assumed relationships between catch efficiency and headline height (calibrated as best as possible from the available data). Further research into the mechanics of prawn capture at the mouth of the trawl, in terms of the gear variables; headline height, lead-ahead and trawl speed, may develop these measures into more reliable and relevant catch performance indicators in the future.

In the consideration of the implications to TED/BRD performance from a transition to quad rig, it was recognised that there is little literature relevant to this topic. The discussion is therefore strongly qualitative, but nevertheless achieves the objective of scoping the issues in a timely manner so that more detailed decisions and a productive debate can occur.

Past research

There has been previous work to estimate the relative catching performance of quad rig relative to double rig. This work and the results are discussed briefly in Appendix A. Table 1 summarises the results of these previous studies.

Table 1. Summary of estimated performance benefit of quad rig compared to double rig from previous studies.

Date	Model	Predicted Quad rig performance improvement	Comments
1989	Elementary Engineering Model	50%	Broad brush picture
1994	PTPM ver1	21%	General +- 10% view
1998	PTPM ver2	27%	NPF - 1987 context average vessel approach
2003	PTPM ver3	24.4%	NPF - 1987 context average of all vessels approach

These previous studies and all work to date that involved calculating the engineering performance of trawlers adopts a heuristic assumption that catch is proportional to the swept area rate (SAR) achieved by trawlers. This assumption is supported by the results of comparing SAR with the fishing power of trawlers as determined by catches recorded in the NPF (Dichmont et al., 2003) (see Figure 6). From the same work it was established that SAR, as estimated from gear configuration data for the NPF, explained 50% - 60% of the variation in catch determined fishing power between vessels (see Figure 7). Year by year comparisons of estimated SAR and the fishing power based on catch was undertaken within Dichmont et al.(2003). This concluded that the heuristic assumption of proportionality between catch and SAR is extensively supported by the historical data on catch and configuration for the NPF. The work also concluded that SAR is most likely responsible for more of the variation in fishing power between vessels in that the strength of association between estimated SAR and fishing power would have been higher except for the limited nature of the data available to run the complex process for SAR estimation within PTPMver3.

Objective 1.1 The advantage of quad rig over double rig for the NPF –2005 context based on the PTPM ver3

Methodology

The process applied to assess the effort implications of converting to quad rig, was to use computer predictions of the potential performance gains of all NPF trawlers that currently fish in the NPF. The trawling performance of each vessel in the 2004 double rig fleet was estimated using the PTPM ver3 and data on the configuration of the NPF fleet for 2004 as supplied by CSIRO. The PTPM ver3 was also used to predict the performance of all vessels for a range of different quad rig conversion scenarios. Performance gains for each vessel were established by dividing the estimated quad rig performances by the vessel's predicted double rig performance. A summary of the performance benefit for each scenario, as defined below, was obtained by calculating the average, median, standard deviation and quartile range of performance gains across the fleet.

The investigation into the performance benefit of quad rig focussed on a set of conversion scenarios that were considered to represent likely quad rig refinements occurring over a period of time and some sensitivity tests. The fleet-wide results for the scenarios and sensitivity tests were graphed to show how the benefit of quad rig is affected by the size of quad rig taken up by the fleet and also the degree to which the new quad gear is stretched by the associated variation in otter board size.

Conversion scenarios

For the scenarios, each vessel was convert to quad rig with the same combined headline length as the double rig used in 2004, the style of otter boards used for each vessel was fixed to that used in 2004 and the body taper for all quad rigs was set to 1p2b irrespective of that used in double rig during 2004 (either 1p4b (25% of fleet) or 1p3b (75% of fleet) – based on the provided configuration data).

There were four fundamental conversion scenarios investigated:

1. Same Rigging   Otter boards are identical to those used in 2004 – this is the cheapest and possibly most convenient option.

2. Same Attitude   As in 1. but the angle of attack was not allowed to change – this relates to rigging the board at finer angle settings that increase the risk of instability.

3. Traditional Headline Height   The otter board height used in quad rig, for each boat, is set by traditional usage in the 1980s.

Flat board height (m) = 0.4992 + 0.09181 * Headline length (m)   (Aspect ratio = 0.425)

Bison board height (m) = Flat board height (m) * 1.083   (Aspect ratio = 0.696)

The angle of attack of all quad rig boards was fixed to the angle calculated for double rig.

4. Optimal Headline Height Otter board height was optimal based on maximising: a) the product of SAR and "effective height" (SV*R). b) the product of SAR and "catch efficiency" (SAR*).

For scenario 4, two different expressions were used to model the importance of headline height and hence establish the optimum height for each quad rig operation:

a) Effective height = (Headline height) ^ erf

b) Catch efficiency = 1- exp(-k * Headline height)

These functions were calibrated by using the 2004 double rig configuration data. This was achieved by hypothesising that the boards (and resulting headline height) used in double rig during 2004 were on average optimal with respect to the underlying engineering and catch efficiency processes occurring during trawling. Given that the PTPM v3 models the engineering process while each of the above expressions reflects an assumption about the structure of the relationship between catch efficiency (proportion of vulnerable prawns in the path of the trawl that is caught) and headline height, the engineering and the headline importance models were combined to form the catch performance measures SV*R and SAR*. The headline height importance equations were then calibrated such that the 2004 double rig fleet was measured by the combined models to be optimal on average; thus fulfilling in theory the proposed hypothesis. The objective for the calibration was to try an make the optimum board for each case equal to the actual board used. The differences between optimum and actual boards across the fleet were summed and made equal to zero through manipulating the unknown parameters in the “importance of headline height” relationships using the secant method.

The result of that exercise suggested that erf was close to 1/6 and k had a value of about 2.45. Figure 1 shows the shape of the relationships after calibration and the degree of agreement between optimum and actual otter board height achieved.

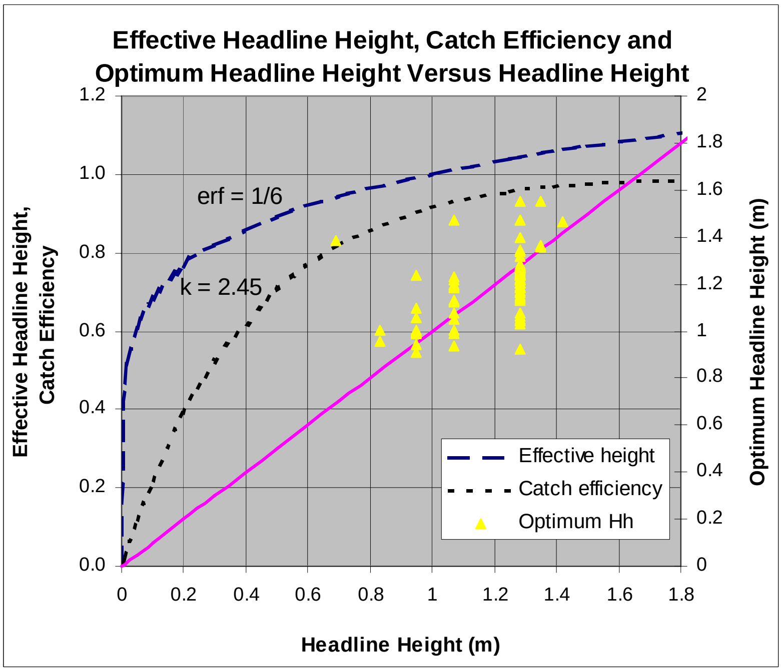

Figure 1. Theoretical models for the importance of headline length on catch efficiency after calibration against the 2004 double rig configuration data. Also exhibited is a comparison of actual headline height and “optimal” headline height (with equal values line) for the double rig fleet of 2004.

Sensitivity tests – Quad rig size

The sensitivity of the performance benefit was considered with respect to quad rig size by calculating the impact of a 20% increase or decrease in headline length, the headline length that would result in maximum SAR and the headline length that is predicted to give effort neutrality. Each of these tests is based on scenario 3 and all results were compared.

Sensitivity evaluation – double rig configuration

The methodology above explores the effect on quad rig benefit of choosing different quad rig configurations. To explore the sensitivity of quad rig benefit to the configuration of double rig prior to conversion, linear prediction models were devised to predict quad rig benefit from predictors that are double rig configuration variables. Forward stepwise regression was used to identify double rig configuration variables that explained more substantial amounts of the variation in quad rig benefit observed. A problem with correlation between predictors was solved using a hierarchical approach to building the final prediction models. Two models were derived, one predicts the SAR benefit of quad rig from scenario 3, while the other predicts the SAR* benefits derived for scenario 4(b). Double rig predictors included in the evaluation were body taper, headline length, spread ratio, trawl speed, board type and developed engine power.

Data for the regression process was pre-processed so that the stepwise regression worked effectively and the resulting prediction model with the associated regression coefficients had a clear practical significance. For this, the values of predictor variables were fully standardised by subtracting in each case the variable's median value and dividing by the standard deviation apparent in the 2004 fleet configuration data. The raw values of the dependent variables were transformed to offsets from their median value. This allowed a simple interpretation for coefficients of prediction variables. Each coefficient was the absolute change in relative quad rig performance for one standard deviation change in the respective predictor variable.

Operator behaviour

The standard approach for the calculation of catch benefit from the conversion to quad rig is the standardisation of engine power for the double rig and quad rig configurations on each boat. This can be called the "Constant Engine Power" assumption.

Given that quad rig is more efficient than double rig, it is generally the case that the resulting trawl speed for quad rig is higher than for double rig. This can cause concern because it is strongly perceived by operators that it is possible to trawl too fast. The problem becomes more intense if the trawl speed for double rig is already high, as might occur after large gear reductions with limited subsequent fleet restructure via SFR trading. It is quite feasible to reach a situation where the operator will not let the trawl speed increase on conversion to quad rig by reducing the engine power applied. The catch benefit can be estimated for this "Constant Trawl Speed" condition by dividing the standard PTPM performance results (constant engine power assumption) by the estimated relative speed result.

In a similar way the spread ratio of some double rig configurations can be as high as that occurring for the quad rig conversion. For a quad rig conversion where there is no change in spread ratio or speed, the swept area rate and catch per unit of headline length is fixed and there is no catch benefit from the quad rig conversion. This situation can be called the "Constant Gear Utilisation" condition.

Results

Table 2 shows the median and quartile range for performance measures and trawling status variables for the fleet and the scenarios investigated. All results for quad rig are expressed as a factor of increase relative to the absolute values for double rig, which are also provided in Table 2.

Table 2. Median and inter-quartile range for hypothetical 2005 quad rig scenarios across relative performance indicators and status variables with respective to values determined for each boat in their 2004 double rig configuration.

Absolute median 2004 double rig performances		Relative 2004 Quad rig performances				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4(a)	Scenario 4(b)
SAR	52.8m^2/sec (47.3-57.5)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.260 (1.196-1.290)	1.326 (1.247-1.343)	1.239 (1.175-1.276)
SR	0.715 (0.693-0.752)	1.215 (1.172-1.236)	1.219 (1.176-1.238)	1.166 (1.123-1.182)	1.116 (1.065-1.139)	1.175 (1.135-1.193)
Speed	3.46knots (3.32-3.64)	0.945 (0.923-0.949)	0.971 (0.941-0.973)	1.084 (1.047-1.101)	1.180 (1.115-1.224)	1.061 (1.011-1.081)
Hh	1.29m (1.07-1.29)	1	1	0.754 (0.735-0.830)	0.612 (0.565-0.688)	0.789 (0.769-0.902)
SVR	64.8m^3/sec (51.8-72.1)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	0.983 (0.921-1.024)	0.828 (0.749-0.894)	1.015 (0.978-1.092)
SV*R	54.3m^3/sec (47.9-59.5)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.210 (1.147-1.232)	1.223 (1.153-1.240)	1.204 (1.138-1.229)
SAR*	49.7m/sec (44.1-54.8)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.192 (1.131-1.217)	1.169 (1.088-1.198)	1.195 (1.131-1.221)
Hl	41.4m (36.0-43.2)	1	1	1	1	1

SAR - Swept Area Rate
SR - Spread Ratio
Hh - Headline height
SVR - Swept Volume Rate
SV*R - Swept Volume Rate X effective Hh
SAR* - Swept Area Rate X Catch efficiency

The median quad rig benefit results of Table 2 are plotted in Figure 2 against a scale indicating the degree of net stretch applied in each scenario.

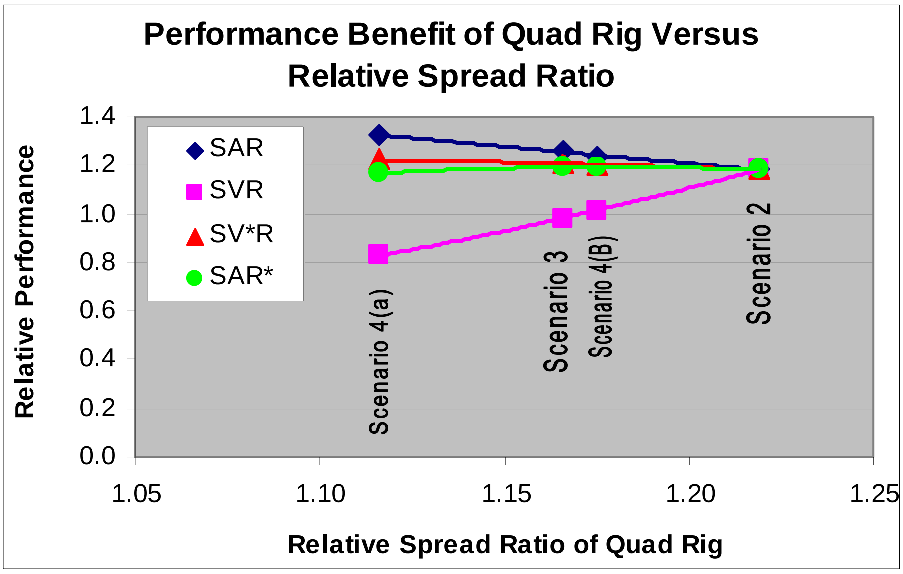

Figure 2. Trend in median performance benefit for quad rig (scenarios 2, 4(b), 3, 4(a)) with respect to median relative spread ratio for a Constant Engine Power.

The results predict that the general SAR benefits of quad rig will progress towards 26% (relative SAR for scenario 3) after a few years of refinement. There appears to be some potential that the median SAR improvement will continue to rise beyond 30% in the longer term, however it is indicated by SV*R and SAR* that the catch improvement for these extreme configurations may be lower than the SAR gain. This is because the high SAR result of scenario 4(a) occurs in conjunction with a 20% lower headline height than the traditional configuration of scenario 3.

SV*R and SAR* predictions also indicated that catch improvements for quad rig may be limited to a maximum of about 22% because of the negative effect on catch of reduced headline height. Trawl nets with a large amount of lead-ahead may allow catch gains to closely match SAR, however such trawl developments will also be of benefit to double rig in terms of both SAR and catch. Thus, the inherent advantage of quad rig is not likely to be improved, particularly since high lead-ahead has traditionally been more difficult to implement into trawl systems that work at high spread ratio (e.g. quad rig).

Figure 3 shows catch benefit while assuming constant speed. For this assumption the benefit of quad for scenario 3 reduces to a range of 10% for SAR* and 16% for SAR.

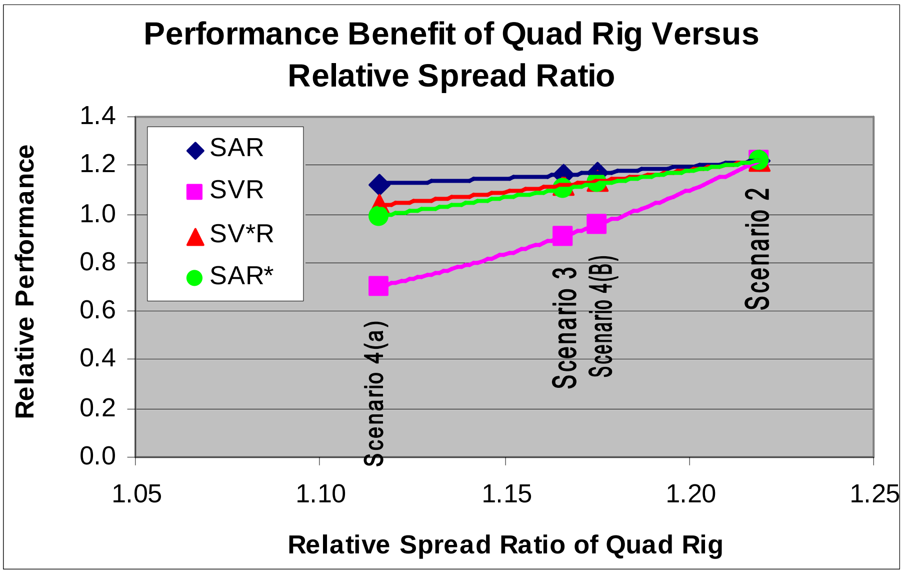

Figure 3. Trend in median performance benefit for quad rig (scenarios 2, 4(b), 3, 4(a)) with respect to median relative spread ratio for the Constant Trawl Speed assumption.

Sensitivity tests – quad rig size

Table 3. Median results for gear size sensitivity tests conducted on scenario 3. The numbers in brackets give the percentage change relative to scenario 3i. For an indication of quartile range see Table 2.

Relative 2004 Quad rig performances					
	Scenario 3neutral Same SAR	Scenario 3ii (-20% Hl)	Scenario 3i	Scenario 3iii (+20% Hl)	Scenario 3opt Max SAR
SAR	1 (-20.6%)	1.198 (-4.9%)	1.260	1.294 (+2.7%)	1.305 (+3.6%)
SR	1.329 (+14.0%)	1.230 (+5.5%)	1.166	1.106 (-5.1%)	1.074 (-7.9%)
Speed	1.495 (+37.9%)	1.217 (+12.3%)	1.084	0.972 (-10.3%)	0.908 (-16.2%)
Hh	0.529 (-29.8%)	0.663 (-12.1%)	0.754	0.846 (+12.2%)	0.899 (+19.2%)
SVR	0.539 (-45.2%)	0.827 (-15.9%)	0.983	1.116 (+13.5%)	1.181 (+20.2%)
SV*R	0.902 (-24.5%)	1.125 (-7.0%)	1.210	1.267 (+4.7%)	1.281 (+5.9%)
SAR*	0.842 (-29.4%)	1.089 (-8.6%)	1.192	1.255 (+5.3%)	1.280 (+7.4%)
Hl	0.489 (-51.1%)	0.8 (-20%)	1	1.2 (+20%)	1.320 (+32.0%)

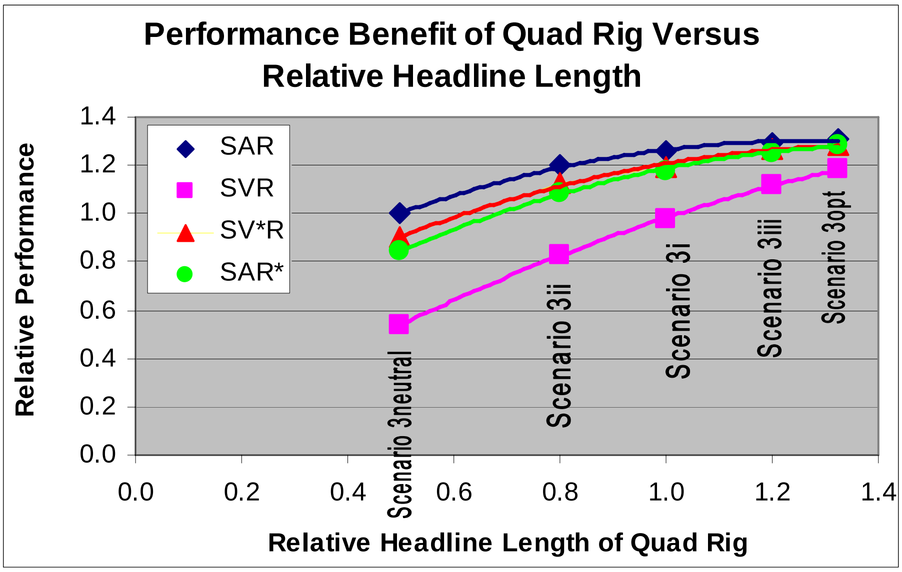

Figure 4. Trend in median performance benefit for quad rig (scenarios 3neutral, 3ii, 3i, 3iii, 3opt) with respect to relative gear size for a Constant Engine Power.

Variation in quad rig benefit for a very wide range of quad rig size is shown in Figure 4. The key feature of the diagram is that the change in quad rig benefit is; as measured by SAR, SV*R and SAR*, quite small considering the range of gear size considered. The change in quad rig benefit is particularly small as quad rig size is increased. It was estimated in scenario 3opt that the Headline length carried on each boat would need to be increased by 32% to achieve maximum SAR performance from the quad rig conversions. This results in performance increases of only 3.6% for SAR and 7.4% for SAR* compared to the performance achieved by using quad rig with the same headline length as the current double rig (scenario 3i). Given the cost of gear units, it seems unlikely that operators would take advantage of quad rig’s low drag nature by increasing the size of gear towed.

In the other direction, it is interesting to consider what fishers will do in response to devalued SFR’s after converting to quad rig. Will they buy more SFR’s (approximately 20% of original holdings) to maintain the original headline length, or will they take a 20% headline length reduction and fish with 4.9% less SAR performance, but still 19.8% more SAR than with double rig. The latter choice looks attractive from the fishers’ point of view but has the underlying problem that the conversion to quad rig is not effort neutral despite taking a 20% reduction in gear, which many people perceive to be the appropriate SFR devaluation. The open question to be raised at this point is whether the 22% increase in trawl speed from that experienced with double rig will substantially increase the loss of prawn catch, and in fact make the chosen conversion (with 20% HL reduction) effort neutral in the end?

Figure 5 factors out the contribution of increased trawl speed on performance. It presents median quad rig benefits that accrue if the constant trawl speed assumption is held. For scenario 3 the effort neutral gear reduction is much less than when constant engine power is assumed. For SAR the 20% gear reduction is adequate to produce the effort neutral result.

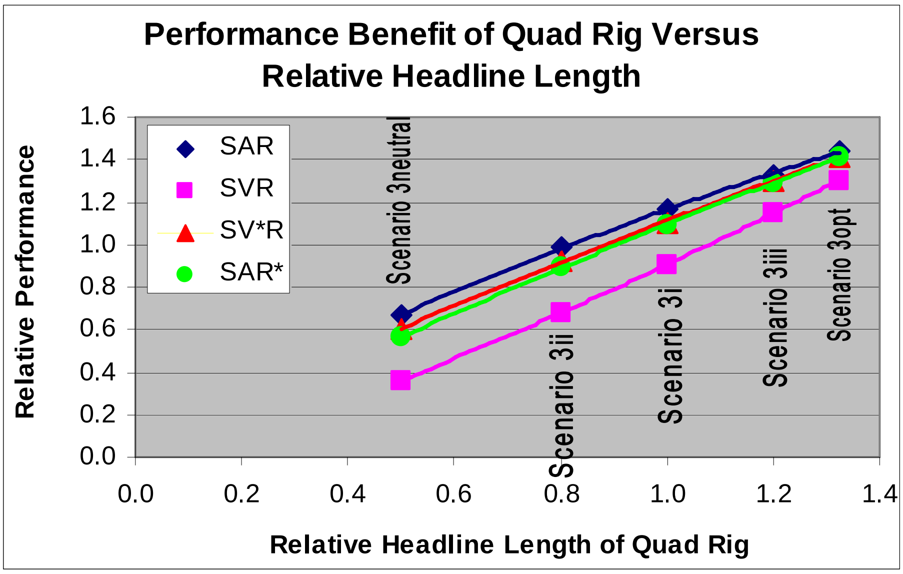

Figure 5. Trend in median performance benefit for quad rig (scenarios 3neutral, 3ii, 3i, 3iii, 3opt) with respect to relative gear size for the Constant Trawl Speed condition.

Sensitivity evaluation – double rig configuration

Figure 30 shows a scatter-plot matrix for all the variables considered in the sensitivity evaluation with respect to double rig configuration. This allows a qualitative selection of the more substantial relationships. Table 11 shows the outputs for the forward stepwise regressions used to rank predictor variables in terms of their strength of association with variation in quad rig benefit. In order of decreasing importance were; body taper, headline length, spread ratio, board type and trawl speed. Most of the variation was explained by the first three variables and trawl speed was considered further because of its special significance in dealing with gear unit reductions applied after the data used in the current study were collected.

A large correlation exists between headline length and spread ratio. A hierarchical approach to building the prediction models was adopted to properly isolate affects for carefully specified variables so as to maximise the practical significance of the model structure. A simple model containing only body taper and headline length was first used to isolate the affect of headline length on quad rig benefit. The coefficient for headline length from this model also includes the effects of all other configuration variables that are correlated with headline length. This coefficient was used in the final prediction model that included transformed versions of the other configuration variables such that the component that is correlated with headline length was removed.

The following equations are the models constructed, which predict the benefit of quad rig from the configuration of the original double rig:

For SAR:

Relative SAR = 1.260 + 0.014 P3B$_{0\text{-}1}$ - 0.089 P4B$_{0\text{-}1}$ + 0.015 STD_Hl + 0.011 DELSR:HL – 0.023 DELSPEED:HL Eqn (1)

For SAR*:

Relative SAR* = 1.195 + 0.014 P3B$_{0\text{-}1}$ - 0.082 P4B$_{0\text{-}1}$ + 0.026 STD_Hl - 0.011 DELSR:HL – 0.005 DELSPEED:HL Eqn (2)

DELSR:HL and DELSPEED:HL represent the unnatural distortions of the trawl fleet’s characteristics due to the imposition of gear units in circumstances where insufficient trading occurs to preserve the “normal” correlation between configuration variables. When insufficient trading occurs, operators choose to tow smaller nets than they would otherwise, and extract enhanced performance from the smaller nets through stretching them to a greater extent (increased spread ratio – DELSR:HL) and towing them at a faster speed (DELSPEED:HL). Both these effects are shown to reduce the SAR* performance benefit available from eventually converting to quad gear with an equivalent headline length.

DELSR:HL and DELSpeed:HL is defined by following equations for the 2004 double rig fleet and is obtained by removing from SR and Speed the component that is correlated to HL.

DELSR:HL = (SR - 0.938 + .00514 HL)/0.05

DELSPEED:HL = (SPEED - 3.942 + 0.01101 HL)/0.32

For the SAR model the coefficient for DELSR:HL is positive. It is felt that this is a result of taking a purely engineering approach to estimating catching performance. For this fine scale analysis, the theoretical relationship between catch efficiency and headline height, which is included in the SAR* model through the underlying calculation of SAR*, seems to produce a physically more sensible result for the spread ratio coefficient (ie. Negative). Similarly no expressions are included in the calculations for the relationship between trawling speed and catch efficiency. Depending on the character of this relationship in reality, the coefficients derived in the models will be biased.

The need for sea trials

One of the major uncertainties in the estimation of catch benefit is the unknown relationship between catch efficiency and trawl gear configuration. This work has identified that it is crucial to establish the effects on catch efficiency of headline height and trawl speed, while other potentially influential factors are lead ahead and spread ratio. Specifically controlled field trials seem to be the only way to establish these important relationships and make progress towards resolving many difficult management dilemmas that connect with these issues.

Conclusions

- After transition to quad rig the SAR advantage will grow quickly to about 26% through adopting the configuration of quad rig that was traditionally used during the 1980s.
- Scenario 4(a) shows an SAR advantage of about 30%, which might be attainable if lower headline height is explored and proves successful.
- Indicators that incorporate estimates for the effectiveness of headline height on catch (SV*R, SAR*) do not increase as markedly for quad rig as SAR.
- The newly investigated measures of catching performance increase by about 19% – 22% in the best cases.
- For the “Constant Trawl Speed” situation the benefit of quad rig for scenario 3 is 10% based on SAR* and 16% for SAR.
- The sensitivity tests undertaken show that if the quad rig used was 20% smaller than the double rig previously used (scenario 3ii); perhaps the chosen response to a gear unit devaluation imposed for using quad rig, then the actual catch is predicted to be only 5 – 8.5% less than scenario 3i.
- If no trading of gear units occurs the gear reduction required to achieve effort neutrality is very large if constant engine power is assumed; about 50% based on SAR and 32% based on SAR* (qualitatively from Figure 4). This comes about because there is an increase in spread ratio and trawl speed, which counteracts the decrease in performance from the reduced size of the gear. However the resulting trawl speeds are very high (up to 5.17 knots)
- For the constant trawl speed assumption, 18% reduction in gear make quad rig effort neutral with respect to SAR and a 10% reduction achieves effort neutrality for SAR*.
- The sensitivity evaluation of quad rig benefit with respect to double rig configuration confirmed that body taper was the major double rig feature that affected the resulting performance benefit from conversion to quad rig. It also found that the SAR* performance seemed to make more practical sense than SAR under fine scale scrutiny.

- Quad rig benefit was found to be higher for larger boats that towed bigger double gear. The performance benefit of quad rig increased in absolute terms by about 2.6% for each 6.8m increase in total headline length (based on SAR*).
- Based on the derived model for quad rig benefit, the spread ratio of the gear and/or its trawling speed, will erode the benefits of conversion to quad rig in absolute terms by about 1.1% for each 0.05 increase in spread ratio and 0.5% for each 0.32 knot increase in trawl speed (based on SAR*). This reduction is in addition to the direct reduction in benefit associated with the reduction in headline length.
- Well-targeted field trials could cost effectively augment the current investigation in terms of producing a clear-cut answer.

Objective 1.2 Comparison with knowledge from WA concerning the introduction of quad rig into their double rig fisheries

The staggered implementation of quad rig into the Exmouth Gulf Prawn Fishery had the desired outcome of improving the harvesting efficiency (cost of landing a kg of prawn) of the fleet without any noticeable increase in fishing effort. The tendency was for MGK vessels remaining in the fishery to tow larger QR systems (20% more headline length) at similar speeds, and possibly at slightly higher spread ratios (based on board area per unit of HL length increasing). A considerable amount of time and effort was spent re-optimising the QR systems following the changeover in 2000.

The generally accepted assumption for the improvement in performance for quad rig compared to double rig in Exmouth Gulf is 25% (Sporer, pers. coms). The basis for comparing the performance of the two systems in that context is different from the basis adopted in the desktop analysis for the NPF. The different basis is a result of the specific approach adopted in WA for introducing quad rig into the fishery in an effort neutral way as opposed to the approach that is proposed for the NPF, which manages trawl effort and fishing power under the gear units regime.

In Exmouth Gulf a memorandum of understanding (MOU) was agreed between management and industry, such that quad rigged vessels were allowed to tow 20% more gear than the double rig limit. To achieve effort neutrality 20% of the fleet no longer fished after quad rig was introduced. This fleet reduction balances the assumed 25% gain in each boat’s fishing power caused by the use of quad rig[1]. The following expression shows how the performance enhancement is balanced by the fleet reduction to achieve effort neutrality:

$$0.8 \text{ x original fleet size x } 1.25 \text{ x original fishing power} = 1 \text{ x original fleet size x original fishing power}$$

$$= 1 \text{ x original effort (i.e. Effort neutral)}$$

For the NPF, an approach used to achieve effort neutrality in a way that is consistent with effort management under the gear units regime might be to reduce the allocation of headline length to the boats that change to quad rig. The decrease needs to be commensurate with the gain in fishing performance that occurs when double rig is changed to quad rig, such that the transition can be considered effort neutral from a fleet-wide perspective.

The median performance improvement estimated for the 2005 NPF fleet is 26% for SAR and 19.2% for SAR*, if traditional quad rig of the same headline length is used. The sensitivity tests conducted in this desktop study (scenario 3(iii) Table 3) predicts that the performance benefit of quad gear that is 20% bigger increases to 29.4% for SAR and 25.5% for SAR* for the median NPF operation that does not change its towing capacity. Equation (1) and (2) from page 11 can be used to correct for the smaller class of boat (smaller headline length, HL = 27m) operating in Exmouth gulf compared to the median NPF trawler towing 41.4m of headrope. This reduces the predicted benefit of quad rig in Exmouth gulf (based on the NPF analysis) to 26.2% for SAR and 20.2% for SAR*. Therefore, the performance gain assumed in WA is at the upper end of the range considered possible from the desktop study of the NPF fleet in 2004. The reason for this could be that the application of gear reductions in the NPF, with the resulting increase in trawl speed and spread ratio, has already eroded the benefit of changing to quad rig for the 2004 NPF double rig fleet.

Objective 1.3 Final recommendation for an appropriate translation formula for a transition to quad rig in the NPF

An appropriate translation formula for the transition to quad rig in the NPF is an exceedingly difficult proposition to deliver. Despite the technical difficulty in predicting the catch benefit of quad rig relative to double rig based on configuration data, the biggest uncertainties in the derivation of catch benefit and setting an appropriate translation formula, relate to the predicting the actions of the operator/owner in the process. This leads to difficulties in establishing the level of engine power that will be applied to the quad gear and the amount of SFR trading that will occur (i.e. what size nets will be towed after the conversion). All that

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[1] It should be noted that the 20% increase in gear and the 20% reduction in fleet size are completely coincidental and is not significant in terms of achieving effort neutrality.

can be done in these circumstances is try to define the range of possibilities and the boundaries of the problem.

Based on the analysis conducted it appears that the maximum performance benefit for quad rig, if currently applied in the NPF, is a range of between 19.2% and 26%. This assumes that the same engine power is applied to double rig and quad rig for each boat. If the current trawl speed in the fishery is already near the maximum possible, the benefit of quad rig reduces to a range of between 10% and 16%. Under extreme circumstances the catch benefit can be zero, if both the spread ratio and trawl speed of the current double rig fleet is at the maximum possible.

For each of these three sets of assumptions; Constant engine power, constant trawls speed, constant trawl utilisation, effort neutral translation formula can be suggested. The easiest suggestion is SFR devaluations inversely proportional to the catch benefit. This is effort neutral if SRF trading occurs to exactly top up to the original holding, or circumstances are such that no further changes in spread Ratio and trawl speed will occur.

At the other end of the range, appropriate SFR devaluation factors can be derived to achieve effort neutrality assuming no SFR trading occurs.

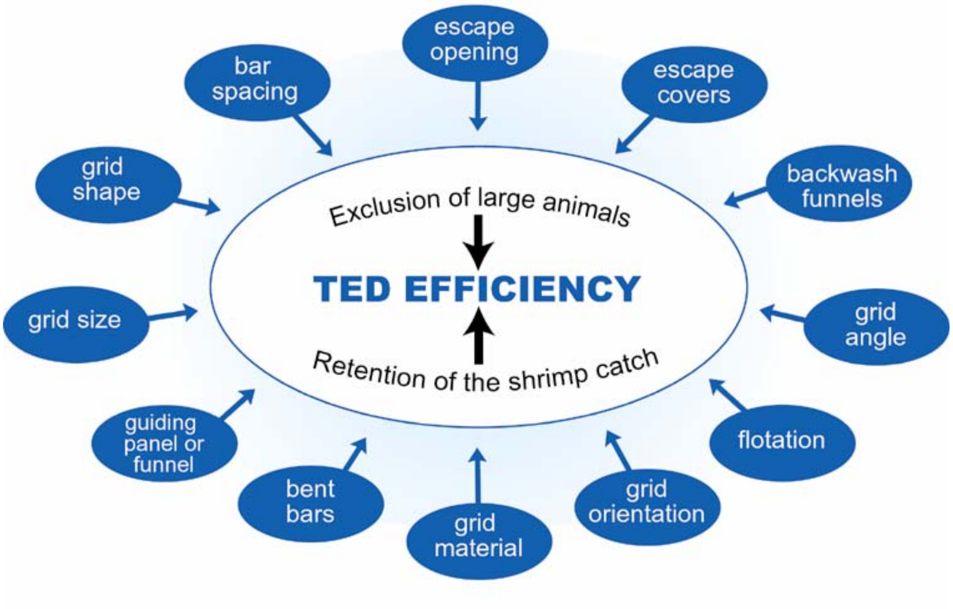
Table 4 provides a summary of the recommendations based on the defined framework of assumptions. The way forward to a final decision will need to rely on a consensus being formed as to which part of the table best represents the current circumstances in the NPF. Unfortunately the data and insight required to make that judgement seems to be very hard to obtain.

Table 4. Summary table and framework for establishing an effort neutral formula for the transition to quad rig in the NPF.

<table>
<tr><th colspan="3">CATCH BENEFIT PERCENTAGE FOR QUAD RIG OF SAME SIZE</th><th></th></tr>
<tr><td colspan="3">CONVERSION ASSUMPTION</td><td></td></tr>
<tr><td>Constant Engine Power</td><td>Constant Trawl Speed</td><td>Constant Trawl Utilisation</td><td></td></tr>
<tr><td>19.2% - 26%</td><td>10% - 16%</td><td>0%</td><td></td></tr>
<tr><td colspan="3">EFFORT NEUTRAL SFR DEVALUATION FOR DOUBLE TO QUAD CONVERSION</td><td>FISHER AND FLEET RESPONSE</td></tr>
<tr><td>0.839 - 0.794</td><td>0.909 – 0.862</td><td>1</td><td>Constant Trawl Utilisation Assumption</td></tr>
<tr><td>unknown</td><td>unknown</td><td>1</td><td>No Constant Trawl Utilisation Assumption
SFR Trading Occurs</td></tr>
<tr><td>NA</td><td>0.90 - 0.82</td><td>NA</td><td>No SFR Trading Occurs
Constant Trawl Speed Assumption</td></tr>
<tr><td>0.68 - 0.49</td><td>NA</td><td>NA</td><td>No SFR Trading Occurs
Constant Engine Power Assumption</td></tr>
</table>

Objective 2 An assessment of the potential effects of quad-rig prawn trawl systems on TED and BRD performance and specification

The re-introduction of quad-rig into the Northern Prawn Fishery (NPF) has the potential to increase the amount of seabed swept by the fleet each day of fishing, unless an effort neutral translation formula is introduced into the fishery. This will be achieved because quad-rig uses smaller nets and otter boards connected in a way that allows an increase in swept width (spread ratio) and towing speed. In this report the potential influence of quad-rigged nets on TED and BRD performance is described.



Source: Eayrs, 2005.

When fishers adopt quad-rig, the ability of a TED to guide turtles safely from a trawl should remain largely unchanged given fishers comply with the current specifications for an approved TED. However, a potential threat to turtles is the use of very small nets in a quad-rigged system or a significant increase in towing speed or spread ratio. Small nets are usually fitted with a small codend and TED, and there is a risk that the exit opening of a guiding panel (or funnel) in the TED may be too small and retard the passage of turtles towards the escape opening. Currently the dimensions of a guiding panel are not specified (and not all fishers use them), and it is unclear how small they can be before threatening turtle escape. The AFMA TED specifications do however include minimum dimensions for an escape opening in the codend, and in very small codends it will be difficult to maintain these dimensions without risking prawn loss; this means that the current TED specifications act as a regulatory mechanism ensuring that adequate codend size is maintained. A minimum size and TED angles are legislated to ensure that the NPF complies with the stringent US specifications to ensure accreditation for the US markets.

TED performance is usually considered to be independent of towing speed, although significant increases beyond that normally used may prove otherwise, and it is not known how TED performance may be influenced by such increased towing speed. In any case fishers may not overly increase towing speed given current high fuel costs and the negative impact it may have on catching efficiency. TED performance is usually also independent of spread ratio, given the TED is fitted to a typical, double-rigged net operated at a spread ratio between 55 and 70% of headline length. However, a small net will most likely be operated at higher spread ratio (85%), and this may cause the angle of an upward-excluding grid to increase and delay turtle escape, though TED angles are presently legislated within approved levels.

Source: Eayrs, 2005.

The ability of a BRD to reduce bycatch will not change dramatically in a quad-rigged net unless very small nets are used or towing speed is increased significantly. The use of very small nets may limit the size and location of some approved devices, and the number of escape openings available for bycatch to escape. It may also reduce BRD performance if the relative swimming distance between the accumulated catch and the device is increased; this could occur if a fisher locates the device 120 meshes from the drawstrings and a smaller catch is retained in the smaller net.

Increased towing speed may reduce BRD performance because small fish will be unable to swim fast enough to reach the escape openings of the device and escape.

The potential impact of quad-rig on TED and BRD performance is based predominantly on anecdotal or scant evidence, and it is perhaps premature to consider revising the TED and BRD specifications. The existing TED specifications should in most instances continue to ensure turtles rapidly escape from a trawl, however, careful monitoring of the performance of these devices is required. While it is possible that fishers will overcome most problem of poor TED and BRD performance themselves, because poor bycatch reduction is often associated with high prawn loss, future changes to the specifications may be required if adverse impacts of quad-rigged nets on bycatch reduction are recorded. Future studies may also be required to quantify the impact of spread ratio on grid angle, and the influence of towing speed on bycatch reduction.

CHAPTER 1 - INTRODUCTION

1.1 Background

NORMAC has discussed investigating the options available to give operators the ability to use gear other than double gear i.e. multi-net systems such as quad gear. This is to improve economic efficiency in the fishery. Presently the NPF Management Plan only allows the use of double gear, and effort in the fishery is controlled by a cap on transferable gear SFRs based on headline length.

A proposal was put to NORMAC 56 (July 2004) recommending the lifting of the restriction requiring all fishers to use double gear and allow them to use other configurations of gear. This proposal was to determine a relative conversion factor for each gear type (e.g. if quad gear was 100% more effective than double gear then you would need twice the SFRs to tow the same headline)

There were several issues identified by AFMA that need to be considered to assess the viability of lifting the restriction on double gear. They are**:**

- A need to establish conversion factors from double gear to other mulit-net systems to ensure effort neutrality between different gears
- To assess the potential bycatch implications, including the efficacy of existing TED and BRD specifications.
- To assess the potential impact of multi-net systems on the environment
- Equitable conversion versus simplicity
- Compliance and reporting
- The need to amend the NPF management plan
- The effect of multi-net systems on stock assessment determination

This scheme relies on being able to find an effective and simple conversion factor to provide “effort parity” between the existing gear and what may be introduced.

Using the approach of defining a relevant conversion factor for each type of net configuration would effectively provide for effort parity. Each operator could then choose which configuration of net they were to use and acquire the appropriate number of gear SFRs.

The use of multiple gear types is likely to have an effect on the stock assessment. At the minimum, vessel log sheets would need to specify the type and amount of gear being used for each operation.

As the current Management Plan limits the number of nets in the fishery to no more, and no less than two, an amendment to the Plan would be required. There would also need to be an evaluation by the Department of Environment and Heritage (DEH) of the relative impacts of multi-net systems on target and by-catch species and the broader marine environment (eg increased benthic impacts, interactions with protected species, TED and BRD performance etc).

Discussion took place on a proposal to remove the current two net restriction and give operators the option of towing other gear configurations at NORMAC 56 in June 2004. It was agreed that, given the tiger prawn stock rebuilding strategy was on target, this option should be explored provided it did not result in any increase in fishing effort. To achieve this, it was agreed that a translation formula would have to be developed to ensure that any translation from double gear to other multi-net systems would be effort neutral.

NORMAC noted that the removal of the two net restriction would be consistent with AFMA’s economic efficiency objective. It was also agreed that this approach may stimulate SFR trading and may result in the removal of additional vessels from the fishery as operators restructured their operations to take up the option of towing multi-net systems.

NORMAC agreed that in the short term it was likely that quad gear will be the configuration chosen by operators who wished to avail themselves of this option, and that AFMA should commission the development of a translation formula based on double gear to quad gear. NORMAC would need to reconsider the development of other translation formulae if operators subsequently applied to use other multi-net systems.

The DEH permanent observer indicated her support for the quad gear option provided that the use of quad gear in the fishery did not result in any additional negative ecological impacts.

NORMAC unanimously resolved that the two net restriction be removed upon the development of effort neutral conversion factors. This was so that operators could have the option of towing different gear types subject to the development of a translation formula to ensure effort neutrality, and data to indicate that multi-net systems do not have any additional negative ecological impacts.

1.2 Objectives and scope

This document reports on the potential impacts of allowing a conversion to Quad gear on the catching performance of NPF trawlers and the design/performance of associated TEDs and BRDs.

Specifically the objectives were:

1. Establish conversion factors to ensure effort neutrality between double gear and quad gear.
    - 1.4 Use the PTPM ver3 to estimate the advantage of quad rig over double rig for a NPF – 2005 context
    - 1.5 Compare knowledge gained in WA from the recent introduction of quad rig into their double rig fisheries with the PTPM ver3 predictions.
    - 1.6 Produce a final recommendation for an appropriate translation formula for a transition to quad rig in the NPF.
2. Produce a short document listing issues connecting the question of TED/BRD specification and performance with respect to a transition from double rig to quad rig.

1.4 PTPM validation and accuracy

A comparison with NPF catch data

Prior to 1987, quad rig and double rig vessels co-existed in the NPF fleet. The catch based fishing power[1] of all these vessels was estimated from logbook records and were compared to SAR predictions from the PTPM ver3 (Dichmont et al., 2003).This work allowed an assessment of how well the PTPM ver3 explains differences in catch between trawlers; bearing in mind that the available data on trawler configuration is variably sketchy. When comparing SAR predictions for trawlers to their aggregated catching performance, any degree of uncertainty in the input data presents additional random scatter of the data points around a relationship that is heuristically proportional. Figure 6 shows an example of such a comparison for all NPF trawlers that fished in 1980 where the fleet was approximately equally divided between double rig and quad rig. Here the fit of the proportional line has an equivalent correlation coefficient to the two-parameter linear model (NB. the brown line is almost totally hidden by the black line). It is of significance that the two lines are very nearly the same as it shows the catches from this sample of trawlers is generally proportional to SAR across the range of trawling capacity[2]. The regression of the proportional line shows that SAR explains 57% of the variation in SRFP[3]. Figure 7 shows the proportion of the variation in fishing power between trawlers explained by the PTPM ver3 over the 30year history of the NPF – it is consistently between 50% and 60%, apart from the early years where data quality was particularly poor and an inexplicable lapse for 2000.

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[1] Average daily economic catch (log transformed) standardised by weekly abundance.

[2] There is no appreciable linear trend in the residuals for the proportional regression.

[3] SRFP is the 3-year average of Relative Fishing Power centred on the year in question. This was done to approximately remove chance variation in RFP due to unintentional correlation with non-operational factors that can bias the average catch one way or the other in any year.

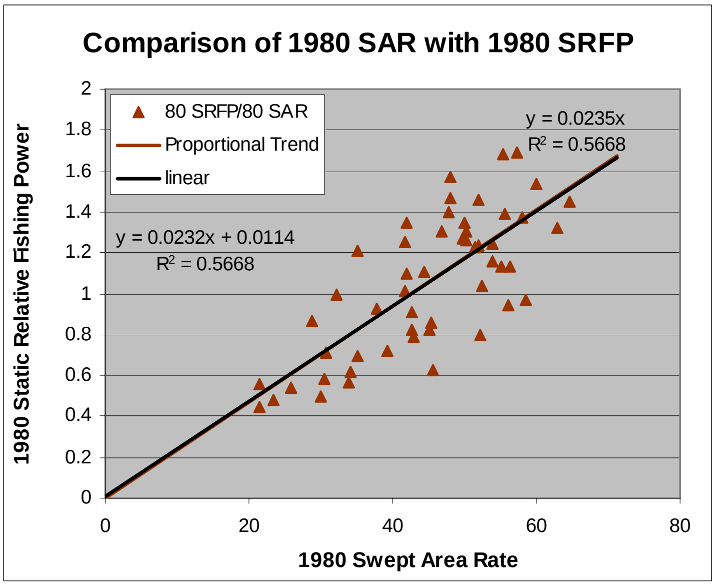

Figure 6. Plot of relative fishing power of NPF trawlers in 1980 against each boat's predicted SAR from the PTPM ver3.

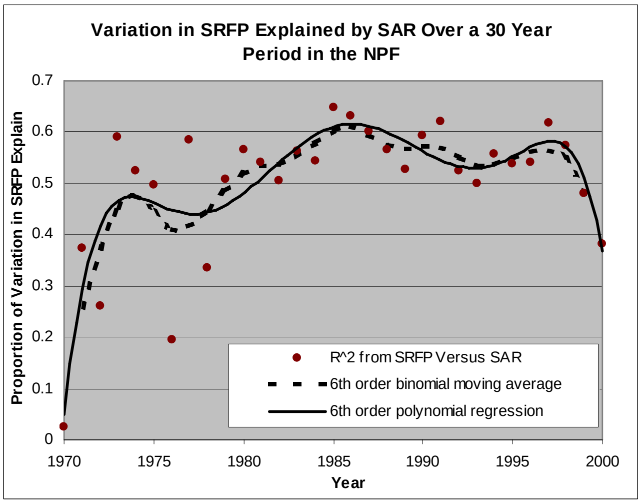

Figure 7. Proportion of variation in catching performance explained each year by estimated SAR as determined by the PTPM ver3 for the configuration data available over the history of the NPF[1].

Even where there is a high degree of random scatter, as in Figure 6, any systematic difference in error between the calculation of SAR for quad rig and double rig will likely be discerned in an analysis of the residuals. Figure 8 shows a plot of the average residual in each year for each rig type over the history of the NPF. Of relevance here is any separation between the trend for quad rig and the trend for double rig. A separation is an indication that the PTPM is not equally estimating the SAR performance for both rigs, or alternatively, there are external

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[1] 6th order binomial moving average added. This demonstrates that the original 6th order polynomial regression does a good job of conveniently depicting the qualitative trend in the data series in this case.

factors that cause the actual catch for any group to be inconsistent with their respective SAR measure.

For the years 1978 – 1981 the NPF fleet of approximately 250 trawlers was in general equally divided between quad rig and double rig. Over this period and beyond there is generally a random scatter of average residual about zero for both rigs. For the first few years after the initial introduction of quad rig (1976) the SAR measures seemed to over predict catch. This is likely due to poor average performance of the early quad rigged boats while they sorted out teething problems.

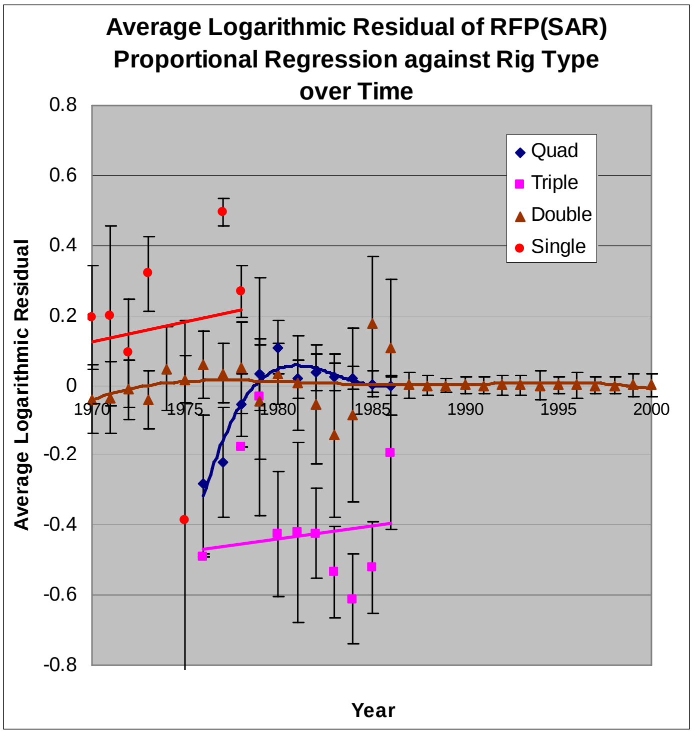

Figure 8. Average residual associated with rig type over time.

For triple rig there is a consistent substantial over-prediction of catch. This corroborates the anecdotal information mentioned earlier under the section on the PTPM ver2. However, the number of triple rigged boats captured by the analysis was very low and they tended to be small trawlers where model inputs were particularly uncertain.

A comparison with full-scale measurements of engineering performance

An indication of the absolute accuracy of the PTPM ver3 is presented in Dichmont et al. (2003). The exercise described involved comparing swept area predictions for an east coast trawler towing a variety of multi-net trawl systems with measurements of SAR obtained directly from measuring the speed, drag and span of the gear during operation. Table 5 shows a comparison of PTPM ver3 predictions and the experimental observations.

The predicted SAR of the three systems tested was within 3.1% of observations in absolute terms. None of the predictions were actually outside the error range of the SAR observations. Additionally, as all the prediction errors were negative (over prediction), the prediction of relative performance has even higher precision.

Table 5. Comparison of performance indicators predicted from the PTPM and determined from sea trial measurements of gear drag and span over a range of trawl speed. Percentage uncertainty (for 95% confidence) is given for the observed values and residual prediction error is also shown.

	Drag @ 1.4m/sec (kN)	*Span @ 1.4m/sec (m)*		*Speed obtained for 18kN tow force (m/sec)*	*Swept area/unit time for 18kN tow force (m^2/sec)*	
		nominal	*effective*		*nominal*	*effective*
5 rig – large boards observed	*17.87 (3.7)*	*40.80 (1.6)*		*1.405 (1.8)*	*57.44 (3.2)*	
PTPM prediction	*18.90*	*44.02*	*32.24*	*1.361*	*59.22*	*43.56*
% residual error	*-5.7*	*-7.9*		*3.1*	*-3.1*	
5 rig – small boards observed	*16.87 (2.0)*	*37.84 (2.4)*		*1.449 (2.1)*	*55.80 (4.1)*	
PTPM prediction	*17.43*	*38.85*	*29.39*	*1.43*	*55.86*	*42.17*
% residual error	*-3.3*	*-2.7*		*1.6*	*-0.1*	
3 rig – large boards observed	*16.81 (4.9)*	*34.47 (0.2)*		*1.452 (2.5)*	*50.48 (3.1)*	
PTPM prediction	*15.87*	*33.66*	*26.47*	*1.51*	*51.30*	*40.30*
% residual error	*5.6*	*2.3*		*-4.2*	*-1.6*	

Larger errors were evident for the predictions of operational status (drag, span and speed). Errors in the status variables, span and speed, appear to be inversely correlated; therefore these errors tend to cancel when the variables are combined to produce SAR predictions. The comparison undertaken was not an independent validation of accuracy because the opportunity was taken to fine tune assumptions in the model for the lift coefficient of flat rectangular otter boards to improve the agreement for operational status variables.

CHAPTER 2 - ESTABLISH CONVERSION FACTORS TO ENSURE EFFORT NEUTRALITY BETWEEN DOUBLE GEAR AND QUAD GEAR.

2.1 The advantage of quad rig over double rig for the NPF –2005 context based on the PTPM ver3

2.1.1 Methodology

Contemporary data on the characteristics of the NPF fleet was provided by CSIRO. The data set relates to all vessels that fished in the 2004 season and is the same as that recently used to calculate the swept area performances of the 2004 fleet, using the PTPM ver3 (Sterling, 2005), for the purposes of extending the historical fishing power series through to 2004 from 2002.

A summary of the trawling characteristics of the 2004 double rig fleet is shown in Figure 9 to Figure 11. The figures show frequency histograms of key configuration characteristics (Figure 9 – Headline length (Hl) and Developed engine power), catch performance measures (Figure 10 - Swept Area Rate (SAR) and Swept Volume Rate (SVR)), and operational status (Figure 11 – Spread Ratio (SR) and Trawl speed).

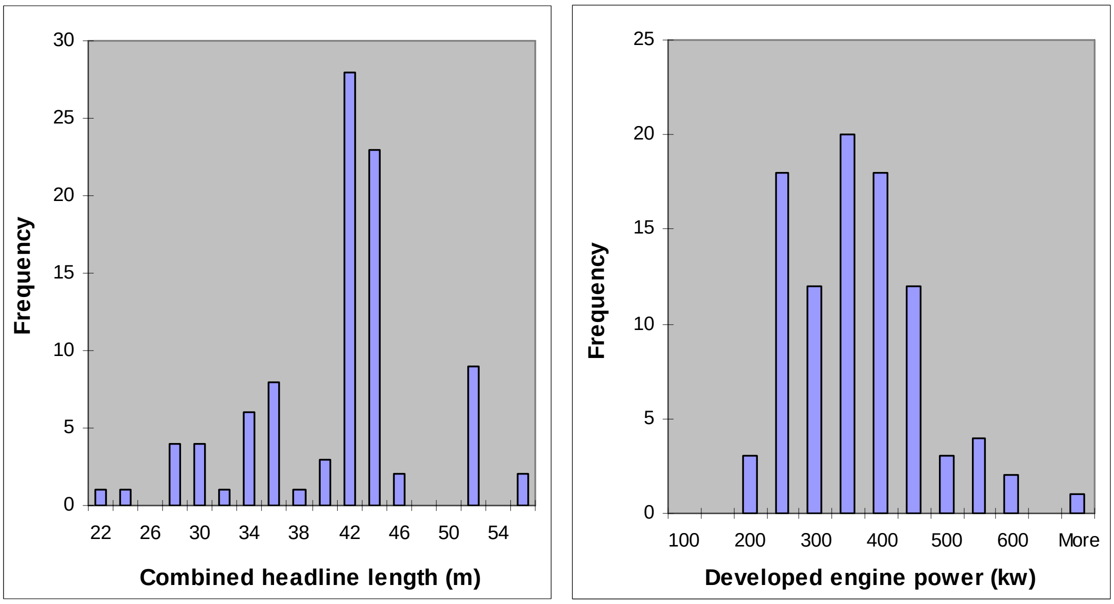

Figure 9. Key configuration characteristics of the double rig fleet in 2004.

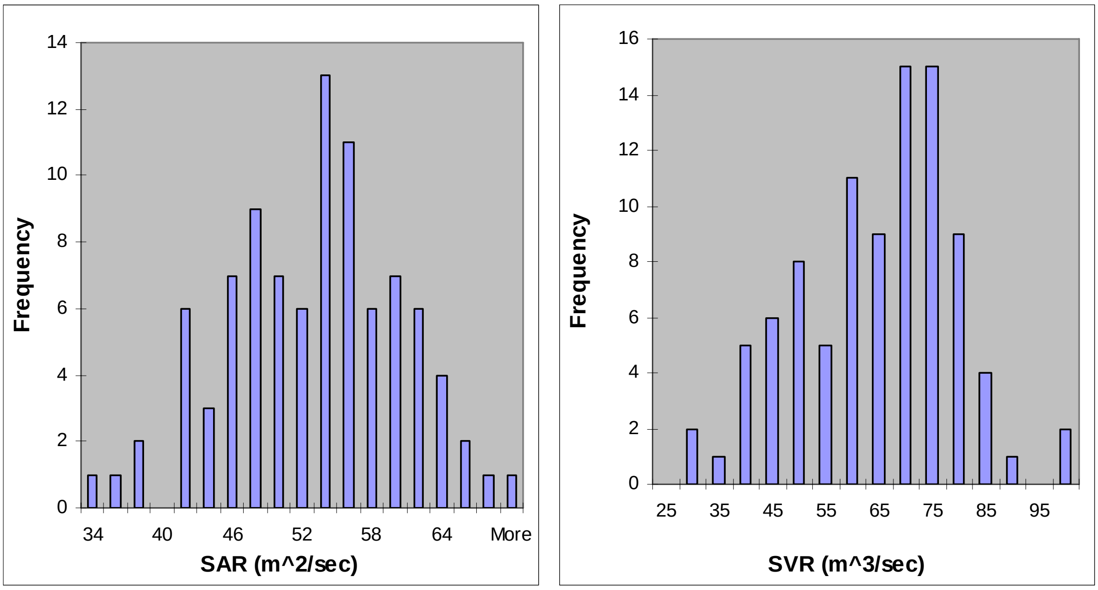

Figure 10. Distribution of predicted performance measures for the 2004 double rig fleet.

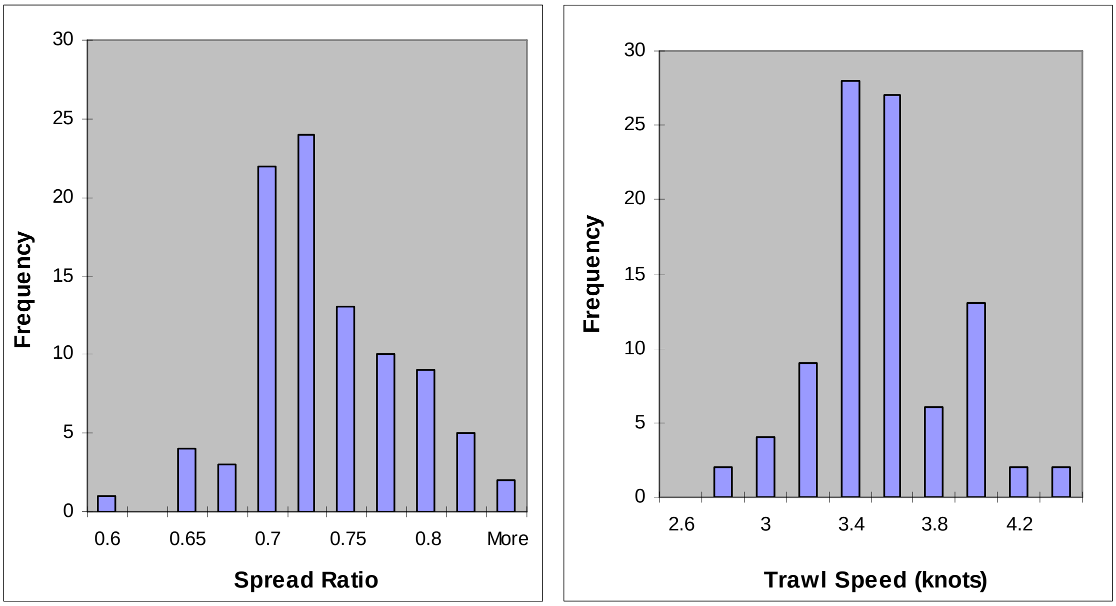

Figure 11. Distribution of predicted status measures for the 2004 double rig fleet.

A range of transition scenarios were considered and the status and performance measures for each scenario across all vessels of the 2004 fleet were calculated using the PTPM ver3. Performance gains for each vessel were established by dividing the estimated quad rig performances by their respective predicted double rig performance. A summary of performance benefit for each scenario was obtained by calculating the average, median, standard deviation and quartile range of performance gains across the fleet.

It was assumed for all transition scenarios (but not sensitivity tests) that all vessels convert to quad rig with the same combined headline length as the double rig used in 2004 and the style of otter boards also remains unchanged. Additionally the body taper for all quad rig scenarios and for all trawlers was fixed at 1P2B irrespective of the body taper used in double rig, which was either 1P4B or 1P3B as recorded in the 2004 gear configuration database.

Each scenario investigated relates to a plausible transition to quad rig where each successive scenario generally exhibits a greater level of optimisation or system perfection and therefore generally results in increased catch performance measures. As all scenarios had the combined headline length for quad rig equal to the combined headline length of the double rig used in 2004, the results give a range of estimated improvements for the transition to quad rig that was displayed against a scale for the degree to which the resulting quad gear nets are stretched by the applied otter boards. This provided a view of the sensitivity of the result against that quad rig configuration variable (spread ratio). The sensitivity of the estimated improvement for quad rig against the size of quad rig chosen was determined by varying one of the scenarios systematically through a range of gear sizes relative to that which was equal to the original double rig. These sensitivity tests established the effect of using bigger or smaller quad rig systems on the advantage of using quad rig.

Scenarios investigated for the transition from double rig to quad rig

The following scenarios for transition from double rig to quad rig were investigated in the computer-based study reported here:

1. Same Rigging Quad rig otter boards are the same as that used in double rig.
2. Same Attitude As in 1. except that the otter board angle of attack for quad rig is held the same as that calculated for double rig.
3. Traditional Headline Height The size of the otter board used in quad rig, for each boat, is set by an empirical board height assumption based on the historical usage of quad rig in the NPF[1]. The style of otter boards used (i.e. Bison or Flat) in quad rig was fixed to the style used in double rig and the aspect ratio[2] of each board style is equal to the average aspect ratio associated with each style as historically used in the NPF.

   Flat board height (m) = 0.4992 + 0.09181 * Headline length (m) (Aspect ratio = 0.425)

   Bison board height (m) = Flat board height (m) * 1.083 (Aspect ratio = 0.696)

   The angle of attack of all quad rig boards was fixed to the angle calculated for double rig.
4. Optimal Headline Height Otter board style, inclusive of aspect ratio, and angle of attack was the same as the double rig case. Otter board size was optimal, based on maximising:

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[1] The empirical data necessarily came from the early 1980's, since this is the period where quad rig was used in the NPF.

[2] Aspect ratio is the ratio of board height to length.

a) the "effective" Swept Volume Rate (SV*R = SAR * Effective height – see definition below)

b) the product of SAR and "catch efficiency" (SAR* = SAR * Catch efficiency - see definition below).

Scenario 4 was selected after running other similar scenarios that alternatively maximised SAR and SVR. For each of the alternative runs, extreme headline height results[1] were obtained. The approach adopted here; to apply an optimal headline height for each vessel that in someway systematically matches industry practice, was to use the double rig configurations of 2004 to establish the apparent "importance" of headline height (more details below). This importance for headline height was then also applied to quad rig scenario 4, so that the resulting "optimal" headline heights were consistent with industry practise in the defined sense. The importance of headline height is very likely also influenced by trawl speed and lead-ahead and these variables may differ between double rig and quad rig. But, due to the current lack of knowledge regarding these relationships these effects cannot be considered in this analysis.

The theoretical importance of headline height for the 2004 double rig fleet was estimated twice by assuming two different model functions to describe the hypothetical variation in catch as headline height increases:

a) The effective height expression returns an effective headline height of a trawling system based on the real headline height raised to the power of an unknown parameter, erf.

Effective height = (Headline height) ^ erf Where erf is expected to be between 0 and 1.

This then gives SV*R = SAR * (headline height) ^ erf.

b) The catch efficiency[2] expression determines the proportion of prawns in the water column that can be caught for a given headline height. Returned values increase with an exponentially decreasing rate and are asymptotic to 1 as headline height increases.

Catch efficiency = 1- exp(-k * Hh), Where k is an unknown parameter and Hh is headline height

This then gives SAR* = SAR * (1- exp(-k * Hh)).

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[1] For maximum SAR, very low board height and high trawl speed was optimal. For maximum SVR, very high board height and low trawl speed was optimal.

[2] Catch efficiency is the proportion of prawns in the path of the trawl that are captured. In this exercise it is proposed that all prawns, that escape, go over the headline and that this can be reduced to zero if the headline is very high off the bottom.

For each model function the unknown parameter was estimated such that the optimal headline heights for 2004 double rig (that which gives maximum respective performance) were as close as possible to the actual headline heights. The unknown parameters were manipulated by the secant method until the sum of differences between optimum board height and actual board height was equal to zero. This exercise suggested that erf was close to 1/6 and k had a value of about 2.45. Figure 12 shows the appearance of the two functions after calibration against the 2004 double rig fleet data.

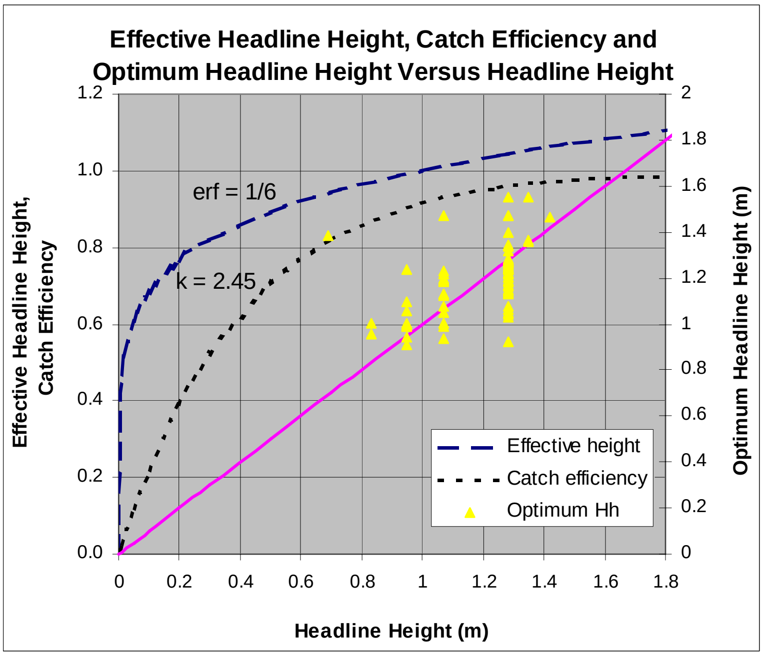

Figure 12. Theoretical effectiveness of headline height based on analysis of 2004 double rig configurations. Also exhibited is a comparison of actual headline height and “optimal” headline height (with equal values line) for the double rig fleet of 2004.

The calibration process for the two functions have caused the curves to be similar, in terms of their marginal effect on performance, over the range of headline height existing in the 2004 double rig fleet. Outside the data range the curves are quite different; particularly as headline height reduces.

In rough terms the result of calibration is similar to the height effectiveness data produced in the field by Eayrs (2005), whereby he found that a large proportion of tiger prawns in the path of the trawl could be caught with a headline height of only 0.6m.

Sensitivity tests – quad rig size

For transition scenario 3 four sensitivity tests were conducted. The first test has the quad rig headline length of all trawlers reduced by 20% (scenario 3ii), while in the second test the quad rig headline length of all trawlers was increased by 20% (scenario 3iii). The last two tests calculated for each boat the size of quad gear that achieved maximum SAR performance (an “optimum” condition) and the size of quad gear where the mechanical efficiency was so poor that the resulting SAR was the same as for the original double rig (an “effort neutral” condition).

Sensitivity evaluation – double rig configuration

The range of transition scenarios investigated and the sensitivity tests conducted for quad rig size allowed an evaluation of the effect of quad rig configuration on the benefit of quad rig from a fleet wide perspective. The benefit of quad rig is also dependent on the configuration of the double rig that was previously used. This is a complex question because the configuration of double rig within the fleet varies across many variables and with a myriad of combinations. This could be explored by focusing on a single hypothetical operation, rather than the whole NPF fleet, and go through a process of systematically varying configuration parameters to build a picture of cause and effect in terms of double rig configuration and the ultimate benefit of changing to a fixed quad rig configuration. This would be of general interest, but to establish the relevance of the results they would need to be matched up against variations in double rig configuration that occur in practice at the current time. The approach adopted here to estimate the sensitivity of the estimated benefits of quad rig to the diversity of contemporary double rig configurations was to discover the strongest relationships; between quad rig benefit and variables that effectively capture the diversity of double rig configuration for the 2004 fleet, within the fleet wide analyses already conducted.

Scenarios 3 and 4(b) were selected for this detailed scrutiny because initially SAR (from scenario 3) was the measure of trawl performance of greatest interest. However, it became apparent that for the fine detail being explored here the engineering domain alone may not be enough to provide realistic answers. Therefore attention shifted towards SAR*, which also includes a theoretical relationship between catch efficiency and headline height, and scenario 4(b) was selected as the source of the SAR* based quad rig benefit because in that scenario maximum SAR* was the basis for selecting otter board size. The configuration variables of double rig selected for attention where body taper, headline length, spread ratio, trawl speed, board type and developed engine power. Forward stepwise linear regression was used to help identify which variables contribute the most to the spread of quad rig benefit results and to quantify the size of the effects. To make the comparison of variables more “fair”, all predictors were standardised by subtracting the median value and dividing by the standard deviation. 1p3b and 1p4b body tapers were treated as separate variables that were either 0 or 1 and could not be standardised. The independent variable for each scenario was converted to an offset from its median value, but was not standardised so that the resulting regression coefficients described the change in quad rig benefit from the median value (or more precisely from the benefit for 1p3b or 1p4b as either of these two variable must be activated for the given data set) for a standard deviation shift in the respective predictor.

For both dependent variables a prediction equation for the benefit of quad rig was derived which contained the predictors; body taper, headline length, spread ratio (after the correlation with headline length was removed) and trawl speed (after the correlation with headline length was removed). The correlation with Headline length was removed from the spread ratio data because there was a strong correlation between the two variables (see Appendix C - Figure 30). The transformed standardised spread ratio variable (to a new variable, DELSPREAD:HL), captures information in the model associated with departures in spread ratio from that which is associated (correlated) with changes in headline length. The same process was also adopted for trawl speed for consistency even though correlation between headline length and trawl speed did not appear strong enough to make it of crucial importance. It is proposed that this model is a good predictor of quad rig benefit and has a theoretical basis to its structure such that it can be used to predict the effect of changes to the double rig made after 2004 on the benefit of converting to quad rig. This is deemed useful given that the fleet has undergone substantial structural change, because of gear unit reductions, since the double rig configuration data used in this analysis was collected in 2004.

2.1.2 Results and discussion

Table 6 and Table 2 provide the relative performance and status values calculated for the four main quad rig transition scenarios. Also shown are the engineering parameters for the double rig fleet, which is the reference point for the results of the quad rig scenarios. Table 6 provides average values for the fleet and standard deviations in brackets to indicate the distribution spread for each item. Table 7 provides median values for the fleet and the quartile range in brackets to indicate the distribution spread for each item.

Table 6. Average outcomes and standard deviation for hypothetical 2005 quad rig scenarios across relative performance indicators and status variables with respective to values determined for each boat according to their 2004 double rig configuration.

Absolute average 2004 double rig performances		Relative 2004 Quad rig performances				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4(a)	Scenario 4(b)
SAR	52.3m^2/sec (7.5)	1.136 (0.057)	1.166 (0.060)	1.244 (0.057)	1.301 (0.064)	1.227 (0.059)
SR	0.724 (0.050)	1.207 (0.052)	1.211 (0.047)	1.157 (0.061)	1.108 (0.074)	1.170 (0.062)
Speed	3.47knots (0.32)	0.940 (0.014)	0.963 (0.017)	1.075 (0.060)	1.173 (0.097)	1.048 (0.057)
Hh	1.20m (0.17)	1	1	0.774 (0.114)	0.622 (0.150)	0.822 (0.125)
SVR	62.3m^3/sec (14.5)	1.136 (0.057)	1.166 (0.060)	0.980 (0.146)	0.824 (0.184)	1.027 (0.156)
SV*R	53.7m^3/sec (8.3)	1.136 (0.057)	1.166 (0.060)	1.197 (0.054)	1.205 (0.053)	1.191 (0.056)
SAR*	49.3m/sec (7.7)	1.136 (0.057)	1.166 (0.060)	1.179 (0.063)	1.143 (0.082)	1.182 (0.062)
Hl	40.2m (6.8)	1	1	1	1	1

Table 7. Median and inter-quartile range for hypothetical 2005 quad rig scenarios across relative performance indicators and status variables with respective to values determined for each boat in their 2004 double rig configuration.

Absolute median 2004 double rig performances		Relative 2004 Quad rig performances				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4(a)	Scenario 4(b)
SAR	52.8m^2/sec (47.3-57.5)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.260 (1.196-1.290)	1.326 (1.247-1.343)	1.239 (1.175-1.276)
SR	0.715 (0.693-0.752)	1.215 (1.172-1.236)	1.219 (1.176-1.238)	1.166 (1.123-1.182)	1.116 (1.065-1.139)	1.175 (1.135-1.193)
Speed	3.46knots (3.32-3.64)	0.945 (0.923-0.949)	0.971 (0.941-0.973)	1.084 (1.047-1.101)	1.180 (1.115-1.224)	1.061 (1.011-1.081)
Hh	1.29m (1.07-1.29)	1	1	0.754 (0.735-0.830)	0.612 (0.565-0.688)	0.789 (0.769-0.902)
SVR	64.8m^3/sec (51.8-72.1)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	0.983 (0.921-1.024)	0.828 (0.749-0.894)	1.015 (0.978-1.092)
SV*R	54.3m^3/sec (47.9-59.5)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.210 (1.147-1.232)	1.223 (1.153-1.240)	1.204 (1.138-1.229)
SAR*	49.7m/sec (44.1-54.8)	1.150 (1.105-1.169)	1.183 (1.126-1.203)	1.192 (1.131-1.217)	1.169 (1.088-1.198)	1.195 (1.131-1.221)
Hl	41.4m (36.0-43.2)	1	1	1	1	1

In most instances the median results provided in Table 7 are slightly larger than the average results given in Table 6. Given that the median result is a better report of the most likely value within a distribution that is asymmetric, discussion of the results will focus on median values. Figure 13 is a plot of the different relative performance results across scenarios 2, 3, 4(a) and 4(b) from Table 7. Instead of the scenario being treated as categories the results are plotted against an X-axis scale reflecting each scenarios median quad rig spread ratio. This provides an indication of the sensitivity of the median benefit of quad rig across the fleet to the choice of otter board size, which determines the degree to which the taken up quad rig is being spread.

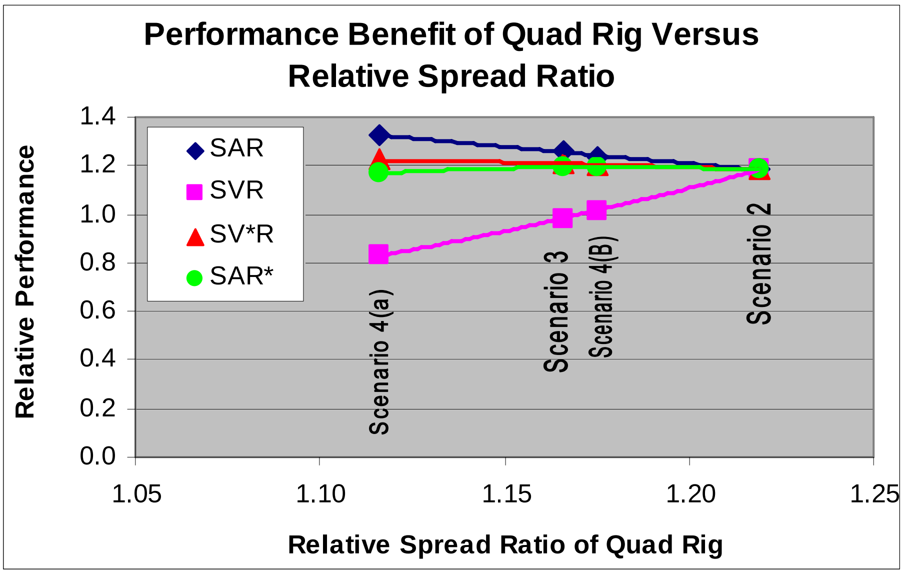

Figure 13. Trend in median performance benefit for quad rig (scenarios 2, 4(b), 3, 4(a)) with respect to median relative spread ratio for a Constant Engine Power.

Scenario 1

For quad rig scenario 1, the median SAR increase for the fleet was 15%. This came about because the spread ratio of the quad rig configurations increased generally by 21.5%, to a value of 0.87, but trawl speed dropped by 5.5% generally, to 3.27 knots.

The spread ratio of 0.87 is very high by industry standards and occurs quite infrequently in practice. The magnitude of the spread ratio found for this scenario is exacerbated because the NPF fleet is regulated by net size and there has been a number of significant gear reduction imposed over the last 5 years. This has caused the gear used on each boat to be generally smaller than traditionally used and the background spread ratio to be higher.

Since the otter board height for the quad rig, and therefore headline height, is the same for each trawler as the respective double rig configuration, the average gain in SVR and SV*R is the same as for SAR.

Figure 14 shows the distribution of relative SAR for this hypothetical 2004 quad rig fleet. The quartile range of quad rig benefit is very broad, 10.5% - 16.9% improvement.

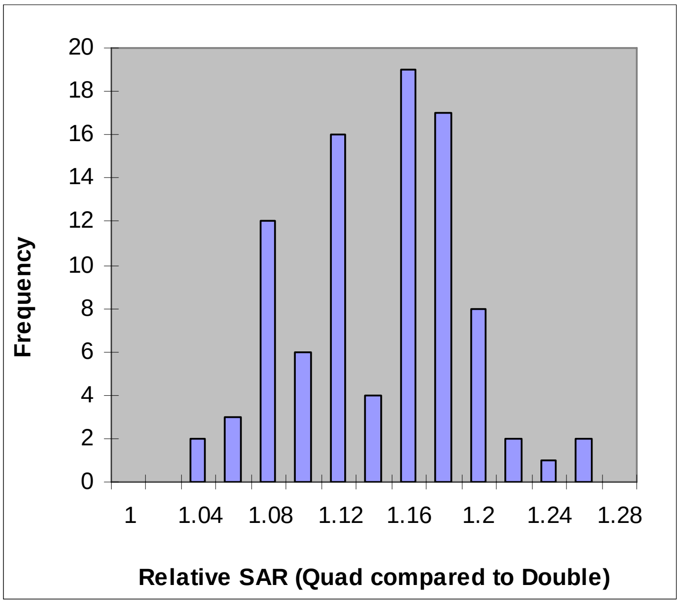

Figure 14. Distribution of relative SAR for scenario 1.

One factor that causes the broad distribution of SAR improvement, and its bimodal appearance, is the split character of the 2004 double rig fleet in that approximately 25% of the fleet use 1P4B body tapers and the rest use 1P3B. The model predicts that those that use 1P4B are more efficient and therefore the improvement from changing to quad gear is not as high as for the users of 1P3B.

Scenario 2

Quad rig scenario 2 produces a similar result to scenario 1, except that the efficiency of the otter boards is maintained at a higher level because the angle of attack is not allowed to increase due to the higher spread ratio. For this to occur in practice the otter boards, in the quad rig cases, need to be set to finer set angles of attack. It is not certain that this can occur to an extent that will preserve the lower angle of attack achieved during double rig operation without introducing unworkable shooting away problems. Therefore the 18.3% gain in SAR is likely to be the best-case advantage of conversion to quad rig where the original otter boards continue to be used.

Scenario 3

For scenario 3, smaller otter boards are allowed such that the board height matches that which was used in the past for the size of nets specified. The median improvement in SAR was 26% through a combination of a 16.6% increase in spread ratio and an 8.4% increase in trawl speed. The median trawling speed in this scenario therefore is 3.75 knots.

The average SVR for this scenario decreased slightly because the substantial (24.6%) reduction in headline height (median relative headline height = 0.754) more than offsets the increase in SAR.

For the first time the change in SV*R and SAR* are also different from that for SAR. SV*R is much less sensitive to changes in headline height than SVR and therefore tends to follow SAR rather than SVR. In this case the median SV*R still increased by 21%. Similarly SAR* (approx. 19.2% increase) did not increase to the same extent as SAR because of the estimated reduction in catch efficiency due to the lower headline height. However, the improvement in SAR* for scenario 3 was still higher than for the previous scenarios.

Scenario 4

For scenario 4(a), headline height (and board height) is allowed to reduce according to the PTPM view on optimality for each trawler with respect to maximising SV*R. The median headline height reduction across the quad rig was about 39%. Note though, that the headline length of the individual trawls in each quad rig case is 50% less than the headline length of the trawls in the respective double rig configuration. Therefore the ratio of headline height to length is still greater for quad rig than for double rig.

The median improvement of SAR for scenario 4(a) was about 33%, with spread ratio increasing by 11.6% and trawl speed increasing by 18%. SVR has reduced by 17.2% for this scenario, producing a contradicting perception of catch improvement compared to the upbeat SAR result.

SV*R on the other hand, predicts a modest 22.3% improvement in catch due to it being less sensitive to the reduction in headline height. This result is the maximum possible improvement in SV*R, given that contemporary otter board styles are used. Higher values of SV*R can be achieved if lower profile otter boards are assumed or the headline can be successfully connected to a lower point on the otter board. Such scenarios are outside the scope of this investigation because such developments in gear will also improve the background performance of double rig and may not necessarily improve the inherent advantage of using quad rig instead of double.

The SAR* improvement for this scenario has dropped to 16.9% because the catch efficiency function is penalising the low headline height more severely than the effective height function.

For scenario 4(b), headline height is allowed to reduce according to the PTPM view on optimality for each trawler with respect to maximising SAR* instead of SV*R. The median headline height reduction across the fleet was only 21%. This is because of the optimisation is taking into account the stronger reduction in performance with respect to decreased headline height. Scenario 4(b) produces the maximum possible median improvement for SAR*, which is estimated to be 19.5%. Meanwhile the median SAR improvement is 23.9%.

It is interesting to note that scenario 3, which fixes all board heights to the traditional trend observed in the 80's, sits between the two optimisation results that differ because of the different functions selected to model the effect on performance with respect to headline height (although it is more similar to scenario 4(b) than scenario 4(a) -see Figure 13). This supports the credibility of scenario 3 as a satisfactory general prediction for the performance advantages of quad rig in the NPF.

Sensitivity tests – quad rig size

Table 8 and Table 9 show performance benefits for scenario 3 contrasted with sensitivity tests where the total headline length of the quad gear was varied. In one case headline length was increased by 20% and in another case headline length was decreased by 20%.

Other calculations are also reported in the tables. The first results column relate to a scenario where the headline length for quad rig in all cases is reduced until the SAR is reduced to the same as the original double rig (scenario 3neutral). The last results column relates to the scenario where the size of each quad rig is increased until maximum SAR is achieved (scenario 3opt).

Figure 15 shows the benefit of quad rig plotted against the magnitude of the quad rig system towed.

Table 8. Average results for gear size sensitivity tests conducted on scenario 3. The numbers in brackets give the percentage change relative to scenario 3i. For an indication of standard deviation see Table 6.

Relative 2004 Quad rig performances					
	Scenario 3neutral Same SAR	Scenario 3ii (-20% Hl)	Scenario 3i	Scenario 3iii (+20% Hl)	Scenario 3opt Max SAR
SAR	1 (-19.6%)	1.188 (-4.5%)	1.244	1.268 (+1.9%)	1.276 (+2.6%)
SR	1.323 (+14.3%)	1.221 (+5.5%)	1.157	1.096 (-5.3%)	1.063 (-8.1%)
Speed	1.515 (+40.9%)	1.216 (+13.1%)	1.075	0.963 (-10.4%)	0.907 (-15.6%)
Hh	0.553 (-28.6%)	0.684 (-11.6%)	0.774	0.864 (+11.6%)	0.917 (+18.5%)
SVR	0.557 (-43.2%)	0.827 (-15.6%)	0.980	1.114 (+13.7%)	1.191 (+21.5%)
SV*R	0.907 (-24.1%)	1.118 (-6.4%)	1.195	1.241 (+3.8%)	1.261 (+5.5%)
SAR*	0.845 (-28.3%)	1.087 (-7.8%)	1.179	1.234 (+4.7%)	1.259 (+6.8%)
Hl	0.499 (-50.1%)	0.8 (-20%)	1	1.2 (+20%)	1.323 (+32.3%)

Table 9. Median results for gear size sensitivity tests conducted on scenario 3. The numbers in brackets give the percentage change relative to scenario 3i. For an indication of quartile range see Table 7.

Relative 2004 Quad rig performances					
	Scenario 3neutral Same SAR	Scenario 3ii (-20% Hl)	Scenario 3i	Scenario 3iii (+20% Hl)	Scenario 3opt Max SAR
SAR	1 (-20.6%)	1.198 (-4.9%)	1.260	1.294 (+2.7%)	1.305 (+3.6%)
SR	1.329 (+14.0%)	1.230 (+5.5%)	1.166	1.106 (-5.1%)	1.074 (-7.9%)
Speed	1.495 (+37.9%)	1.217 (+12.3%)	1.084	0.972 (-10.3%)	0.908 (-16.2%)
Hh	0.529 (-29.8%)	0.663 (-12.1%)	0.754	0.846 (+12.2%)	0.899 (+19.2%)
SVR	0.539 (-45.2%)	0.827 (-15.9%)	0.983	1.116 (+13.5%)	1.181 (+20.2%)
SV*R	0.902 (-24.5%)	1.125 (-7.0%)	1.210	1.267 (+4.7%)	1.281 (+5.9%)
SAR*	0.842 (-29.4%)	1.089 (-8.6%)	1.192	1.255 (+5.3%)	1.280 (+7.4%)
Hl	0.489 (-51.1%)	0.8 (-20%)	1	1.2 (+20%)	1.320 (+32.0%)

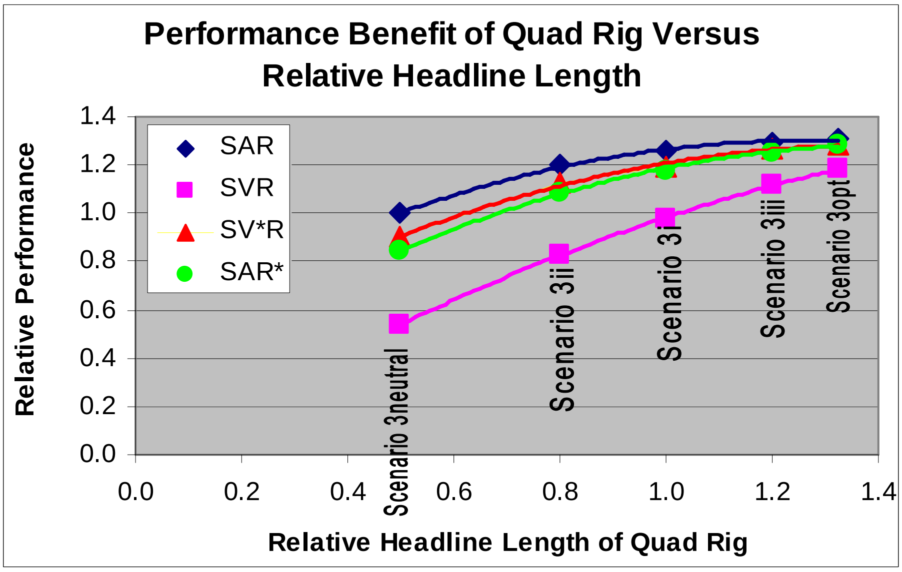

Figure 15. Trend in median performance benefit for quad rig (scenarios 3neutral, 3ii, 3i, 3iii, 3opt) with respect to relative gear size for a Constant Engine Power.

The change in median SAR performance for the +20% and –20% change in headline length was only +2.7% and -4.9% respectively. The low response of SAR to headline length is due to the countervailing effects of the SR and speed responses on SAR.

SVR changed to a much greater extent and in a way that was more commensurate with the change in headline length. This was due to the influence of headline height on the measure. The catch indicators, SV*R and SAR*, responded in an intermediate way compared to SAR and SVR.

In summary, the marginal catch benefit of increasing the size of quad rig by 20% across the fleet is only about 2.5 – 5.5% (not including SVR). This is the small increment in performance that occurs as gear size on a trawler is increased towards its optimum size. The last sensitivity test in Table 9 (scenario 3opt) indicates that the median increase in gear size required to achieve maximum swept area performance was 32% and this is predicted to produce a marginal catch benefit of 3.5 – 7.5%.

For the first sensitivity test of Table 9 (scenario 3neutral) all transitions to quad rig are effort neutral, based on SAR. For this scenario it was found that the median reduction in quad rig size had to be 51% to maintain the same SAR result as the original double rig (ie. relative SAR =1). A number of important issues should be raised here:

1 The resulting trawl speed is very high (median speed of 5.2knots).

2 The catch indicators, SV*R and SAR*, indicate that the gear may be worse than effort neutral by 10 – 15%.

3 The resulting small quad gear maybe effort neutral, but this has come at the cost whereby there is now no efficiency gain available to operators through taking up quad rig.

Sensitivity evaluation – double rig configuration

Table 10 shows the effect of body taper on performance enhancement for the transition to quad rig under scenario 3. The group of double rig boats that had 1P3B had a greater benefit from changing to the quad rig system than the group of boats that used 1P4B in their double rig. This is because 1P4B trawls have less netting for the same headline length and gives rise to a double rig performance that is closer to that of the specified quad rig.

Table 10. Median and quartile range results for scenario 3 with the fleet sub-grouped by body taper.

Relative 2004 Quad rig performances			
	Scenario 3i (1P3B)	Scenario 3i (combined)	Scenario 3i (1P4B)
SAR	1.287 (1.257-1.293)	1.260 (1.196-1.290)	1.181 (1.166-1.185)
SR	1.170 (1.160-1.184)	1.166 (1.123-1.182)	1.125 (1.110-1.155)
Speed	1.095 (1.061-1.102)	1.084 (1.047-1.101)	1.049 (1.006-1.064)
Hh	0.754 (0.735-0.826)	0.754 (0.735-0.830)	0.754 (0.735-0.843)
SVR	0.986 (0.966-1.040)	0.983 (0.921-1.024)	0.914 (0.885-1.002)
SV*R	1.227 (1.209-1.236)	1.210 (1.147-1.232)	1.129 (1.125-1.138)
SAR*	1.213 (1.185-1.223)	1.192 (1.131-1.217)	1.115 (1.108-1.128)

Figure 16 shows the frequency distribution for SAR improvement for the two groups of boats with different double rig body taper. There is about a 10% absolute difference in quad rig benefit between boats using 1p3b and boats using 1p4b body taper. The mode for 1p3b is 1.3 while the mode for 1p4B is 1.2. There are about 3 times more boats using 1p3b than use 1p4b.

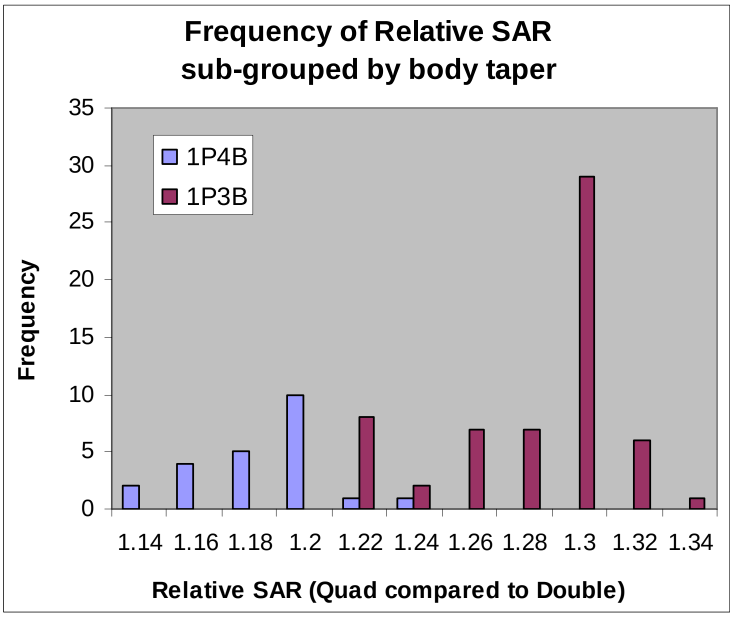

Figure 16. Frequency distribution of relative SAR for scenario 3, sub-grouped by the body taper used in double rig.

Appendix C (Figure 30) contains a scatter-plot matrix for dependent variables (quad rig benefit measures) chosen from scenarios 3 and 4(b) (relative SAR and relative SAR*, respectively) and the double rig configuration predictors under scrutiny in this evaluation. The scatter plots allow a qualitative assessment of the strength of association between the variables. A strong association can be seen between quad rig benefit and the body taper used in double rig (1p4b or 1p3b) as would be expected from viewing Figure 16. There also appears to be a strong positive correlation between quad rig benefit and headline length, and a strong negative correlation between quad rig benefit and spread ratio.

The scatter plots also indicate that there is a strong negative correlation between headline length and spread ratio. This indicates that only one of the variables is required to account for the majority of the associated variation in quad rig benefit within the fleet. The correlation between headline length and spread ratio is due to the industry practice of generally keeping headline height constant irrespective of net size. This results in the situation where the boards on larger nets are not sufficiently bigger to maintain the spread ratio at the same level as that occurring for smaller nets. To a large extent therefore, the range of spread ratio observed in the double rig fleet, by way of PTPMver3 estimation, is the associated structural consequence of the range in gear size that exists.

The reason the advantage of quad rig increases for larger double rig operations (for both SAR and SAR*) is not clear to the author. Despite the effect of headline length on quad rig advantage being consistent for both performance measures, it appears that different mechanisms are producing the result for each case. In the case of SAR the effect might be linked to the way that the SAR benefit for quad rig decreases with increased spread ratio, as depicted in Figure 13. While for SAR*, where this performance measure is constant with spread ratio in Figure 13, the reduced benefit of quad rig for smaller double rig systems is probably linked to the sharp reduction in catch efficiency that occurs for small quad rig systems where headline height becomes relatively low.

Table 11 give the results of the two stepwise regressions applied to the two quad rig benefit cases. In both cases the order in which the predictors was brought into the model was the same. Essentially body taper had the strongest association with variation in quad rig benefit. The coefficients for the body taper variables give the shift in benefit from the calculated median value for the fleet (1.26 for SAR and 1.195 for SAR* from Table 7) to the benefit for the respective component of the fleet at standard conditions (median values for the rest of the factors). The total absolute difference in quad rig benefit between the 1p4b boats and the 1p3b boats is 10.3% (ie. 1.171 (SE = .006) versus 1.274 (SE = .003)) for SAR and 9.6% (ie. 1.113 (SE = .004) versus 1.209 (SE = .002)) for SAR*.

Headline length was the next double rig configuration variable brought into the models. It came in earlier than 1p3b only because the arbitrary reference for the dependent variables was the median value for the fleet, and since 75% of the fleet was 1p3b, the reference was located quite close to the quad rig benefit for 1p3b boats at standard conditions. The coefficients for headline length in both models do not reflect the practical effect size for the variation in headline length in the double rig fleet because the regression process produces “partial regression coefficients” that do not include the effect of the correlated factors like spread ratio and trawl speed if they are also present in the model.

Table 11. Outputs from forward stepwise regressions between selected dependent variables, relative SAR from scenario 3 (SAR_DIFF) and relative SAR* from scenario 4(b) (SARXDIFF), and independent variables associated with double rig configuration.

Regression Summary for Dependent Variable: SAR_DIFF
R= .91487826 R^2= .83700222 Adjusted R^2= .82308778
F(7,82)=60.153 p<.00000 Std.Error of estimate: .02349

	B	St. Err. of B	t(82)	p-level
P4B	-.0885	.0065	-13.72	.000000
STD_HL	.0068	.0067	1.02	.312754
P3B	.0144	.0031	4.71	.000010
STD_SR	.0113	.0054	2.09	.040064
FLAT	.0257	.0096	2.68	.008944
STD_SPEED	-.0225	.0046	-4.92	.000004
STD_DEVH	.0235	.0052	4.51	.000021

Regression Summary for Dependent Variable: SARXDIFF
R= .97048829 R^2= .94184751 Adjusted R^2= .93688328
F(7,82)=189.73 p<0.0000 Std.Error of estimate: .01403

	B	St. Err. of B	t(82)	p-level
P4B	-.0819	.0039	-21.26	.000000
STD_HL	.0148	.0040	3.72	.000360
P3B	.0140	.0018	7.64	.000000
STD_SR	-.0111	.0032	-3.44	.000917
FLAT	.0127	.0057	2.21	.029796
STD_SPEED	-.0049	.0027	-1.80	.075419
STD_DEVH	.0035	.0031	1.13	.260804

Table 12 shows regression results for models that include headline length as the only factor other than body taper. This produces regression coefficients for headline length that reflects the practical effect on quad rig benefit caused by the size of double rig used in 2004. For SAR an increase of double rig size of one standard deviation (6.8m increase in total headline length) causes a 1.5% (SE = 0.3%) absolute increase in quad rig benefit (ie. for 1p3b and a median headline length of 41.4m, a relative SAR change from 1.274 (SE = .003) to 1.289 (SE = .004)). For SAR* an increase of double rig size of one standard deviation (6.8m increase in total headline length) causes a 2.6% (SE = 0.2%) absolute increase in quad rig benefit (ie. for 1p3b and a median headline length of 41.4m, a relative SAR* change from 1.209 (SE = .002) to 1.234 (SE = .003)). The effect of double rig size on the SAR* benefit of quad rig from scenario 4(b) is significantly higher than the effect on the SAR benefit from scenario 3 (2.6%/6.8m verses 1.5%/6.8m). The author is not able to describe why this occurred.

Table 12. Outputs from linear regressions between selected dependent variables, relative SAR from scenario 3 (SAR_D2) and relative SAR* from scenario 4(b) (SARXDIFF), and independent variables, body taper and headline length.

Regression Summary for Dependent Variable: SAR_DIFF
R= .87287139 R²= .76190447 Adjusted R²= .75359881
F(3,86)=91.733 p<.00000 Std.Error of estimate: .02773

		St. Err.		
	B	of B	t(86)	p-level
P4B	-.0829	.0052	-15.97	.000000
STD_HL	.0150	.0030	5.01	.000003
P3B	.0142	.0036	3.93	.000174

Regression Summary for Dependent Variable: SARXDIFF
R= .96154188 R²= .92456279 Adjusted R²= .92193126
F(3,86)=351.34 p<0.0000 Std.Error of estimate: .01560

		St. Err.		
	B	of B	t(86)	p-level
P4B	-.0873	.0029	-29.92	0.000000
STD_HL	.0255	.0017	15.18	.000000
P3B	.0143	.0020	7.07	.000000

The next variable introduced into the models, after body taper and headline length, was spread ratio (see Table 11). The coefficients for this variable in the two models have similar magnitude, but opposite signs. Intuitively the negative sign for the SAR* model seems to make more practical sense and promotes the idea that the SAR model may be inferior in predicting the fine scale details of trawling performance. The problem with the SAR model maybe that the dependent variable, relative SAR from scenario 3, is a performance measure based only on the engineering domain. The coefficient for spread ratio in the models, which is a measure of the effect of spread ratio on the relative performance of quad rig (often referred to here as quad rig benefit), is sensitive to the performance of the resulting quad rig (numerator) and the background performance of the original double rig (denominator). Therefore, the coefficient for spread ratio is the end result of the balance between decreasing double rig performance as spread ratio increases and the decrease in the resulting quad rig performance due to becoming less optimal through the imposition of the double rig configuration variables. For the SAR model the decrease in double rig performance with increased spread ratio must be greater than the decrease in quad rig performance from being pushed to a less optimal configuration, therefore the coefficient for spread ratio is positive. For the SAR* model the reduction in double rig performance with respect to increased spread ratio is reduced because of the positive contribution to double rig performance from increased headline height and the catch efficiency(Hh) function. Therefore the change in relative SAR* performance of quad rig due to increased spread ratio of double rig is dominated by the reduced performance of quad rig as it is made less optimal and thus the coefficient for spread ratio has a negative value. Since the spread ratio of quad rig is essentially fixed by the definition of the scenario, the reduced performance of quad rig is manifested by the increased trawl speed for quad rig as the spread ratio of double rig is increased. In this area both models may lack accuracy in determining the change in quad rig benefit since the impact of speed on the performance of quad rig is assessed only in the engineering domain; no effect of trawling speed on catching efficiency is included in the calculation. This may bias low the estimated effect of double rig spread ratio on quad rig benefit, that is, the coefficients for spread ratio might in fact be more substantially negative in both cases. As it is, the coefficient for double rig spread ratio in the SAR* model indicates that an increase in double rig spread ratio of one standard deviation (an absolute value of 0.50 - Table 6) causes a 1.1% (SE = 0.3%) absolute reduction in quad rig benefit.

The remaining variables included in the stepwise regression models contribute very little to explaining the variation in quad rig benefit across the fleet. For the Board type variable (FLAT), this is because very few vessels in the fleet use flat boards and the effect of using these boards on the performance benefit of quad rig is small. Given that the number of vessels using flat boards is not likely to increase in the future, it will not be considered further here.

On the other hand increasing trawl speed is a matter that is continually raised when discussing the future of the NPF. For that reason the author feels that it is important to explore the effect of increased double rig trawl speed on the performance benefit of quad rig. Increasing trawl speed has become a historical feature of the NPF since the introduction of gear units and the implementation of gear unit reductions. More reductions have occurred since the 2004 gear configuration data was collected and it is likely that trawling speed for some trawlers has increased further. Increased trawl speed is a natural consequence of the application of gear cuts and is only mitigated by the conscious action of the skipper to reduce engine power. This is said to readily occur depending on the commitment and possibility of setting each vessels trawling speed to some nominated value. Even if a commitment to set the trawl speed to a given value exists, the measurement of trawl speed and the quality of feedback to the skipper (under trawling conditions) is not ideal for such a task.

Based on the modelling and the available data for 2004, Table 11 provides coefficients for the independent effect of double rig trawl speed on the benefit of quad rig. In both cases the coefficient is negative, suggesting that the performance benefit of quad is eroded by the imposition of gear cuts and any resulting increase in double rig trawl speed. For SAR the absolute decrease in quad rig benefit is 2.3% (SE = 0.5%) for one standard deviation increase in trawl speed (0.32knots - Table 6). For SAR* the absolute decrease in quad rig benefit is estimated to be only 0.5% (SE = 0.3%) for the same increase in trawl speed. In both cases the coefficients are estimated from modelling limited to the engineering domain. Any real relationship that exists between catch efficiency and trawl speed would affect the magnitude of the coefficients for double rig trawl speed. The affect of a relationship between catch efficiency and trawl speed on quad rig benefit might be dampened however, depending on the characteristics of the relationship, because it will affect the performance of both double rig and quad rig.

From the sensitivity evaluation of the effect of double rig configuration on the performance benefit of quad rig, the following functional equations were derived to predict quad rig benefit from the configuration/operating status of the double rig previously used:

For SAR:

Relative SAR = 1.260 + 0.014 $P3B_{0\text{-}1}$ - 0.089 $P4B_{0\text{-}1}$ + 0.015 STD_Hl + 0.011 DELSR:HL – 0.023 DELSPEED:HL

For SAR*:

Relative SAR* = 1.195 + 0.014 $P3B_{0\text{-}1}$ - 0.082 $P4B_{0\text{-}1}$ + 0.026 STD_Hl - 0.011 DELSR:HL – 0.005 DELSPEED:HL

Where DELSR:HL and DELSPEED:HL are the standardised spread ratio and trawl speed that is beyond that which is correlated with headline length. Put in non-technical terms DELSR:HL and DELSPEED:HL represent the unnatural distortions of the trawl fleet’s characteristics due to the imposition of gear units in circumstances where insufficient trading occurs to preserve the “normal” correlation between configuration variables. When insufficient trading occurs, operators choose to tow smaller nets than they would otherwise and attempt to extract enhanced performance from the smaller nets through stretching them to a greater extent (increased spread – DELSR:HL) and towing them at a faster speed (DELSPEED:HL). Both these effects are shown to reduce the SAR* performance benefit available from eventually converting to quad gear with an equivalent headline length.

DELSR:HL and DELSpeed:HL can be calculated from the following equations, which were derived from the regressions of STD_SR and STD_SPEED against STD_HL provided in appendix C:

DELSR:HL = (SR - 0.938 + .00514 HL)/0.05

DELSPEED:HL = (SPEED - 3.942 + 0.01101 HL)/0.32

The need for field trials

Uncertainties in the results established in this study for the benefit of quad rig compared to double rig relate mostly to the unknown extent to which catch efficiency can vary the actual catching performance of the trawl gears under investigation away from that estimated by analysis of their engineering characteristics and the heuristic assumption that catch is proportional to swept area rate. Catch efficiency, which is narrowly defined here as the proportion of vulnerable prawn in the path of the trawl that are captured, is identified in this study to be particularly affected by headline height, perhaps importantly affected by trawl speed, and feasibly also a function of lead ahead and spread ratio. None of these relationships have been quantified by scientific research and remain issues of great conjecture within matters of great importance to fisheries management.

Given that this computer based analysis has produced a range of predictions for the performance enhancement of quad rig over double rig; notwithstanding that they have been methodically "pigeon-holed", there exists a need to develop a process to make clear the particular result that most appropriately answers the question being asked. An indispensable insight may be obtained by undertaking field trials, particularly trials that are carefully designed within a framework coinciding with the current desktop investigation and suggested by the issues that have been raised.

Field trials to directly quantify the benefit of quad rig over double rig, based on prawn catch, are generally difficult to execute because of standardisation difficulties; also problems in identifying appropriate configurations of double rig and quad rig to test and the high associated costs of field trials. A hybrid approach involving both field trials (to measure the magnitude of catch and engineering variables) and computer-based predictions would be the most cost effective way to produce higher quality results.

The modelling here works with three status variables of trawl gear that combine to affect trawl catches per unit of headline length in response to the different trawl systems. These are speed, spread ratio and headline height. Speed is the most problematic response variable to deal with in field trials because it cannot be kept free unless either:

a) two boats with different trawl gear configurations are used to simultaneously take catch samples, or

b) trawl gear on a given boat is randomly changed from one configuration to another.

For a) emergent problems are to standardise the performance of the two boats[1], bottom time and location. For b) a large number of gear changes and replicate trawl shots are required to remove the effect of temporal and spatial changes in local abundance and vulnerability.

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[1] This may best be achieved by swapping the test trawl gears between the two boats a number of times.

It seems to be worthwhile noting that the affects on catch from the other response variables, spread ratio and headline height, can be measured independent of speed through using only one trawler; and without any serious standardisation problems[1]. As it happens field trial information on these two facets of the problem would address the major information gaps in the current desktop analysis and also allow extensive validation/improvement of model predictions. Additionally, the effect of speed on catch can be directly measured more easily if pursued on its own (ie. all other things being fixed or at least tightly monitored)[2].

It appears that it might be possible to conduct appropriately designed field trials to supply crucial information on the question of quad rig performance within existing prawn stock surveys without compromising survey results, and for very little additional cost. Further work is required to fully assess the potential of this idea, but that is well outside the scope of this report.

2.1.4 Conclusions

Based on the computer-based investigation of a wide range of practical conversions to quad rig it is estimated that the short term SAR advantage would grow quite quickly to about 26% (median for scenario 3). Over a period of time the median SAR advantage might increase to 30% (see Figure 13) as lower headline height options are explored, but only if catch efficiency(Hh) does not prove problematic to catches.

For the short-term advantage (26%), where the quad rig utilised is assumed to be consistent with that used in the fishery during the 80’s, there are two distinct groups of boats in terms of the magnitude of benefit in the 2005-context. The magnitude of benefit depends on the current configuration of double rig with respect to the body taper used. For 1P4B double rig boats (about 25% of the 2004 fleet) the most common advantage obtained by shifting to quad rig was a SAR increase of 20%. For the rest of the fleet, which used 1P3B double rig, the most common advantage was a higher SAR increase of 30%.

The actual catch advantage however may not completely keep pace with SAR because of the possible negative catch implications of reduced headline height. Based on the significance of headline height on catch as hypothesised in the analysis, the short term increase in catch (SV*R, SAR*) might only be 19 - 21% (see Figure 13) and this might increase slightly over time towards 22%. Given that the latter benefit relies on all vessels having optimal board size, of the current styles, it is not likely to be achieved.

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[1] By towing half of each system on each side of the vessel. The two gear configurations inherently travel at the same speed, have the same shot time and fish at the same location at the same time.

[2] This information would be of value here and also for many other issues.

The sensitivity tests undertaken show that if the quad rig used was 20% smaller than the double rig previously used (scenario 3ii); perhaps the chosen response to a gear unit devaluation imposed for using quad rig, then all catch indicators do not decrease by anywhere near 20% and the conversion would not be effort neutral. The actual catch reduction is predicted to be only 5 – 8.5% (SAR, SV*R, SAR* in Table 9 and Figure 14), but given the complex nature of the economic drivers to business decisions and the current situation where there have already been substantial gear unit reductions in the fishery such that the gear on all vessels might already be considered “the bare minimum”, the relatively low reduction in catch might be sufficient to encourage owners to trade effort units to top up their holdings. This is desirable because it will to a greater extent ensure effort neutrality for the transition to quad rig.

If no trading of gear units occurs the gear reduction required to achieve effort neutrality is very large; about 50% based on SAR (Table 9) and 32% based on SAR* (qualitatively from Figure 15).

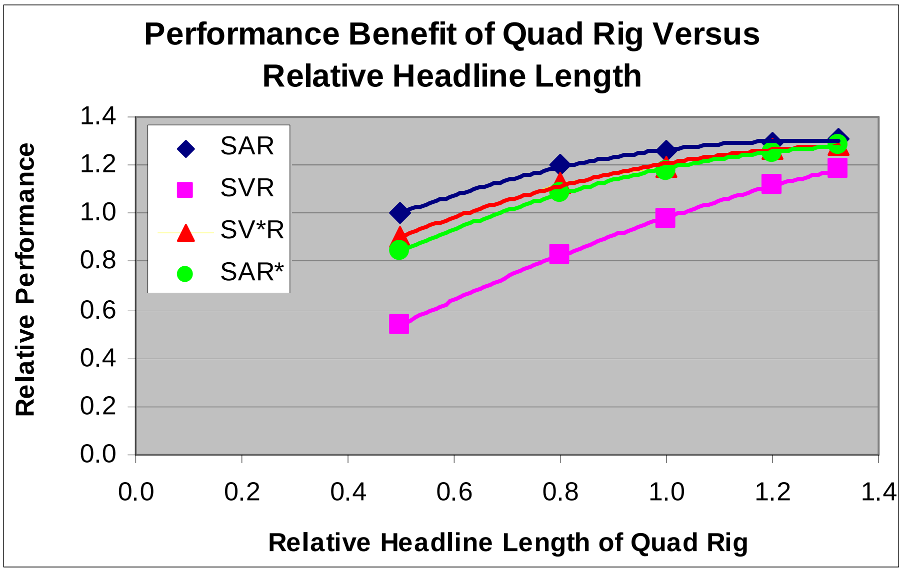

Figure 15

The sensitivity evaluation of quad rig benefit with respect to double rig configuration confirmed that body taper was the major double rig feature that affected the resulting performance benefit from conversion to quad rig. It also found that the SAR* performance seemed to make more practical sense than SAR under fine scale scrutiny.

Quad rig benefit was found to be higher for larger boats that towed bigger double gear. The performance benefit of quad rig increased in absolute terms by about 2.6% for each 6.8m increase in total headline length (based on SAR*).

Quantified evidence was found that supported the claim that further gear reductions, which results in a boat choosing to increase the spread ratio of the gear and/or its trawling speed, will erode the benefits of conversion to quad rig in absolute terms by about 1.1% for each 0.05 increase in spread ratio and 0.5% for each 0.32knot increase in trawl speed (based on SAR*). This reduction in benefit would be over and above the direct reduction in benefit associated with the reduction in headline length according to the estimated relationship described in the previous paragraph.

To clarify the prediction results further in terms of the research question, information from the experience of WA Fisheries with respect to field trial etc. may be enlightening. It would be beneficial to augment these results by conducting well-designed field trials in the NPF to ultimately resolve the effect of the complicating catch efficiency issues identified in this investigation.

2.2 Comparison with knowledge from WA concerning the introduction of quad rig into their double rig fisheries

2.2.1 Introduction

During 1998 to 2000 the trawlers operating in the Exmouth Gulf Prawn Fishery (EGPF) were converted from double rig (DR) to quad rig (QR) in an endeavour to improve harvesting efficiency. As much as fisheries management supported this move, they were also wary of whether this action would result in effort creep and possibly jeopardise the sustainability of the fishery. As a precautionary measure, a variety of fishing controls were agreed upon before the conversion process took place. In essence, the controls placed upper limits on the total headline length and board area in the fishery, without being too prescriptive in terms of rig configuration, overall rig size or the board to trawl size. Upper and lower catch limits were also introduced to maintain catch quality and harvest efficiency respectively. The flexibility in these new gear controls opened a gateway for trawlers to tow higher order multiple net systems, such as quad rig, as well as explore high spread ratios and bigger systems.

Some five years on (2005), the EGPF provides a unique insight into the gear-related adjustments that can take place during and after such a trawl-rig transition, and whether the overall objective of improving harvesting efficiency while maintaining effort neutrality was actually achieved.

The Australian Maritime College (AMC) is well placed to report on this matter as it has assisted with the development of trawl gear in the EGPF and other Australian prawn trawl fisheries over the last 25 years. More recent EGPF examples include advice on the relative swept area rate (SAR) of DR and QR during pre-conversion negotiations, as well as scale-model and full-scale trawl gear tests in 2000 and 2004, respectively; these latter tests were primarily aimed at optimising the SAR of the newly introduced QR systems.

Most of the information presented below came from MG Kailis (MGK) Group[1] and WA Fisheries. Daryl Elmer's[2] preparedness to disclose details on MGK Group's fishing activities, as well as facilitate information transfer with MGK staff through a questionnaire (see Appendix B for sample questions), is gratefully acknowledged. MGK is a company with a vision towards sustainable and responsible fishing practices, and clearly prepared to assist others in this pursuit. The data collected in the interviews/questionnaire should provide insight into the question of reintroducing QR in the NPF.

Following is a historical overview of trawl gear development in the EGPF, with particular emphasis on the 'quad-rig years'. The intention is to outline gear related changes in this fishery and what induced them, and secondly, facilitate comparison with gear developments in the NPF, as certain facets of each fishery clearly differ, and therefore may influence how one interprets information from the WA context.

Mention is also made of how certain components of trawl gear have been deliberately altered during the 'quad-rig years'. Where possible, an attempt is made to relate these gear changes to parameters describing the catching power of a trawler(s) and its fishing-gear[3]. The intention here is to give some insight into what may eventuate in the NPF and prompt consideration of whether existing gear controls in this fishery are suitable should QR be reintroduced.

2.2.2 Trawl gear development in the Exmouth Gulf Prawn Fishery

Pre quad rig (1962 to 1997)

Prawn trawl gear used in the Exmouth Gulf Prawn Fishery (EGPF) underwent a number of changes since the pioneering days of the 60's. In the early days a variety of vessels, not necessarily suited to trawling, worked close inshore with a single-net rig. Within a decade most of these vessels had been replaced with purpose-built trawlers capable of towing much larger double-rig trawl configurations. Single-rig trawl designs such as the Dawn, Stebenhousen and Drynan were replaced with the Flat trawl not long afterwards. By the early eighties concerns of over-fishing and the need to cap fishing effort were responsible for each licensed trawler being limited to towing a pair of 7.5-fathom headline trawls. With these limitations in place operators explored other ways of increasing the span and/or speed at which this gear could be towed through the water. Low-drag netting, large-mesh netting, new otter board designs and other alterations were all tried with varying degrees of success. As

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[1] Currently the holder of 15 of the 16 trawler licenses operating in the fishery, 12 of which are still operating.

[2] General manager for MGK operations in the EGPMF

[3] Swept area performance, catching efficiency and skipper's skill.

historical records up to around 1990 show, this pattern of trawl-gear development in the EGPF was very similar to that which occurred in the Northern Prawn Fishery (NPF); apart from two major differences.

Firstly, NPF operators were allowed to use triple and quad rig for a period before it was banned in 1987 due to concerns of over-fishing. Operators in the EGPF eventually had an opportunity to use QR in 1998-2000, but in contrast to the NPF, this coincided with when the number of licensed trawlers, as well as the total HL and board area in the fishery, had been considerably diminished.

Secondly, apart from some interest in banana prawns during the pioneering days, the EGPF is more reliant on the harvest of tiger, king and endeavour prawn with low-opening trawl-systems. Clearly this simplifies matters when it comes to managing the transition to a new trawl rig configuration in the fishery. In contrast, it is conceivable that the NPF may need more complicated gear controls to regulate low-opening QR systems for tiger-prawn and the high-opening systems for banana-prawn.

Introduction of quad rig (1998)

The transition to quad rig from double rig began in 1998 in a conservative way. Initially, a single MGK trawler was allowed[1] to tow a 4 x 5 fathom QR system. Two DR trawlers were also permitted in the same year to tow larger trawls (9 fathom) for comparative purposes. To create the extra HL needed for these modified trawl systems (11 fathom in total) under the 240 fathom HL cap for the fishery, it was necessary for a trawler to remain at the wharf. This brought the total number of ‘operating’ trawlers down to 15 (14 x MGK trawlers + 1 x independent trawler). The total board area in the fishery also fell from 1368 in 1997 to 1291 sq. ft. in 1998, reflecting in part the need for less board area in a QR system to spread a given total HL length to a certain spread ratio (or span).

In 1999, another four MGK trawlers started towing QR, bringing the total to five. All of these QR trawlers opted to tow 4 x 4.5 fathom systems. The remaining nine MGK trawlers towed the standard DR arrangement (2 x 7.5 fathom HL). This QR and DR combination maintained the total HL in the MGK fleet at 225 fathom. Total board area fell again; bringing the total down from 1368 sq. ft. in 1997 (DR 7.5 fathom trawls) to 1180.8 sq. ft.

Complete transition to quad rig (2000) and the board area implications

In 2000, the transition to quad rig was complete; the MGK fleet was comprised of twelve trawlers, all towing QR trawl systems (4 x 4.5 fathom trawls spread by 6’ x 3’ flat,

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[1] Granted an exemption from the existing gear-restrictions.

rectangular, wooden otter-boards). Another two MGK trawlers were left at the wharf to enable these larger (>15 fathom) total HL systems to be towed. Total board area reduced further to 864 sq. ft., down by 504 sq. ft. from the 1997 DR fleet figure. Despite this reduction in available board area, 219 fathom of headline was still fished, reinforcing that with QR it is possible to achieve the same overall trawl gear span with considerably less board area, simply because the nets are smaller. An examination of the figures on board area per fathom of trawl headline (sq ft. / fathom HL) for the DR and QR fleets in 1997 and 2000 respectively, puts this reduction at about 1/3 (eg. 6.08 down to 3.95 sq.ft./fathom of HL)

Trials with larger otter boards (2001)

In 2001, the fleet of twelve MGK QR trawlers were given the option to use larger boards (7’ x 3’ instead of 6’ x 3’), which brought the total board area up to 1008 sq. ft. This interest in larger boards followed gear trials in the AMC flume tank in March (just prior to the fishing season opening), where a similar board-size adjustment caused a 4% gain in spread-ratio (or horizontal trawl-opening). Other subtle gear adjustments were also made in the flume tank, with most yielding between 0 and 4% gain in trawl spread ratio. To accommodate these higher spread ratios, adjustments were made to the frameline tapers used in the flat trawl.

Fine–tuning and further refinements (2002 & 2003)

In 2002 and 2003, the records indicate that the number of trawlers, total utilised headline length, and total board area, all remained constant in the EGPF. However, within the fleet further fine-tuning and refinement was taking place.

Planks made from plastic were used to replace the wooden planks in the flat rectangular otter boards, with varying levels of success. The main objective here was to extend the longevity of the boards and apply recycling technology.

Number 5 Bison boards made a brief appearance, but due to rigging difficulties did not see prolonged service. This failure seemed to stem from using an over-sized board and may in time be rectified.

Several trawls were made from Dynex netting of thinner diameter than the standard PE netting, promising a reduction in trawl drag, and the added possibility of even higher lateral spreads (with the same sized boards) and trawl speeds (with the same amount of applied thrust). The true cost-benefit of using this material remains unquantified however.

Larger quad rig systems and larger trawlers (2004)

In 2004 the MGK Group explored the bigger trawl gear option on two fronts. An existing trawler in the fishery, FV Point Cloates, with her 450hp compared to the other 350hp K-trawlers, was equipped with larger 4 x 6 fathom trawls spread by 7.5’ x 3’ boards. A second trawler, FV Sea Fury, with even more horsepower (500hp), was purchased and brought into the fishery with 4 x 7 fathom trawls spread by 8’ x 3.5’ boards. Once again, to accommodate these HL increments (6 fathom + 10 fathom) and the new trawler, it was necessary for one more K-trawlers to remain at the wharf. As a consequence of these changes, the total utilised HL length and the available board area, both fell slightly to 217 fathom and 980 sq. ft. respectively.

More trawl and otter board changes (2005)

In 2005, the eleven MGK trawlers towed three different sized trawls (4.5, 5 and 6 fathom) in QR configuration. The independent trawler opted to downsize its trawls from 4.5 to 3.75 fathom. The 7 fathom nets towed by FV Sea Fury were downsized to sixes; possibly because spread measurements with Scanmar sensors in August 2004 put the inside board clearance at about 1m. Within the fleet there were also trawlers towing similar sized QR systems with different sized boards. For example, the two 6 fathom trawl systems were spread by 8’ x 3’ and 8’ x 3.5’. The independent trawler was also towing the smaller 3.75 fathom nets with the same sized boards (6’ x 3’) as those used on the 4.5 fathom nets.

Given the variety of quad rig configuration there was likely to be a fair degree of variation in trawl spread-ratio amongst the trawlers. This is worth noting because conceivably the spread ratio of a trawl may not only have some bearing on the SAR of the entire system, but may also influence its catching efficiency.

After analysing the prawn catch per fathom of HL for these different QR configurations, it is the opinion of MGK management that there is no discernable harvesting efficiency benefit attached to any one arrangement. One example related to data collected over thirty nights of fishing. Catch-rates for particular boats and nights varied by 15% either side of the mean. It was considered by MGK that skipper-skill may account for 5% of this variation, and the remainder can be attributed largely to skippers focussing effort on different prawn species that have different levels of local abundance. In order to determine variations in harvesting efficiency, it will be necessary to standardise the catch rates in terms of target prawns (size and species), location and time. Unfortunately, at this point in time the data required to standardise the catch rates was not available and this work does not appear to have been done previously.

Beyond 2005 – hard choices

It is evident from the changes made in the years following the appearance of the first QR system in 1998, that MGK Group has been quick to explore all the trawl and trawler options available to them in an endeavour to improve their harvesting efficiency. Skipper skill is always a confounding factor in terms of the effect of their variable ability to remain trawling on grounds with the highest local abundance of prawn. In the case of the EGPF, the sharing of information between trawlers on a daily basis would tend to bring the fleet together, in terms of catches, in a way that may not occur in the NPF. Conceivably therefore, most of the prospects for increased improvement must lie with modifications that yield gains in SAR, of which there are many: use of larger boards to give higher spread-ratios, net-design modifications, more efficient otter board designs, low-drag netting, optimum trawl speeds, and optimum-sized trawls for a given otter board/vessel combination. The MGK Group have experimented with most of these variables in the last seven years, and are now in a position to make informed choices, which includes factoring in the associated implementation and running cost. Whether operators in the NPF would arrive at a similar point as quickly is debatable.

From the fisheries department perspective

Comparison of catches between DR and QR trawlers during the years either side of QR being introduced revealed that rig type did not have any great bearing on the catch per unit of headline length once differences in trawl speed were corrected for (1.7%). There was however a potential gain in SAR of between 16 and 22% based on observed increases in trawl speed, which when combined with the 1.7% increase in adjusted catch per QR tow, was responsible for the 1.25 conversion factor used later (Sporer, pers. coms.) to adjust vessel numbers. This saw 5 x DR trawlers being equated to 4 x QR trawlers of equivalent total HL length. Some representatives from the catching sector feel this conversion ratio erred on the steep side, and 1.2 may have been more appropriate (ie. 6 DR trawlers = 5 QR trawlers).

Concluding remarks

According to MGK management, the introduction of QR had the desired outcome of improving the harvesting efficiency (cost of landing a kg of prawn) of the fleet without any noticeable increase in fishing effort.

Interestingly, the catch per unit of HL length seems to be relatively constant between MGK trawlers towing different sized QR rigs (20% range) at different speeds (20% range) with a fixed amount of thrust. This result suggested there was not much difference in catching efficiency between these rigs whilst trawl speed ranged between 3 to 4 knots and spread ratio hovered around 80%. In other words, SAR was the main factor governing catch level for a given trawler.

To optimise the swept area performance of QR systems, it is evident that operators require a certain amount of freedom to explore the alternatives available to them.

Operators in the EGPF, in an endeavour to improve the SAR of their QR systems, have explored many options. They now believe they are approaching a position, some seven years later, to formulate a mix that yields the most cost efficient harvesting outcome for the available technology and knowledge.

2.2.3 How the WA experience informs the issues facing the NPF

It appears that the overriding imperative during the introduction of quad rig into Exmouth Gulf has simply been to maintain a cap on the total headline used in the fishery. Apart from that, the most characterising feature of the quad rig transition in Exmouth Gulf has been that trawlers changing over to quad rig have been able/allowed to tow at least 20% more headline than previously.

Taken at face value there does not appear to be an equivalent gear unit penalty operating in WA to compensate for the utilisation of the more efficient quad rig system. But a close inspection of the transition process reveals that in fact effective effort neutralising arrangements have occurred for Exmouth Gulf.

For the EGPF, effort neutrality was achieved through ensuring that boats equating to 25% of the new quad rig fleet are no longer fishing. This balances the proposition that the each quad rig boat is 25% more effective than before the transition to quad rig. However, since the same total headrope is still working in the fishery there are risks that effort can escalate if:

1) headline length is allowed to be transferred back to the unutilised boats

2) larger vessels are introduced into the fishery that can extend the swept area performance of the large quad rig systems.

Due to the tight agreement between industry and management on the arrangements for the introduction of quad rig into the EGPF, the first risk is probably not possible but the latter scenario may constitute a real risk if scrutiny of boat replacements/upgrades is not tight.

For the NPF both scenarios constitute a management risk in terms of an effort increase because the effort control mechanism is based on a single factor, ie. Gear units. For the NPF and the gear unit’s regime, there is no control over the gear unit market (transfers) or the replacement and upgrading of vessels. For this reason it is important to ensure effort-neutrality with the introduction of quad rig by NPF operators.

Effort-neutrality represents the ideal situation where the catch taken by the fleet containing quad rig boats is no different from the catch that would have been taken if the fleet all towed double rig. Unfortunately, the amount of catch taken by the fleet containing quad rig boats will depend on how operators react to the SFR revaluation formula applied to boats that have changed to quad rig. Therefore the appropriate SFR revaluation formula (that insures effort-neutrality) depends on the assumed response of operators. One can describe two possible responses that define the space occupied by all possible responses. The bounding examples can be called the "constant gear utilisation" response and the "constant engine power" response. These can be viewed as extreme examples that define the limits of all possible examples. However, it must be noted that they do not represent "rare" response examples, and may in fact be reasonably viewed simply as two clear options in a lot of cases.

For the "constant gear utilisation" response, the appropriate SFR revaluation formula is a balancing correction that reflects the increased efficiency of quad rig over double. Effort neutrality is achieved through a process where the gear unit trading generates unutilised boats. If this does not occur to an extent that is commensurate with the quad/gear units revaluation then there is an effort increase from day 1 (effort neutrality does not occur). This situation would be equivalent to circumstances in WA where some of the unutilised vessels re-entered the fishery using gear taken from the effort neutral fleet.

At the other extreme, no gear unit trading occurs and the area swept per fathom of headline in increased to the maximum extent possible through a combination of the inherent efficiency of quad rig and maintaining the same level of engine power (the "constant engine power" response). To achieve effort-neutrality the gear can be reduced in sized, through SFR revaluation, to a point where the accumulated inefficiencies of operating non-optimally cancel out the inherent efficiency of quad rig. The result is effort neutral, but it also represents a situation where there is no improvement in operating efficiency associated with the transition to quad rig.

CHAPTER 3 - AN ASSESSMENT OF THE POTENTIAL EFFECTS OF QUAD-RIG PRAWN TRAWL SYSTEMS ON TED AND BRD PERFORMANCE AND SPECIFICATION

3.1 Introduction

The catching performance of a low-opening prawn trawl is considered to be proportional to the amount of seabed swept by the trawl per unit of time, or swept area rate (SAR)[1] (Dichmont et al, 2003). This assumes that most prawns are caught on or near the seabed, and that a gain in the amount of seabed swept by the trawl will equate to a gain in prawn catch.

The SAR is a product of swept width[2] and the distance trawled per unit of time. SAR is therefore a function of trawl headline length, the ratio of wingend spread to headline length (spread ratio), and towing speed. To increase SAR, a fisher can use nets with a longer headline length, use larger otter boards to increase spread ratio, or tow the net faster. In all instances, this can only be achieved if a boat has sufficient reserve thrust to accommodate the increased drag forces that are produced by using larger trawl gear or towing at higher speed. Another alternative is to use a trawl configuration that is more efficient, such as adopting quad-rig over double-rig.

In the Northern Prawn Fishery (NPF), consideration is being given to the re-introduction of the quad-rig prawn-trawl system. This will purportedly improve the economic efficiency of the fishing operation through a relative reduction in the costs of fishing for a given catch (Sterling, 2005). The adoption of quad-rig over double-rig will provide fishers the opportunity to increase SAR and catching performance without increasing the drag forces acting on the boat. They will be able to achieve these gains because quad-rig uses smaller nets and otter boards connected in a way that produces an equivalent swept width to that for double-rig. Fishers then have surplus boat thrust available to utilise in one of two ways; first, they can increase towing speed beyond that used for double-rig, or second, they can select a net and otter board combination (size) that produces similar drag to double-rig, with the advantage that the quad-rig configuration will have a greater total swept width. The introduction of quad-rig into the NPF therefore allows fishers to select one of several options to increase SAR and catching performance:

- Use nets with the *same* total headline length as double-rig, with otter boards that give the *same* spread ratio, but at a *higher* towing speed;

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[1] Swept area rate is sometimes referred to as swept area performance

[2] Swept width is equivalent to the lateral distance between the wingends of a trawl, and is sometimes referred to as wingend spread

- Use nets with the *same* total headline length as double-rig, with otter boards that give a *higher* spread ratio, but at the *same* towing speed as that for double-rig;
- Use nets with a *greater* total headline length than double-rig[1], with otter boards that give the *same* spread ratio, but at the *same* towing speed as that for double-rig; or,
- Use any combination of the above such that the available boat thrust is utilized as before.

Given that the re-introduction of quad-rig generally allows fishers to use smaller nets, increase towing speed and have higher spread ratio, consideration of the implications for TED and BRD performance and specification is required. The objective of this paper is therefore to briefly consider how the efficient performance of these devices may be affected in a quad-rig prawn-trawl system, noting that if the fishery were to introduce quad gear the intent would be to ensure that any conversion was effort neutral. The efficacy of current TED and BRD specifications, given that fishers adopt quad-rig, is also considered.

3.2 Turtle excluder devices (TEDs)

3.2.1 TED efficiency

The efficient performance of a TED is a measure of its ability to quickly exclude large animals and retain the prawn catch. The parameters that influence the efficiency of TEDs currently used in the NPF are shown in Figure 17. Note that increased towing speed or spread ratio are not listed as parameters that influence TED performance.

Towing speed is not listed because there is no evidence that it affects the ability of a TED to perform effectively given the range of tow speeds currently used in the fishery. However, there is potential for some large animals, such as stingrays, to become impinged against the bars of a grid at extremely high speeds and struggle to escape. This will increase the risk of prawn loss because the escape cover of the TED will be pushed aside by the animal for a longer period as it struggles to escape from the net. The effect of towing speed beyond the range currently used in the fishery has not been assessed, although a sudden increase is perhaps unlikely given that seabed contact and catching performance may decline at very high speed.

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[1] Clearly, this requires additional headline units.

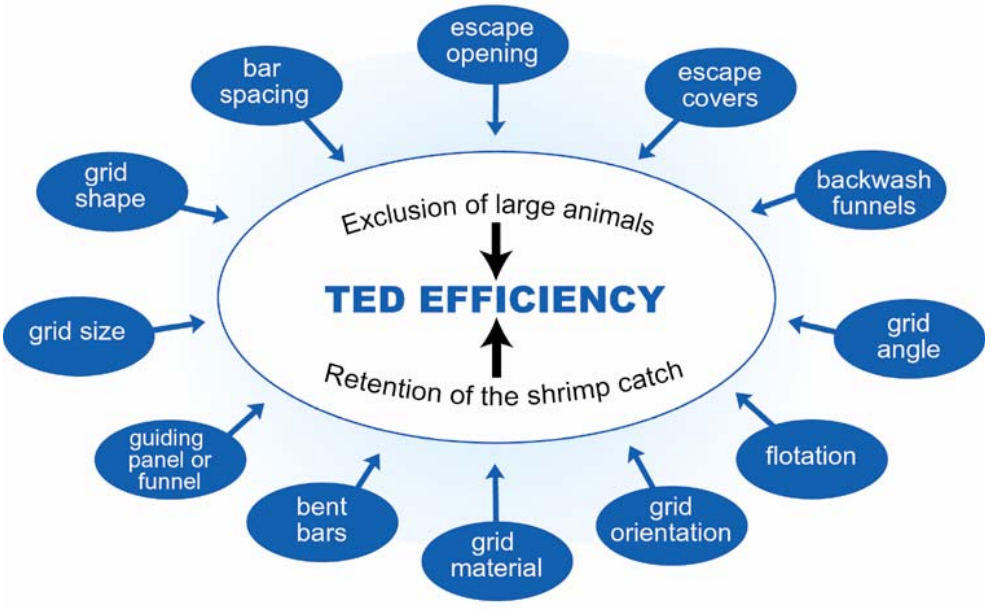

Figure 17. The various design and construction parameters that influence efficient TED performance. Note that a failure to rapidly exclude large animals is likely to cause prawn loss. Source: Eayrs, 2005.

In the NPF, the spread ratio of large, double-rigged nets ranges between 55 - 70% of headline length (Eayrs, pers obs.), and there is little evidence of a link between these ratios and TED performance. However, the spread ratio of smaller, quad-rigged nets is typically higher and may exceed 80% of headline length. At these spreads, the top panel of the net is pulled further forward relative to the bottom panel, and this may increase the grid angle of an upward-excluding TED. In turn the rapid escape of turtles or other large animals may be hampered because the grid less efficiently guides the animal toward the escape opening of the TED. Some animals may even become impinged against the bars of the grid for a period. This problem is thought to occur with nets that have a large lead-ahead, and may be alleviated in practice by “letting the headline go” or using nets with less lead-ahead. It may even be necessary to consider reducing the maximum grid angle for these TEDs. The ability of a bottom-excluding TED to allow turtle escape should not be affected by high spread ratio, although a substantial reduction in grid angle may increase the risk of prawn loss.

Grid shape

Grids are typically rectangular, oval or tombstone shaped. There is presently no information documenting which shape is more efficient in terms of large-animal exclusion and prawn retention. Grid shape is usually based on personal preference, and is independent of net size.

Grid size

In recent years, many NPF fishers have voluntarily gravitated toward the use of TEDs with larger grids. These grids have a larger filtering area and escape opening, hence they generally exclude large animals at a faster rate than smaller TEDs and reduce the risk of prawn loss.

If fishers adopt quad-rig and use smaller nets, the circumference of the codend (number of meshes around the codend x mesh size) may need to be reduced. A smaller grid may now be required to fit into the smaller codend, although this should not directly influence the ability of a TED to exclude large animals provided the escape opening remains sufficiently large and meets the TED specifications for the fishery. However, the use of a smaller grid means reduced grid-filtering area, and a higher risk of prawn loss because they will pass through the smaller codend and grid in closer proximity to the escape opening.

It should be noted that AFMA will legislate minimum TED sizes (these are anticipated to be at least 81cm by 81cm) which will ensure that small TEDs cannot be used. TED angle is also being legislated to ensure that the fishery keeps its US TED accreditation (in the range of 30-60 degrees from the horizontal).

Grid material

Grids are currently constructed from aluminium or stainless steel. Grid material is independent of net size.

Grid orientation

Grids are usually orientated to exclude animals through an escape opening in the top of the codend (upward-excluding TED) or the bottom of the codend (bottom-excluding TED). There is little evidence of either orientation being superior, although bottom-excluding TEDs are generally more effective at excluding heavy objects such as rocks and sponges from the net. The choice of orientation is usually one of personal preference, but is linked to the expected conditions of the fishing ground. There is no evidence of a link between grid orientation and net size.

Grid angle

Grid angle is measured between the bars of the grid and the horizontal plane. Typically it ranges between 45 – 60^o for a well-maintained TED, irrespective of grid orientation. There is no evidence of a direct link between grid angle and net size. However, as some fishers begin using smaller nets they may be tempted to save costs by installing their existing large grids into the smaller codends. This may not be a problem provided grid angle is maintained within the aforementioned range. The grid will distort (enlarge) codend circumference and help ensure the escape cover sits tightly over the escape opening in contact with the grid. However, if fishers reduce grid angle to fit a large grid into a small codend, they may suffer prawn loss because the escape cover will be less able to effectively contact the grid and seal the escape opening.

If fishers adopt quad-rig and use smaller nets, the nets will be operated at higher spread ratio. The effect of spread ratio on grid angle is described in section 3.1 TED efficiency. If the performance of an upward-excluding TED is compromised by high spread ratio, fishers will be encouraged to reduce grid angle to accelerate the exclusion of large animals and avoid prawn loss. There is no evidence that reduced grid angle compromises the escape of turtles and other large or heavy animals; in fact the escape of poor swimming or heavy animals may actually be improved using a downward-excluding TED and low grid angle.

Bent bars

Bent bars are sometimes incorporated into the design of a grid to overcome the problem of grid blockage. This occurs on flat-bar grids because sponges and other non-swimming animals may become lodged against the grid where the bars are attached to the grid’s outer frame. This impedes the exclusion of these animals, during which time they may push aside the escape cover allowing prawns to escape. Bent-bar grids overcome this problem because the animal has passed through the escape opening before contact with the outer frame of the grid is possible. Moreover, a well-designed TED will ensure the escape cover sits tightly over the escape opening in contact with the bent-bars so that the risk of prawn loss is low. There is no evidence of a link between net size and bent bars.

Flotation

Flotation is used to counter the negative buoyancy of the metal grid and ensure it remains correctly orientated during trawl deployment. As larger nets allow the use of larger (= heavier) grids, additional buoyancy is usually required to counter the weight of larger grids.

Guiding panel or funnel

These are located immediately ahead of the grid to guide the catch away from the escape opening of a TED. In this way prawns pass through the grid at a distance from the escape opening and the risk of prawn loss is low. The use of this modification is optional, and many NPF fishers currently do not use them. However, if net size is reduced, the codend may also (but not always) be reduced in size, including the overall dimensions of a guiding panel or funnel. The rapid passage of turtles though the TED is now at risk because the exit opening of the panel or funnel is smaller and the potential for blockage by large animals or fouling by animals with sharp teeth, spines etc. is high. Very small codends ie. less than 120 meshes in circumference, are perhaps at greatest risk, although this has not been assessed in detail. Overcoming this problem may require specifying minimum exit opening dimensions and/or a minimum codend circumference, although as poor panel or funnel performance usually causes prawn loss, there is strong inducement for fishers to modify their panel or funnel to maintain TED performance.

Legislating minimum escape openings should alleviate this problem. This is being implemented in 2006.

Bar spacing

In the NPF bar spacing can be no more than 120 mm. This ensures that only small animals pass through the bars of a grid while larger animals are guided toward the escape opening. There is no link between bar spacing and net size.

Escape opening

The size and dimension of an escape opening is important to ensure efficient TED performance. The size of the opening is linked to grid size, and larger openings generally allow more rapid exclusion of large animals. In turn this reduces the risk of prawn loss.

A reduction in net size may lead to reduced grid size and escape opening, particularly if small-circumference codends are used. Those fishers that voluntarily increased grid size (beyond that required in the NPF specifications) in recent years to optimise TED performance may now have to use smaller-than-desired grids. While the minimum size of the escape opening is currently specified, the escape opening of these devices will be smaller and the exclusion rate of turtles and other large animals may be less than that for the larger devices. However, as this is also likely to lead to prawn loss, a reduction in TED efficiency should also act as an inducement for fishers to quickly optimise the performance of smaller grids.

Escape covers

These are used as a barrier over the escape opening to prevent prawn loss. A well-designed escape cover will sit tightly over the escape opening, be readily pushed aside by large animals and objects as they are excluded from the trawl, and then quickly resume position over the escape opening. The design and use of escape covers is largely independent of net- and codend size, although ensuring the cover seals tightly over an escape opening in a very small net may require modification. This is because the escape opening may need to extend around the sides of the codend to allow large animals to escape, and the leading edge of the cover may need to extend around the sides of the codend to perform effectively. Again minimum escape openings should mitigate these possible impacts.

Backwash funnels

These are funnels of net attached anteriorly to the grid or BRD. They guide small animals that have passed through the grid into the codend and prevent them from swimming forward or being flushed toward the escape opening during haul-back. The design and use of backwash funnels is largely independent of net size.

3.2.2 TED specification

Given a need in the NPF to avoid turtle capture and lift the US embargo on prawn imports from countries or fisheries using non-approved TEDs, it is useful to consider the potential interplay between the use of quad-rig and the existing TED specifications for the fishery.

The current requirement in the NPF is for TEDs to exclude turtles immediately upon capture in a trawl, and the following specifications are designed to ensure that immediate exclusion of these animals occurs:

- Bar spacing no more than 120 mm;
- Attachment of the grid frame to the entire circumference of the codend;
- Rigid or semi-rigid grid of inclined bars;
- Grid angle between 30 – 60 degrees;
- One or more escape openings with a simultaneous measurement of at least 760 mm across and 380 mm in length;
- Use of either a double- or single- escape cover; and,
- No weights, floats or other items attached to the escape cover.

Given the adoption of quad-rig and use of smaller nets, there is little reason why fishers cannot adhere to all of these specifications providing they do not use very small codends. The material used to construct the grid, the grid’s design, bar spacing, mode of attachment to the codend and the width of the escape opening, are all largely unaffected by a quad-rig prawn-trawl system. However, use of small codends less than 120 meshes in circumference may pose a risk to turtles and other large animals if the exit opening of a guiding panel or funnel is too small. It is also possible that the escape cover will not seal tightly over the escape opening in a small codend and the risk of prawn loss will be high. This is because the width of the escape opening is usually linked to the width of the grid, and a small grid will be used in a small codend. To ensure the escape opening remains compliant with TED specifications and allows large animals to escape, the opening may need to extend around the sides of the codend, and the trailing escape cover may now be unable to effectively seal over the escape opening, even if the so-called double-cover is used. Attaching the sides of the escape cover around the sides of the codend so that it trails over the escape opening may overcome the problem of prawn loss, but it usually impedes the rapid escape of turtles and other large animals. The escape cover is now less able to act as a trapdoor and spring back into place as large animals escape, and the meshes of the cover will become quickly stretched as it is pushed aside by the escaping animals. An escape cover that is stretched will not seal tightly and substantially increases the risk of prawn loss, and consequentially fishers will be required to replace these on a more-regular basis. The potential impediment of turtles and other large animals through a smaller guiding panel or funnel may need to be monitored, and perhaps specified in the future if turtle mortality occurs, although increased risk of prawn loss may discourage fishers from substantially reducing their size.

The specification of grid angle goes some way to ensuring efficient TED performance and protection of turtles. However, the relationship between grid angle and spread ratio has not been assessed, so it is not possible to determine the magnitude of any change in grid angle given fishers adopt quad-rig. There are only two ways to accurately assess this relationship, either using an acoustic grid angle sensor or model tests in a flume tank. Upon completion of these tests it may even be possible to determine a relationship between the grid angle measured onboard (dry) and the operational (wet) grid angle. Only then can the utility of the current grid angle specifications be determined.

Given there is increased risk to the rapid escape of turtles from smaller, quad-rigged nets, it is essential that as fishers adopt quad-rig any change in codend circumference is monitored. Smaller nets usually require that smaller codends are used, but there are operational limitations that will limit a reduction in codend circumference. For example, small codends may limit tow duration because they quickly fill with catch. This means less time fishing and increased time hauling the nets, emptying the codends and deploying the nets – all of which is unproductive time in a catching sense. Small codends also limit the positioning of a TED or BRD and their distance from the accumulated catch; the distance between the catch and the escape opening of the device is likely to be less and consequentially the risk of prawn loss is higher. These and other operational limitations may prevent fishers from gravitating toward very small codends, and it is therefore possible that the aforementioned risks will not eventuate. However, by monitoring codend circumference, warning of the potential risks is available. Another option is to use net size as a proxy for codend size, given there is a link between net size (headline length) and codend circumference.

3.3 Bycatch reduction devices (BRDs)

3.3.1 BRD efficiency

The parameters that affect the efficiency of a BRD are shown in Figure 18. Note that BRD efficiency is a measure of the BRD's ability to rapidly exclude fish and other small bycatch and retain the prawn catch.

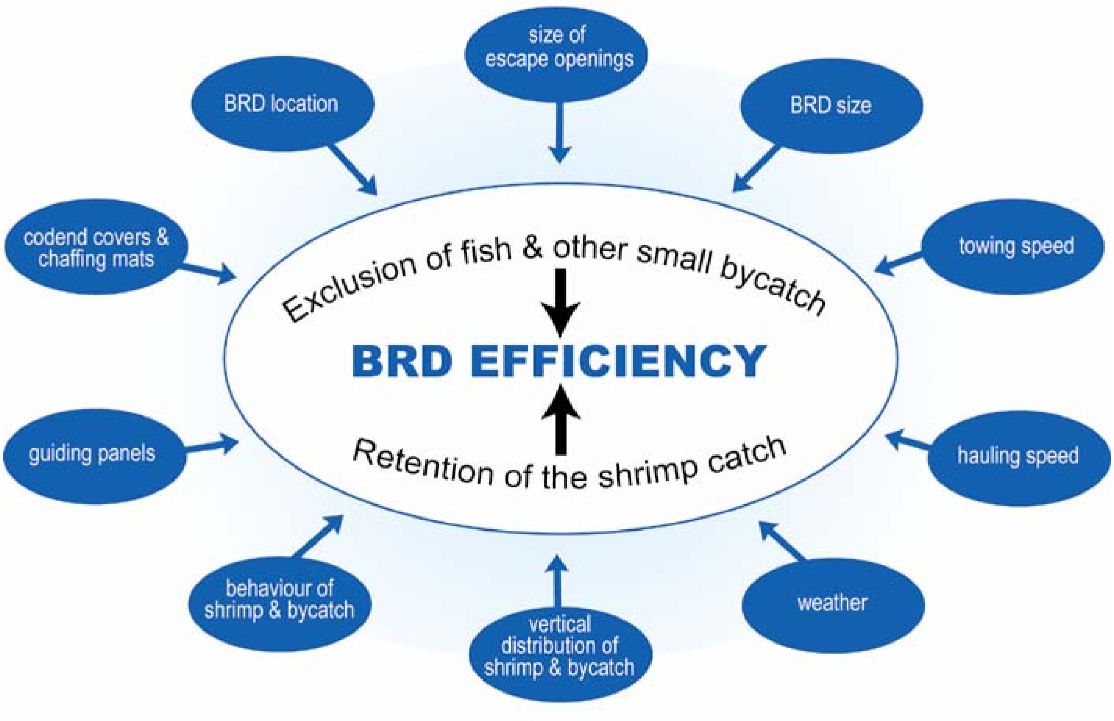

Figure 18. The various design and construction parameters that influence efficient BRD performance. Source: Eayrs, 2005.

In the NPF, five BRD designs are currently approved to reduce bycatch; the square-mesh codend, square-mesh window, fisheye (including yarrow fisheye), radial escape section and modified TED. To assess the potential effect of quad-rig on these devices, each parameter that influences BRD efficiency is assessed both in terms of net size and increased towing speed. The spread ratio of trawls currently used in the NPF does not directly influence BRD performance because all BRD designs are located in the codend, where codend geometry and performance is largely unaffected by changes in spread ratio (although at high spread ratios, such as those expected with quad-rig, changes to catch rate and catch composition may alter BRD performance, but how and by how much is unknown).

BRD size

The size of a BRD is important because it influences the size and number of escape openings in the codend and the size and number of bycatch animals that can escape from the codend. For example, the mesh openings of a square-mesh codend must be small enough to prevent prawns from escaping but large enough for small bycatch to escape. On the other hand, the large escape openings of a fisheye or RES will allow relatively larger fish and other bycatch to escape from the net.

The size of the fisheye and square-mesh window currently approved for use in the NPF is independent of net size and towing speed. However, as the overall dimensions of a codend are linked to net size, a square-mesh codend, RES or modified TED may be reduced in size if a smaller net is used. This means there will be smaller or fewer escape openings available for bycatch to escape, although it is perhaps impossible to quantify any change unless extremely small codends and BRDs are used, and perhaps consideration will then be required to establish minimum overall dimensions for these devices.

Towing speed

All BRDs approved for use in the NPF exclude bycatch to a greater or lesser extent by exploiting a difference in swimming performance (speed and endurance) between bycatch and prawns. Even the modified TED requires fish to swim directionally toward the escape opening while prawns are filtered through the grid and passively enter the codend.

Most fish species have superior swimming performance than prawns. While higher towing speed can mean larger catches of prawns through gains in SAR, the effect on fish bycatch is generally negative because relatively fewer fish can now reach the escape openings of a device and escape. Moreover, the average size of fish-bycatch will decrease as fewer small fish escape from the trawl. Despite this risk, towing speed in the NPF is commonly between 2.8 – 3.4 kts (Bishop and Sterling, 1999, Dichmont et al., 2003), and at these speeds a relatively small increase in speed may have little noticeable impact on bycatch.

Hauling speed

In most instances hauling speed should be as high as possible because slow hauling allows prawns to swim forward and escape through the escape openings of a BRD, particularly if a wash-back funnel is not used. On the other hand, there is some evidence that slow hauling allows a high proportion of bycatch to escape as they find it easier to reach the escape opening, although fishers will obviously prefer the former option. Hauling speed is largely independent of net size and towing speed, being governed more directly by winch capacity.

Weather

In poor weather the accumulated catch in the codend may surge forward and escape through the escape openings of a BRD. This may improve bycatch reduction but it can also increase prawn loss. The influence of weather on TEDs and BRDs fitted to small nets may be different to that on large nets, but by how much is largely unknown. Any difference is likely to be linked to differences in codend size, catch volume, and catching efficiency as the boat responds to poor weather conditions.

Vertical distribution of prawns and bycatch

In the NPF, most prawn species are caught using low-opening nets because they are distributed on or near the seabed. Using a multi-level beam trawl, Eayrs (2000) found that over 96% of tiger prawns (*Penaeus semisulcatus* and *P. esculentus*) and endeavour prawns (*Metapenaeus ensis*) were caught within 600 mm of the seabed. As a result of this behaviour, the height of nets used in the fishery are generally between 1 to 1.5 m, and are equal to otter board height because the headline is attached to the top of the otter board. If fishers choose to adopt quad-rig they either have the option of spreading smaller nets with their existing otter boards or by using smaller otter boards. If they use their existing otter boards, headline height may be reduced because the headline can be attached to the otter board at a lower height (the exact height will be largely influenced by the mesh-depth of the wingend). In this way fishers may increase SAR because reduced headline height should equate to increased spread ratio and reduced net drag. If fishers choose to use smaller otter boards, headline height will again be reduced because the headline will be attached to the top of the smaller otter board. SAR will also be increased.

In contrast to prawns, many fish-bycatch species are more uniformly distributed within the water column. Eayrs (2000) reported that almost 90% of bycatch entered a trawl less than 600 mm above the seabed but that almost 60% of this bycatch responded upwards to avoid the trawl. This means that a reduction in headline height has the potential to allow many species to escape over the headline and substantially reduce the amount of fish bycatch caught compared to current levels in the fishery.

Behaviour of prawns and bycatch

By exploiting the behaviour of prawns and bycatch in the trawl it may be possible to exclude bycatch and retain the prawn catch. This can potentially be achieved either by exploiting differences in their vertical distribution as they pass through the trawl or by differences in swimming performance between these animal groups.

There is no evidence that net size influences the behaviour of prawns and bycatch as they pass into and through the trawl, although it is unlikely that this is truly the case. As net (and otter board) size influences spread ratio, the behaviour of prawns and benthic animals to ground chain contact may differ between large and small nets. Spread ratio also affects the amount of effective[1] lead-ahead in the net, and hence the ability (or otherwise) of prawns and other animals to react vertically and escape over the headline. The link between lead-ahead and catch rates has not been assessed in detail.

In the NPF, assessment of underwater video footage indicates there is little vertical separation of the catch in the codend, with prawns and fish passing into and through the codend at all heights. Therefore, exploiting the vertical separation of these animals may not be possible. Many fish-bycatch species have superior swimming performance to prawns; they have higher swimming speeds and directional swimming capability. Several BRDs approved for the NPF, including the fisheye and RES, exploit these differences in order to exclude fish and retain the prawn catch. The success of these devices relies largely on the ability of fish to enter the codend, turn immediately ahead of the accumulated catch, then swim forward and through the escape openings of the device. However, if small nets are used, the accumulated catch is likely to be smaller than that for large nets. If fishers then locate a BRD the same number of meshes from the codend drawstrings as they do with larger nets, the relative distance the fish must swim to escape is increased, and fewer fish will escape. Moreover, the average size (length) of this bycatch can be expected to decrease as fewer small fish are able to escape from the trawl. A similar result can also be expected at higher towing speed.

Guiding panels

These are panels of netting located ahead of a BRD to guide prawns away from the escape openings of the device. They are typically used in front of a fisheye or square-mesh window. The leading edge of these panels is attached to the top of the codend several meshes ahead of the BRD. The sides of the panel are generally sewn to the sides of the codend at an angle, for example, along a row of bars. Care is required that they are attached well forward of the BRD to ensure they do not cover the escape openings and impede the escape of bycatch. There is no evidence that the performance of these panels is affected by net size. However, there is some anecdotal evidence that towing speed may influence the performance of these panels. Underwater video footage has shown that many fish are ‘attracted’ to regions of water turbulence, and are often observed motionless whilst maintaining station with the camera or net. This is possible because forward movement of the turbulent water carries the fish forward at a speed similar to towing speed. A guiding panel will generate water turbulence as the net is towed along, and as this turbulence is influenced by towing speed, so too will be the

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[1] Effective lead-ahead is the or sum of nominal lead-ahead (the horizontal distance the headline extends ahead of the foot line) and inherent lead-ahead (the lead-ahead that exists in the absence of nominal lead-ahead, and a function of towing speed and headline height); see Eayrs, 2000 for details.

behaviour of fish behind the guiding panel. If greater numbers of fish are ‘attracted’ to this region, bycatch reduction should be enhanced.

Codend covers

These modifications are principally designed to prevent codend damage due to seabed contact or attack by sharks and other animals. They also serve to prevent prawn loss resulting from a loosely tied codend drawstring. Codend covers are typically a cylinder of old netting surrounding the trailing (anterior) part of the codend. The performance of codend covers is independent of net size and towing speed.

BRD location

All currently approved BRDs for the NPF are located in the codend of the trawl. With the exception of the square-mesh codend, the trailing edge of the escape openings of a BRD can be no more than 120 meshes forward of the codend drawstrings. If fishers use small codends it may not be possible to locate the device at the 120th mesh, and they may have to locate it closer to the drawstrings. In the case of strong, powerful swimming fish this may facilitate their escape from the codend. This could also help weak swimming fish, as the distance to swim through the escape openings may be less. However, for these fish it is the relative distance between the accumulated catch and the escape openings of a device that plays a major role in determining if they can escape or not. In the case of a small codend, location of a BRD closer to the drawstrings may have little impact if the accumulated catch is low and the fish have to swim a relatively greater distance to escape. This will be a particular problem if fishers are able to maintain location of their BRD in the 120th mesh. If fishers also increase towing speed, the performance of these devices could be reduced further, and it may be necessary to reconsider the maximum specified distance from the drawstrings.

Size of escape openings

The size of a BRD is important because it influences the size (and number) of escape openings available for bycatch to escape. In turn, this influences the volume and size of bycatch that can escape from the net. As there is a link between net size and codend size (length and circumference), net size will also influence the size of a BRD located in this part of the trawl. There is no documented evidence of a link between towing speed and the size of escape openings in the NPF, although larger (or more) openings would be prudent at higher speeds given the increased difficulty for fish and other bycatch to escape.

3.3.2 BRD specification

The range and specification of BRDs currently approved for the NPF may not be seriously affected by the re-introduction of quad-rig into the fishery. All devices can be fitted to smaller codends, as evidenced by the Queensland east coast prawn fishery, without requiring adjustment to their specification. Even the square-mesh codend, with its requirement for a codend length of least 75 meshes (bar lengths) should be possible given smaller nets are used. Whilst BRD location and increased towing speed will influence fish escape, it is difficult to identify pre-emptive changes to BRD specifications to enhance bycatch reduction (although even if fishers do not adopt quad-rig, changes should in any case be considered given their modest performance to date), particularly when performance is highly variable and difficult to assess in all locations and conditions within the fishery.

3.4 Conclusion

The adoption of quad-rig does not appear to significantly jeopardize efficient TED performance and the continued protection of turtles. The use of small nets should not adversely influence TED performance given that the dimensions and rigging of a TED, including escape opening, is already specified. The use of a guiding panel or funnel in a small codend is currently not specified and is perhaps the greatest risk to the rapid escape of turtles from a TED, although this should only occur if very small codends are used.

If fishers choose to use available thrust and increase towing speed, there is a risk that stingrays and perhaps sponges and debris will be caught for a time against the bars of the grid. This will delay their exclusion and may lead to prawn loss as the escape cover is pushed aside for a longer period. There is no evidence that increased towing speed negatively impacts on the exclusion of turtles from a TED, although at very high speeds these animals are likely to struggle to reach the escape opening, push aside the escape cover and escape. There is also no proof that spread ratio will influence TED performance, although limited anecdotal evidence suggests the grid angle of an upward-excluding TED maybe be increased at high spread ratios. This relationship requires further assessment as high grid angle may pose a risk to the rapid escape of turtles from a trawl.

Although use of small nets may risk prawn loss, the risk to turtles and other large animals does not appear to be high. Unless very small codends are used there seems little need to consider any adjustment to current TED specifications. However, it is recommended that any reduction in codend circumference is monitored as fishers commence using quad-rig, as this may flag an increased risk to the rapid escape of turtles from the trawl. Monitoring of trawl size as a proxy for codend circumference is possible but carries some risk that needs to be considered.

The efficient performance of a BRD is unlikely to be influenced negatively by increased spread ratio. However, use of very small nets and codends has the potential to adversely influence the ability of small fish to escape, particularly if the relative distance between the accumulated catch and the device increases. An increase in towing speed could also reduce the performance of these devices. The quantum of these influences has not been assessed in detail, so it is unclear if the net benefit is in fact negative or otherwise. At this stage it is perhaps wisest to monitor how fishers respond to quad-rig and adjust their fishing operation before considering changes to BRD specification.

The potential for fishers to reduce headline height using quad-rig is high. This means that a substantial amount of bycatch swimming above the seabed could be avoided, and the overall amount of bycatch may be reduced providing this reduction is not eroded by increased spread ratio and capture of animals close to the seabed. Future assessment of the trade-off between reduced headline height and increased spread ratio is required to quantify the effect of headline height modification.

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APPENDIX A – Previous estimation of quad rig benefit using various versions of the PTPM and a review of model accuracy

Introduction

Objective 1 was achieved through comparing performance predictions for double rigged and quad rigged trawlers based on an available engineering model of trawling performance (PTPM ver3). The engineering model of trawling performance is numerical, and incorporates equations that either depict the theory of physical processes that occur in prawn trawling or, where important processes are too complex, portray the character of empirical data purposefully produced over the last 20 years from scale model tests in the AMC flume tank or full-scale field trials of Australian prawn trawling gear.

The PTPM has developed to its current form (ver3) over many years. Along the way less complex versions have been used to assess the performance of quad rig relative to less efficient trawl systems. A review of these previous results conveniently allows a qualitative description to be made of the PTPMver3 model, starting with its core features, and show how the prediction of the performance benefit of quad rig compared to double rig changes as the PTPM becomes more complex such that it captures more, increasingly subtle, aspects of prawn trawling systems.

Validation of PTPMver3 and an assessment of its accuracy was an important process undertaken in the final stages of its development. This is described in detail in chapter 3 of (Sterling, 2005) and reviewed, with particular attention to its ability to discern the relative performance of different commercial prawn trawling rigs, in the last section of this appendix.

Previous PTPM models and associated predictions of quad rig performance benefit

The elementary engineering model

The first engineering model for Australian prawn trawling systems was described by Sterling (1986). This model was based on equations that described the broad scale physical theory of prawn trawling (see appendix B) and a small amount of flume tank data to empirically capture the trend of trawl drag and inpull variations with respect to spread ratio; these variations being the result of physical processes within the trawl that are too complex to describe in a practical way using a theoretical approach[1]. There were many assumptions made in the model, which were designed to simplify the mathematics, while maintaining a model that displayed the first order characteristics of prawn trawling systems.

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[1] Sterling (1986) does present a simple theoretical model for net drag and inpull in order to gauge the likely outcome of conducting the flume tanks tests; hence helping to justify the direction taken.

Improvements to the model were made during 1989 (Sterling and Cartwright, 1991), whereby data from the flume tank was collected from a model trawl net suspended in mid-stream. This provided water flow through the net that was more uniform and allowed test conditions to be more repeatable. Further improvement to the data was achieved during 1991 by revising the design of the Trawl Evaluation Rig (TER), to increase measurement accuracy (Sterling and Klaka, 1993). Apart from providing a broad-brush picture of the performance of prawn trawling systems this engineering model cannot be used to confidently predict trawling performance in absolute terms or even accurately compare the performance of different systems. It does however clearly show that there are significant performance advantages through using high order multi–net systems, eg quad rig as apposed to single or double rig, and that for each rig type, there is a unique optimum otter board size that gives maximum swept area performance. These features of the engineering model are shown in Figure 19.

The indicated advantage of quad rig compared to double rig, in terms of Swept Area Rate (SAR), is about 55%.

The performance curve for double rig is relatively broad and flat such that there is not a distinct peak in performance at an optimum otter board size. For quad rig on the other hand, the performance curve displays a more distinct peak at an otter board size that produces a spread ratio of about 80%.

For this engineering model, trawling performance is not affected within a particular rig by the size of gear towed. Due to the simplifying assumptions made, the effect of the increased gear size on SAR, through increased span, is exactly offset by the reduction in trawl speed that will result[1].

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[1] Reduced speed will occur because the SAR of the various trawl gear options is calculated for a given available trawler thrust. The degree of speed reduction estimated depends on assumptions made regarding how trawl system drag increases with system size.

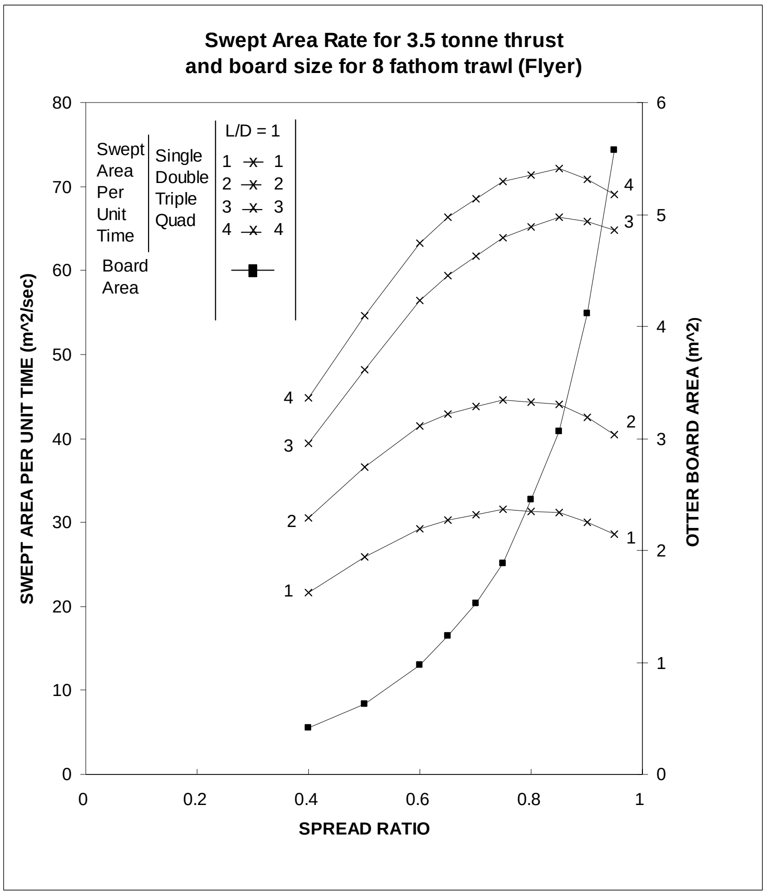

Figure 19. First order engineering character of low opening prawn trawling systems (Sterling and Klaka, 1993).

The PTPM ver1

The engineering model of 1986 was the embryonic start to the first version of the Prawn Trawling Performance Model (PTPM), which was not completed until 1994[1] and is described in Sterling (1998) and Sterling (2000b).

The PTPM ver1 was designed to allow predictions of trawling performance to typical engineering accuracy (ie 10%). This was achieved by removing three simplifying assumptions from the elementary engineering model:

1. Trawls of different size are geosims.

This assumption was replaced by flume tank measurement of trawl drag for scale model nets of differing headline length and body taper (Sterling et al., 1992).

2. Ground effect forces acting on the trawl system are insignificant and assumed equal to zero.

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[1] The PTPM ver1 was an outcome of a project conducted by the Australian Maritime Engineering CRC.

This assumption was removed by including in the model an overall ground effect force, which had a broad scale magnitude, in comparison to hydrodynamic forces, as estimated from sea trial data collected by Sterling et al. (1995).

3. Available thrust does not change with trawl speed.

The degree to which available thrust reduces with tow speed from the “bollard pull” at zero speed to zero available thrust at the design steaming speed of the vessel was approximated using a simple empirical formula published by Ming Yi and Endal (1983).

The resulting system of equations for PTPM ver1 is given in appendix B. Due to the more exact nature of PTPM ver1 the output picture of trawling performance from the model became more complicated. Figure 20 shows a PTPM ver1 picture of performance for double, triple and quad rigs towed by a standard trawler capable of delivering a bollard pull of 3.5 tonne (Sterling, 1998). This equates to a smaller than average trawler in the NPF.

Trawling performance depends on both spread ratio and headline length. To complete the trawl performance picture, trawling speed is also shown on Figure 20 in the form of a second, overlaid, contour plot.

For quad rig, for all configurations that are towed with a speed of 3 knots, the best SAR achieved is just over 55m^2/sec. This can be compared to triple rig, where for 3 knots the best SAR is 64m^2/sec, and to double rig where the comparable SAR is 45.5m^2/sec. This indicates that quad rig outperforms double rig by about 21%.

It is interesting to note that this model predicts the performance of triple rig to be better than quad rig by about 15%. This is the opposite of that suggested by Figure 19. Contributing strongly to the different result is the specification, within the PTPM ver1 run, of a longer body taper (1P2B)[1] for quad rig than triple rig (1P4B). This is very consistent with industry practise, however anecdotal evidence on the fishing grounds suggest that quad rig in fact out catches triple rig for prawn, while scallop catches may be less (pers. obs.). The possible inconsistency between predictions and observations regarding prawn catches for triple rig might be the result of an obscure mechanism that causes catch efficiency of prawn species to be sensitive to rig type, possibly through differences in trawl speed. It is generally the case that triple rigged trawlers tend to tow at slower speed because the nature of triple rig easily allows large gear to be practically used.

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[1] 1P2B means “1 point 2 bar”, which defines the rate at which netting width, in the top and bottom panels of trawls, reduces with distance towards the codend. 1P4B reduces more quickly than 1P2B and therefore results in a shorter trawl that contains less netting and has less drag.

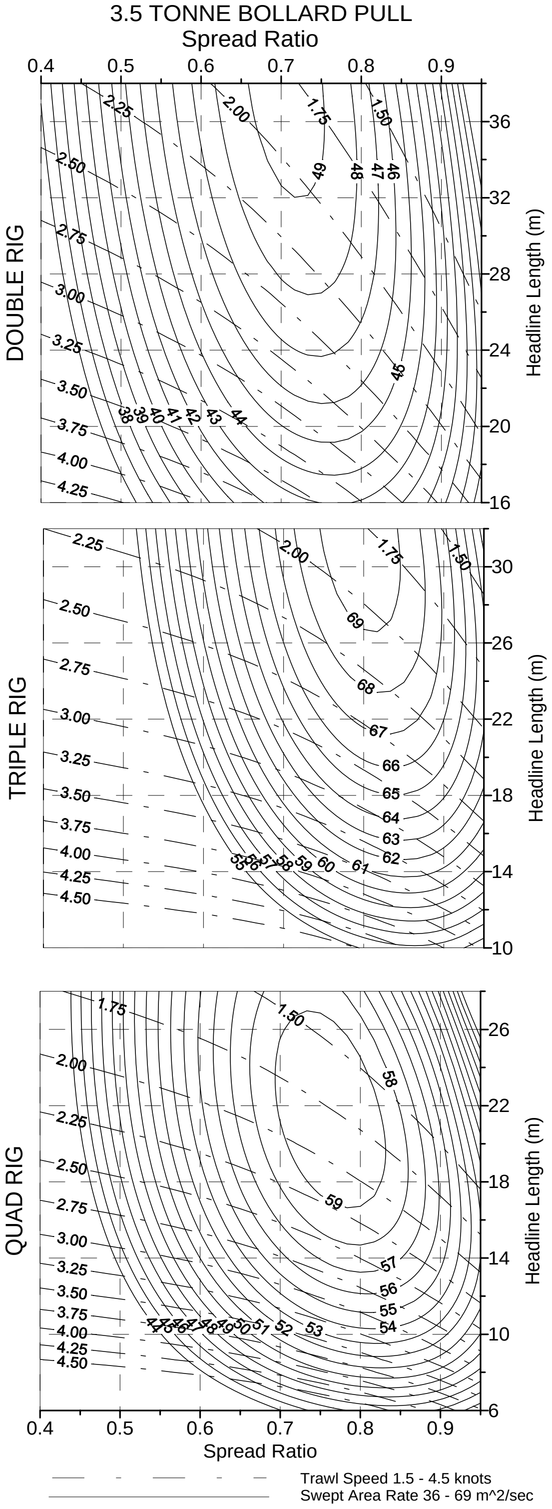

Figure 20. Fishing Performance Maps for Double, Triple and Quad prawn trawling systems with otter boards having low efficiency (L/D =1) for vessels capable of 3.5 tonne bollard pull (Sterling, 1998).

The PTPM Ver 2

PTPM ver 2 was a commercial software product developed in 1998 and is described in Sterling (2005). It contained significant changes to the structure of the model, to expand its range of application through capturing more of the fine detail and associated mechanisms that go towards completely describing the character and status of an operating prawn trawling system. The software also allows searches for optimal performance and other specifiable operating goals.

Version 2 is an expansion over version 1 in six areas:

1. Prediction of vessel thrust from the characteristics of the trawler's propulsion system.
2. Prediction of spread ratio by matching otter board and system characteristics.
3. Accounting for ground effect forces at the component level rather than the system level.
4. A detailed system geometry model is incorporated.
5. Each net in multi-net systems is specified explicitly.
6. Optimisation of trawl system design is carried out using Excel Solver rather than graphical methods.

The structure and equations used are given in appendix B. The PTPM ver2 was specifically used in 2000 to predict the relative performance of quad rig in comparison to double rig for NPF trawlers that fished in 1987 [Sterling, 2000a #64]. This was part of a study to estimate the historical changes in fishing power for the NPF fleet. Figure 21 shows the results of that investigation whereby lines labelled "Table 1" and "Table 2" refer to that project's outcomes. The line labelled "5%" was the contemporary assumption for historical fishing power used in NPF stock assessments and the line labelled "Basic low" is a later estimation of the fishing power profile obtained from another study that utilised the PTPM ver3 (Dichmont et al., 2003).

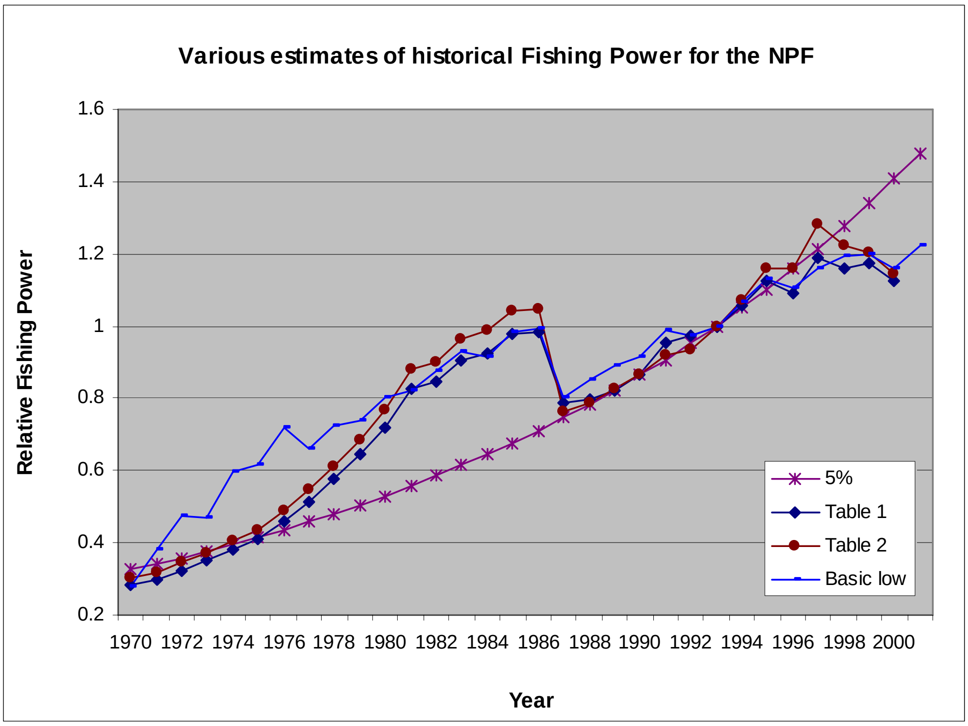

Figure 21. Fishing Power history for the NPF with large drop at 1987 due to banning more than two nets.

The PTPM ver2 estimated the average performance advantage of using quad rig compared to double rig. This was achieved by running the software twice, to calculate the SAR for the average boat in the fleet under the two circumstances; where it towed double rig and secondly, quad rig. The difference in the average vessel's performance was 27%. This improvement in performance is a significant component of the increasing fishing power for the decade after 1975, during which the NPF fleet almost universally changed to quad rig. This level of performance enhancement is also responsible for the sharp reduction in fishing power that occurred in 1987 when quad rig was banned.

The relative performance of quad rig estimated by the PTPM ver2 for the NPF during the late 80’s (1.27) is somewhat higher than the more general relative performance given by the PTPM ver 1 in Figure 20 (1.21). This appears to be mainly due to the fact that the PTPM ver2 predictions for the NPF/1987 context assumed ground effect forces were acting at twice the intensity as assumed for the general PTPM ver1 contour plots. The higher intensity (ground effect factor = 2.8) is considered more realistic for tiger prawn fishing because the lower assumption (1.4) equates to an estimate of the ground effect factor obtained from sea trial experiments conducted along a semi-surf shoreline where the seabed was quite firm.

The PTPM ver3

A thorough description of the PTPM ver3, including all equations and parameters, is provided in Appendix B, while an expanded description that includes details of the comprehensive revision and upgrade from version 2 can be found in Dichmont et al. (2003) and Sterling (2005)[1]. Appendix B also shows the Excel based implementation of the PTPMver3 for the standard quad rig case.

The PTPMver3 was used to generate the latest assessment of historical fishing power for the NPF, which is shown in Figure 21 and labelled "Basic low". In this instance the effect of the introduction and removal of quad rig from the NPF on fishing power was estimated by using the PTPM ver3 to predict the SAR performance of every NPF trawler for every year that it fished. Each boat's contribution to the historical fishing power picture was weighted by the number of respective days fished in each year.

An indication of the performance of quad rig compared to double rig, for the vessels fishing in 1987, can be obtained by comparing the SAR predictions for boats that fished both 1986 and 1987[2]. This comparison showed that on average the boats fished with 24.4% higher SAR in 1986, by using quad rig, compared to 1987 where they used double rig. The distribution of performance improvements is shown in Figure 22 and had a standard deviation of about 4.5%.

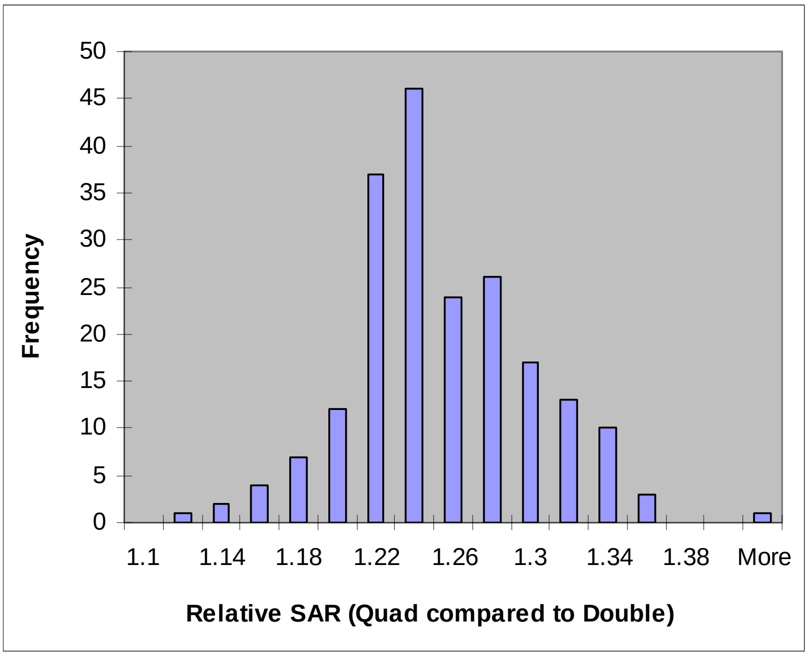

Figure 22. Distribution of relative SAR for quad rig in the NPF - 1987 context.

Changes to version 3 of the PTPM compared to version 2 relate to eight areas of improvement. This is described in detail in Sterling (2005) and reflects a comprehensive revision of all operational facets of the model, which encompassed a reassessment of

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[1] Some funding for the latest phase of the PTPM development was provided by AFFA and AFMA through the project "A new approach to fishing power analysis and its application in the Northern Prawn Fishery".

[2] Boats that changed their propulsion system between 1986 and 1987 were not compared.

background data, experimental methodology and simplifying assumptions, and the assessment of newly collected data from the flume tank and at sea:

1. A new “reflected trawl” test system was devised and used to collect more accurate data in the flume tank.
2. Otter board/net interaction was investigated using the reflected trawl test format.
3. Vessel thrust calculations were upgraded based on published thrust characteristics for tugs.
4. Otter board angle of attack and associated hydrodynamic coefficients are estimated as part of the performance prediction process.
5. A theoretical model for trawl net ground effect was implemented.
6. The theoretical model for otter board ground effect from the 3RDOF orientation model (Sterling, 2000b) was implemented.
7. Headline height and the number of wingend meshes were included as drag parameters.
8. Headline gape (inherent spread ratio) was included as an additional drag parameter.

The inclusion of headline height as a parameter in PTPM ver3 causes significant ramifications when predicting the performance of hypothetical situations. This is because the predicted performance and operating characteristics of trawling systems is now a function of the headline height variable. It is therefore necessary to accurately specify headline height within exploratory scenarios. Such is the strength of these new model relationships that if one allows headline height[1] to be a free variable, to be calculated in the quest for maximum SAR for an otherwise specified trawl system, the optimum solution tends to have very low headline height; much lower than is usually used in practice, and a very high trawl speed. Similarly, if one chooses to maximise the swept volume rate (SVR), the optimum trawl system tends to have a very high headline height and a low trawl speed. This tends to suggest that neither of these engineering parameters specify precisely the real objective function for prawn trawling. The biology and behaviour of the target prawn species are likely to have a role in determining the optimal headline height for trawling[2]. Work on the catching efficiency of trawling with respect to headline height needs to be progressed so that important advances to the prediction model can be made. Work by Eayrs (2005) seems very relevant to the needs identified here. That work indicated that for important commercial prawn species caught at

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[1] By varying headline height, otter board size is also altered because otter board style fixes the connection point for the headline at a specific distance from the top edge; style also fixes aspect ratio.

[2] Along with practical considerations regarding the form and function of the trawl gear’s components.

night in the NPF, over 95% of the prawn can be captured with a headline height of 600mm, provided there is sufficient lead-ahead. This tends to support the direction for improved efficiency indicated by the maximum SAR scenario, based on the PTPM ver3, and suggests that headline height may generally be too high in Australia's night-time prawn fisheries to maximise efficiency.

Appendix B – Technical specification and description of the different versions of the PTPM.

Notation

Symbol: Definition (Units)
Ab: otter board area (m^2) 104
C/Dw: tow cable to water depth ratio 106
Cl: lift coefficient 104
COP: *position of otter board hydrodynamic force from leading edge (fraction of board length)* 104
cpflag: control pitch flag 103
ctflag: constant torque flag 102
Dn: trawl net drag (N) 100
Dp: propeller diameter (m) 101
Dt: total gear drag (N) 101
E: propeller performance coefficient 101
F7: vertical reaction force between otter board and seabed (N) 106
F8: *otter board ploughing force (N)* 104
$F8_{=}$: component of ploughing force tangential to otter board face (N) 106
$F8_{\perp}$: component of ploughing force normal to otter board surface (N) 104
F9: *otter board sliding friction (N)* 104
$F9_{\perp}$: component of sliding friction normal to otter board face (N) 104
Fb: *otter board hydrodynamic force (N)* 104
$Fb_{=}$: *component of otter board hydrodynamic force parallel to face (N)* 104
$Fb_{\perp}$: *component of otter board hydrodynamic force perpendicular to face (N)* 104
Fn: *trawl wingend tension (N)* 104
$Fn_{=}$: *component of trawl wingend tension parallel to otter board face (N)* 104
$Fn_{\perp}$: *component of trawl wingend tension perpendicular to otter board face (N)* 104
Fw: *bridle tension (N)* 104
$Fw_{=}$: *component of bridle tension parallel to otter board face (N)* 104
$Fw_{\perp}$: *component of bridle tension perpendicular to otter board face (N)*_ 104
HL: headline length (m) 100
In: inpull force of net (N) 100
It: inpull force of system (N) 101
K: Kort nozzle thrust factor 101
Nb: number of otter boards 101
$N_{max\ trawling}$: max RPM during trawling 102
Nn: number of nets 101
$N_{op\ trawling}$: rpm used while trawling 102
N_{rated}: rpm associated with rated power 102
p: maximum continuous rated engine power (kW) 102
P: developed engine power (kW) 101
ply: number of strands in polyethylene netting 100
RPM: engine speed (revolutions/minute) 102
SAR: swept area rate (m^2/sec) 107
T_0: bollard pull (N) 101
Tapf: side taper drag factor 100
Tv: available thrust or tow force (N) 103
V: trawl speed (m/sec) 100
Vd: free running speed (m/sec) 103

Wbw: weight of otter board in water (N)..106

x,y: *position of bridle connection point relative to centre of board (fraction of board length)* 104

x2,y2: *position of net connection relative to centre of board (fraction of board length)* 104

Ω: effective wingend angle of net (degrees)...100

α_2: bridle divergence angle (degrees)..101

μ_k: kinetic friction coeficient 106

μ_{pn}: ploughing force normal component coefficient..107

ψ: *otter board angle of attack (deg)* 104

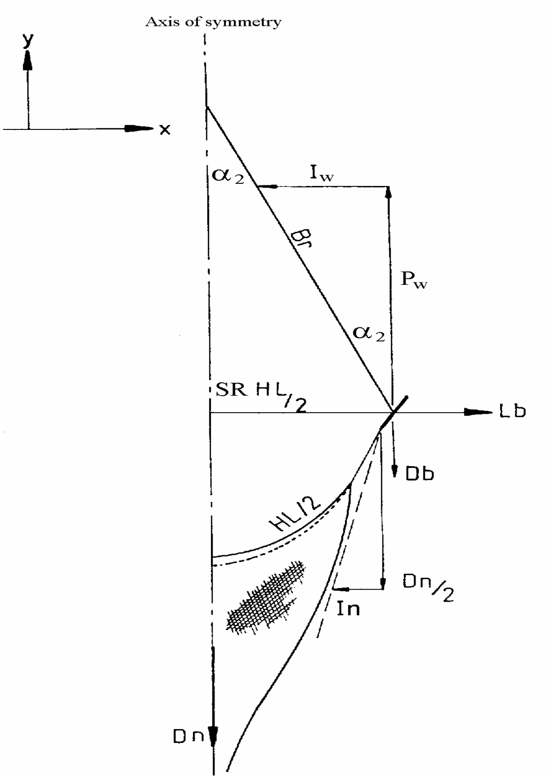
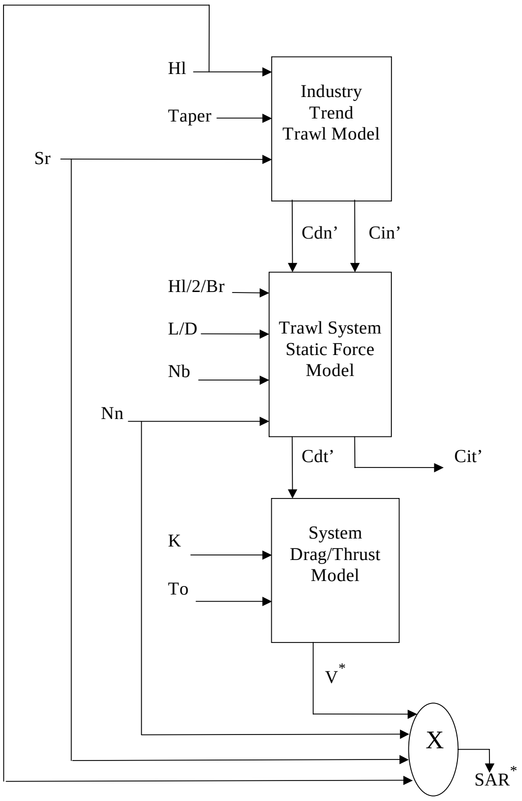


Figure 23. Elementary engineering model.



$$Cdn' = (1.069 \times Hl^{1.473}) \times (0.306 + 2.83 \times Sr - 4.89 \times Sr^2 + 3.14 \times Sr^3) \times Tapf$$

$$\Omega = 16.36 - 61.37 \times Sr + 79.25 \times Sr^2 + 26.56 \times Sr^3$$

$$Cin' = \frac{Cdn'}{2} \times \tan(\Omega)$$

$$Cit' = \frac{Cin' + \frac{Cdn'}{2} \times Sr \times HL/2/Br}{1 - \frac{(Sr \times HL/2/Br)}{\frac{L}{D}}}$$

$$Cdt' = Nn \times Cdn' + Nb \times \frac{Cit'}{\frac{L}{D}}$$

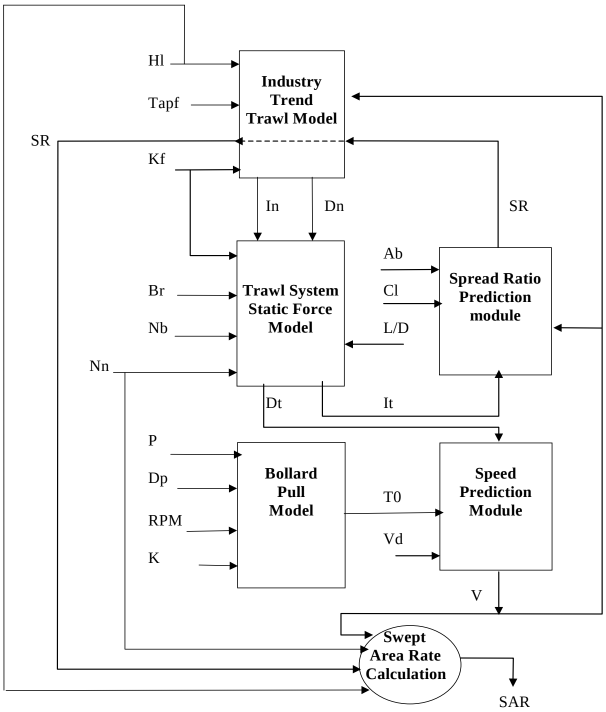
$$Dt = Cdt' \times V^2 + F$$

$$T(V) = T_0 \left(1 - \frac{V}{2V_d}\right)$$

$$V^* = \frac{-\frac{To}{2Vd} + \sqrt{\left(\frac{To}{2Vd}\right)^2 - 4Cdt'(F - To)}}{2Cdt'}$$

$$SAR^* = V^* \times 0.51444 \times Nn \times Sr \times Hl$$

Figure 24. Block diagram of the PTPM ver1.



$$Dn = (39.66\ HL^{1.473})\ (0.306 + 2.83\ SR - 4.89\ SR^2 + 3.14\ SR^3)\ \left(Tapf\ \left(\frac{ply}{27}\right)^{0.5} \frac{50}{mesh}\ V^2 + Kf\right)$$

$$\Omega = -58.55 + 274.55\ SR - 393.07\ SR^2 + 241.02\ SR^3$$

$$In = \frac{Dn}{2} \tan(\Omega)$$

$$It = \frac{In + \frac{Dn}{2} \operatorname{Tan}\left(\frac{\alpha}{2}\right)}{1 - \frac{\operatorname{Tan}\left(\frac{\alpha}{2}\right)\left(1 + \frac{Kf}{V^2}\right)}{\frac{L}{D}}}$$

$$Lb = Cl\ Ab\ \frac{1}{2} \rho_w V^2$$

$$Dt = \sum_{n=1}^{Nn} Dn_n + Nb \frac{It}{\frac{L}{D}} \left(1 + \frac{Kf}{V^2}\right)$$

$$T0 = E \times (P \times Dp)^{2/3} \times K$$

$$Tv = T0 \left(1 - \frac{V}{2Vd}\right)$$

$$P = \left[p \left(\frac{Nmax\ trawling}{Nrated}\right)^{ctflag} \left(\frac{Nop\ trawling}{Nmax\ trawling}\right)^{2.8}\right]^{(1-cpflag)} \left[p \left(\frac{Nmax\ trawling}{Nrated}\right)^{ctflag} 0.9\right]^{cpflag}$$

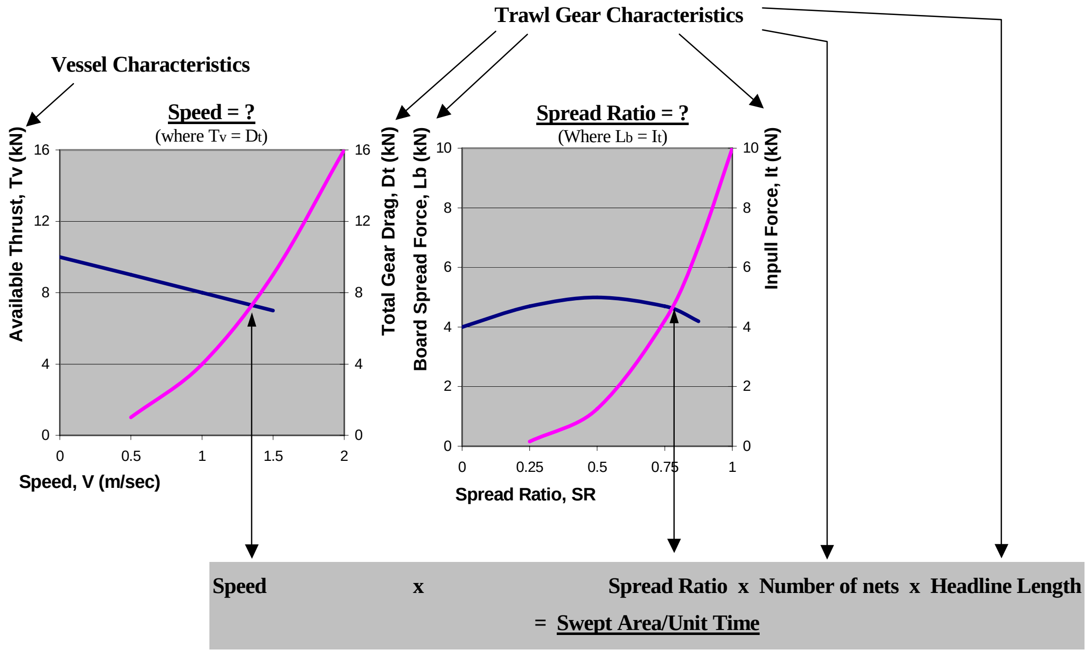
$$SAR = V \sum_{n=1}^{Nn} (SR_n\ Hl_n)$$

Figure 25. Block diagram of the PTPM ver2 showing six sub-components.

The structure of the PTPM ver3

Prawn trawling is an active fishing method that utilises flexible gear. To trawl across the seabed and spread the gear two large and dominant forces need to be applied; namely vessel thrust and otter board spreading force. The prediction of the swept area rate of a prawn trawling operation requires that the magnitude and effect of these two forces be assessed (see Figure 26).

In both cases, steady state equilibrium can be assumed to occur if perturbations in these dominant forces are relatively small. That is, the force applied by the vessel to tow the gear (available thrust) is equal and opposite to the drag of the gear at the resulting trawl speed. And similarly, the spreading force produced by the otter boards is equal and opposite to the inpull force induced in the system at the resulting spread ratio. The characteristics of the vessel and the trawl gear must be used to predict the character of the four forces mentioned above. Iteration is then used to ascertain the resulting trawl speed and spread ratio, which are the only unknowns in predicting swept area rate.



<u>Figure 26.</u> Broad outline of the PTPM ver3 showing the connection between system characteristics, analysis to determine operating parameters and the calculation of swept area performance.

The PTPM ver3 has eight main sub-components as per Figure 27 (in bold). These give rise to the conversion of input data into the four force functions specified above and subsequent processing to predict trawl speed, spread ratio and finally swept area rate. Each sub-component is briefly described below and the combined implementation of the model, in Excel spreadsheet format for standard quad rig, is depicted in the last section of this appendix.

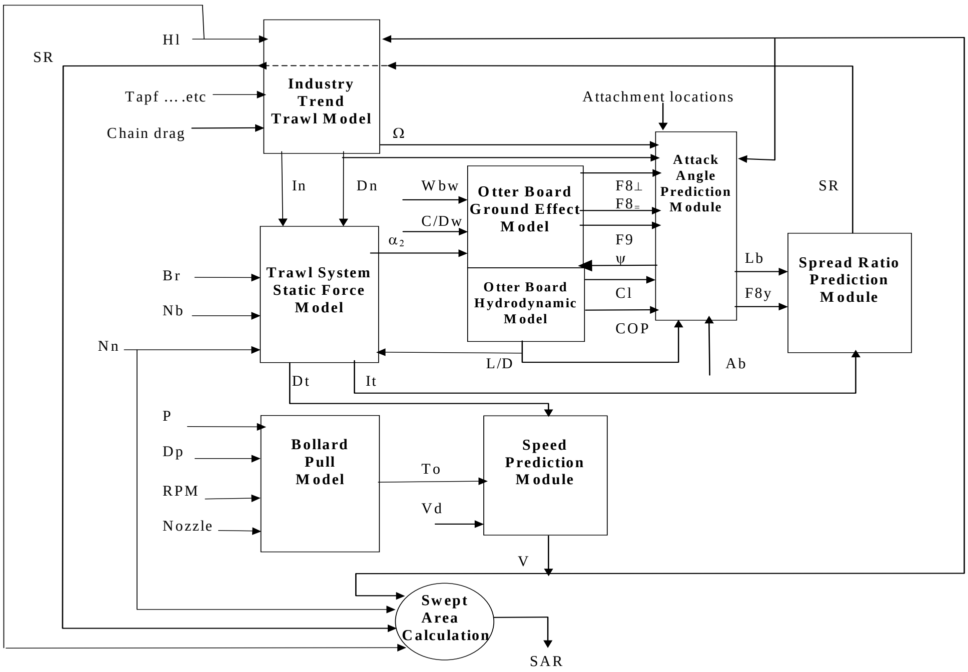


Figure 27. Block diagram of the PTPM ver3 showing eight sub-components.

Industry trend trawl model

The drag of a trawl net (Dn) of a particular size (HL) and design (Tapf, ply, mesh) and at a particular spread ratio (SR) and trawl speed (V) is given by equation 1.

$$Dn= (3.111 + 27.012\ MR\ \exp^{(1.2205\ MT)})\ HL^{2}\ 1.095\ (0.8453 + 0.0095\ \exp^{3.72\ SR})\ (1 + .1223\ SR^{2.145})$$

$$(1 + 0.3866\ (gape - 1.53)\ Tapf\ \rho_w/1000\ \left(\frac{ply}{27}\right)^{0.5}\ \frac{50}{mesh}\ V^{2} + \text{chain drag} \qquad (1)$$

Chain drag = Hl 0.53 (1 + 4 SIN(73 SR))

The effective wingend angle of a trawl net (Ω), which is the angle between the force vector representing the combined tension in the footline and headline at the wingend and the direction of tow, is given by equation 2.

$$\Omega = 4.444 + 3.427\ \exp^{2.963\ SR} + 1.96\ SR^{0.604} \qquad (2)$$

The inpull force for the wingend of the trawl, In, is given by equation 3 in terms of the drag of the net and the effective wingend angle.

$$In = \frac{Dn}{2}\tan(\Omega) \qquad (3)$$

The first two equations are empirically derived expressions from tests conducted in the flume tank on two systematic series of model prawn trawls by Sterling, (2005). In equation 1, Tapf is a factor (see Table 13) that accounts for differences in trawl drag due to various body taper options as calculated in Sterling (2000b) section 2.4.

Table 13. Trawl Drag Factor for Various Body Taper Options

BODY TAPER	*DRAG FACTOR*
1P5B	*0.953*
1P4B	*1*
1P3B	*1.164*
1P2B	*1.296*

Trawl system static force model

$$It = In + (Dn + Db)\,\mathrm{Tan}\,(\alpha_2) \qquad (4)$$

$$Dt = \sum_{n=1}^{Nn} Dn_n + Nb\,Db \qquad (5)$$

The static force model allows the fundamental building blocks of prawn trawl systems (ie. nets and otter boards) to be assembled to form a variety of rigs and then calculates the system's inpull (It) on the otter boards and total drag (Dt).

In addition to these equations, Version 2 also contains expressions derived from applying the conditions of equilibrium at all points in the trawl system where nets are joined together. At these points a towing wire (bridle) is also connected and may have an angle of divergence to the direction of tow depending on the balance of forces between the two nets and the geometry of the bridle system. Such an angle of divergence is calculated for all bridles in the system by ensuring that all conditions of force equilibrium are satisfied at all net junction points and also ensuring that the lateral span of the bridle system equates to the lateral span of the net system.

Bollard pull model

Mathews (1966) provides a thrust formula (Equation 6) that uses quantified developed power (P) and propeller diameter (Dp) to derive bollard pull (T_0).

$$T_0 = E \times (P \times Dp)^{2/3} \times K \qquad (6)$$

Where, E is an empirically determined constant that incorporates physical constants and effects that relate to the detailed shape of the propeller and the shape of the hull, and K is a factor that is applied depending on whether or not a Kort nozzle is fitted.

The factors captured by E are of lower significance in determining the thrust of any given trawler than the other variables explicitly included in the equation. The value of E ideally represents the average of these effects for typical trawlers. However there is a paucity of information available to ensure that this is the case and we have assumed a value of 75. This value calibrates the equation to give an estimate of the bollard pull of the trawler and was derived from data given in Moor (1963) for the bollard pull of three different propellers on a 30m tug over a range of developed power.

If a nozzle is fitted K has a value of 1.25 or 1.0 if no nozzle is fitted. This empirical correction is commonly quoted for the estimation of trawler or tug thrust, for example Sedat (1984).

$$P = \left[p \left(\frac{N_{\text{max trawling}}}{N_{\text{rated}}} \right)^{\text{ctflag}} \left(\frac{N_{\text{op trawling}}}{N_{\text{max trawling}}} \right)^{2.8} \right]^{(1-\text{cpflag})} \left[p \left(\frac{N_{\text{max trawling}}}{N_{\text{rated}}} \right)^{\text{ctflag}} 0.9 \right]^{\text{cpflag}} \qquad (7)$$

Equation 7 is used in the bollard pull model to calculate the delivered power from a trawler given engine performance information (as rated power, p), details associated with its operation and assumptions about the physics of the propulsion system. The methodology represents a view that the rated output of the motor is not by itself a sufficiently accurate indication of the power applied to a given trawling operation for the purposes of predicting swept area performance. The methodology attempts to capture a range of the most significant factors that culminate in determining the power applied to the propulsion system during trawling. In addition to the installed engine power (continuous rating) consideration is given to how hard the motor is driven and how well the propeller is matched to the engine, that is, whether it loads the motor to its rated output or not.

The latter issue is determined by the ratio $N_{\text{max trawling}}/N_{\text{rated}}$. For a well-matched propulsion system (from the point of view of maximising thrust) this ratio is close to 1. Typically the ratio is less than 1 for fixed pitch propellers so that there is some opportunity to operate the motor at higher rpm while the boat is steaming compared to trawling. This compensates for the reduced propeller load at a higher speed of advance. That factor in the equation is raised to a power of either 0 or 1 depending on the power characteristics of the engine:

ctflag = 0; engine exhibits constant power with rpm.

ctflag = 1; engine exhibits constant torque with rpm.

Figure 28 shows graphically the two different power characteristics. Traditionally, diesel engines had a constant torque character, which determined that maximum engine power output increased with rpm. However, for modern more sophisticated diesel engines the maximum power curve is quite flat over the operating rpm range of the engine. This makes the motor somewhat more flexible in propulsion applications because maximum power can be delivered at engine speeds less than the rated speed. This makes propeller matching less critical and allows full power to be produced for trawlers both while trawling and steaming, for a fixed pitch propeller.

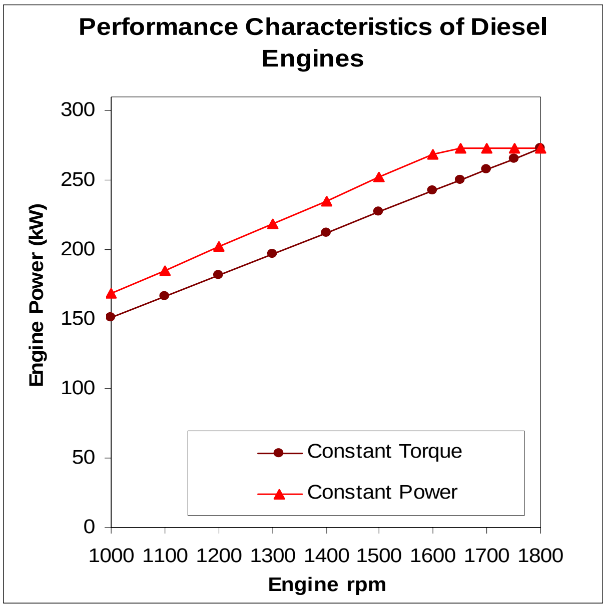


Figure 28. Performance characteristics of illustrative diesel engines (based on Caterpillar engine specification sheets).

The issue of "how hard is the motor driven" is indicated by the ratio Nop trawling/Nmax trawling. This ratio is raised to the power of 2.8, which reflects the sensitivity to which a fixed pitch propeller absorbs power with respect to speed of rotation[1]. For control pitch propellers it is assumed that the motor is loaded such that it produces 90% of the maximum torque possible for the operating RPM. This is applied in equation 7 using a control pitch flag (cpflag).

Speed prediction module

The PTPM calculates actual forces acting in the system at the component level (including ground effects). Because of that it is not possible to find an expression for total system drag that is a simple function of trawl speed. Excel Solver is used to find the value of speed that satisfies a constraint that available thrust must equal total gear drag. Equation 8 (Sterling, 2005 based on data from Moor, 1963) is used to account for the effect of speed on available thrust (Tv), where Vd is the free running speed for the vessel.

$$Tv/T0 = 1 - 0.1731\ V/Vd - 0.667\ (V/Vd)^2 \qquad (8)$$

Spread ratio prediction module

The spreading force (Lb) produced by the otter boards is assumed to be constant with respect to spread ratio and given by equation 9, where Cl is the lift coefficient, Ab is the plan area, ρ is the density of sea water and V is the trawling speed.

---

[1] Specification sheets for Caterpillar marine engines use an exponent of 3.0 for fixed pitch props, while Cummins interchangeably use either 2.7 or 3.0. The author suggests that an exponent of 3.0 is probably correct if the speed of advance is held constant while an exponent of less than 3.0 would be appropriate if the speed of the vessel is allowed to increase as more engine power is applied.

$$Lb = Cl\ Ab\ \frac{1}{2}\ \rho_w\ V^2 \qquad (9)$$

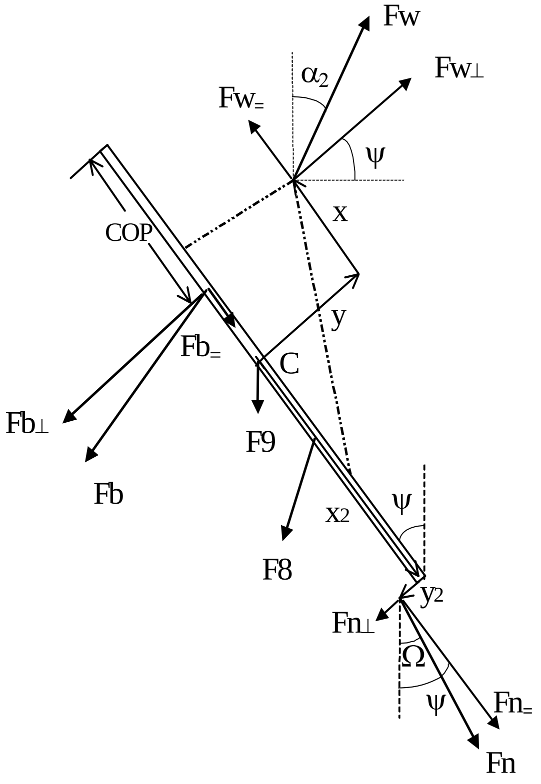
Excel Solver is used to find the value of spread ratio that satisfies the constraint that Lb must be equal to the inpull from the system (It) as calculated from equation 4.

For multiple net systems the spread ratios of nets that are not connected to otter boards are found by satisfying constraints that the bridle system, which initially is described by divergence angles as calculated from equations that express the equilibrium of forces at net junctions, must form a connected towing web.

Angle of attack prediction module

The angle of attack prediction module is essentially equation 14. It expresses the condition that the sum of moments about a vertical axis through the centre of the board's length must equal zero for equilibrium. This equation can be used to find an unknown angle of attack if the applied forces and their points of application are known.

Figure 29 shows an overhead view of the application of forces to an otter board. Equation 14 is an expression of the moment equilibrium condition pertaining to Figure 29 (clockwise positive).



Fb = hydrodynamic force
$Fb_=$ = component parallel to face
$Fb_\perp$ = component perpendicular to face

Fn = wingend tension
$Fn_=$ = component parallel to face
$Fn_\perp$ = component perpendicular to face

Fw = bridle tension
$Fw_=$ = component parallel to face
$Fw_\perp$ = component perpendicular to face

F8 = ground ploughing force
F9 = shoe friction
α_2 = bridle divergence angle
Ω = wingend angle of net
ψ = otter board angle of attack
x,y = position of bridle connection relative to the centre (C) of the board.
x2,y2 = position of net connection relative to the centre (C) of the board.
COP = position of hydrodynamic force (centre of pressure)

Figure 29. Schematic of forces acting on an otter board.

$$\sum M_C=0=Fn_\perp\, x2-Fn_=\, y2+1/6\ F8_\perp-(0.5-COP)Fb_\perp+(Fb_\perp+Fn_\perp+F8_\perp+F9_\perp)(x-\tan(90-\psi-\alpha_2)\ y) \qquad (14)$$

It is assumed that the friction on the otter board shoe (F9) acts through C, therefore it does not generate any moment around C. It is also assumed that the ploughing force (F8) acts at a point 1/3 of the board length from the trailing edge of the otter board. In practise the position of F8 would depend on the orientation of the otter board, particularly the tilt angle[1]. No method has been developed to estimate the location of this force with respect to any influencing factors. This situation gives rise to an essential caveat that the accuracy of angle of attack prediction relies on the tilt angle in practise being close to zero degrees. This is the desirable attitude of the board and it can be assumed that this is generally achieved.

Otter board hydrodynamic model

The objective of incorporating an otter board orientation model into the PTPM is to allow adjustment of otter board hydrodynamic parameters (Cl, L/D) in response to the board's attack angle condition. Also, in order to predict angle of attack the relationships between attack angle and certain hydrodynamic parameters (CL, L/D, COP) are required. Therefore a detailed understanding of the hydrodynamic characteristics of the otter board is required for this aspect of the PTPM to be implemented. The problem is that the hydrodynamic characteristics of a board are a complex function of the shape of the spreading surfaces of the board and there is a large variety of different designs used in practice. Hydrodynamic models for the three most popular otter board styles used within Australian fisheries were developed. These empirical models are based on flume tank measurements taken by Edmondson (1994b). Only one specific design was tested for each style of otter board, so there remains some room for error between model predictions and actual board forces due to variations of design that exist within a design style. The three design styles covered are the Flat rectangular, Bison and Kilfoil.

Flat rectangular

$$CL = (1.564E\text{-}07\ \psi^5 - 2.199E\text{-}05\ \psi^4 + 1.137E\text{-}03\ \psi^3 - 0.02754\ \psi^2 + 0.3461\ \psi - 1.373) * 0.9 \tag{15}$$

$$L/D = -1.567E\text{-}06\ \psi^4 + 2.381E\text{-}04\ \psi^3 - 0.01252\ \psi^2 + 0.2271\ \psi + 0.8699 \tag{16}$$

$$\mathrm{COP} = a + b(\psi \times \mathrm{ASPECT}^{e}) + c(\psi\ \mathrm{x}\ \mathrm{ASPECT}^{f})^2 + d(\psi \times \mathrm{ASPECT}^{g})^3$$

a = 0.09606 c = -1.980 e = 0.2935 g = 0.1738

b = 1.290 d = 1.098 f = 0.2307

Bison

$$CL = (-1.955E\text{-}05\ \psi^3 + 8.070E\text{-}04\ \psi^2 + 0.02709\ \psi + 0.07876) * 1.1.5 \tag{17}$$

---

[1] Tilt is equivalent to pitch – elevation of front relative to back.

$L/D = -3.352E-06\ \psi^4 + 5.083E-04\ \psi^3 - 0.02772\ \psi^2 + 0.5731\ \psi - 0.9228$ (18)

$COP = 3.951E-07\ \psi^4 - 5.049E-05\ \psi^3 + 2.425E-03\ \psi^2 - 0.05029\ \psi + 0.7860$ (19)

Kilfoil

$CL = -9.726E-06\ \psi^3 + 3.502E-04\ \psi^2 + 0.02178\ \psi - 0.07231$ (20)

$L/D = 3.406E-05\ \psi^3 - 5.226E-03\ \psi^2 + 0.2130\ \psi - 0.6736$ (21)

$COP = 4.250E-07\ \psi^4 - 5.438E-05\ \psi^3 + 2.500E-03\ \psi^2 - 0.04862\ \psi + 0.7578$ (22)

Otter board ground effect model

The ground effect model used for the otter boards in PTPM ver3 is very similar to that developed in Sterling (2000b) section 5.2.2 for the 3RDOF orientation model. To increase the generality of the model a speed dependent term was included. Very little information is available to fix the parameters of the model.

The components of the ground effect model are vertical ground reaction, sliding friction and ploughing. Sliding friction is calculated using a simple Newtonian kinetic friction model, while ploughing forces are derived in terms of components normal and tangential to the otter board's shoe.

The vertical reaction force (F7) between the otter board and the seabed is derived by subtracting from the submerged weight of the board (Wbw) the upward component of tension in the tow cable, which is dependent on the drag transferred to the cable and the ratio of cable length used to the depth of the water (C/Dw). Equation 25 is the expression used.

$F7 = Wbw - (Db + Dn/2)\ \mathrm{Tan\ Asin}\ (1/(C/Dw))$ (25)

The sliding friction, F9, is given by:

$F9 = \mu_k\ F7$ Where $\mu_k = 0.2$ (Deutschman et al., 1975).

Sliding friction does not have a first order influence on the calculation of angle of attack in the PTPM because it is assumed to act at the centre of the board length (about which moments are summed in equation 14) and therefore does not generate a turning moment. Otter board pitch is not calculated so the sliding friction force is always fixed at this point.

The normal and tangential ploughing forces ($F8_{\perp}$, $F8_{=}$) derived by the equations below are used by equation 14 to estimate angle of attack but they are also transformed into the directions inline and normal to the direction of tow to account for their contributions to otter board drag and spreading forces.

$F8_{\perp} = \mu_{pn} F7\ \mathrm{Sin}\ \psi\ \mathrm{GSF}$ where $GSF = 0.05$

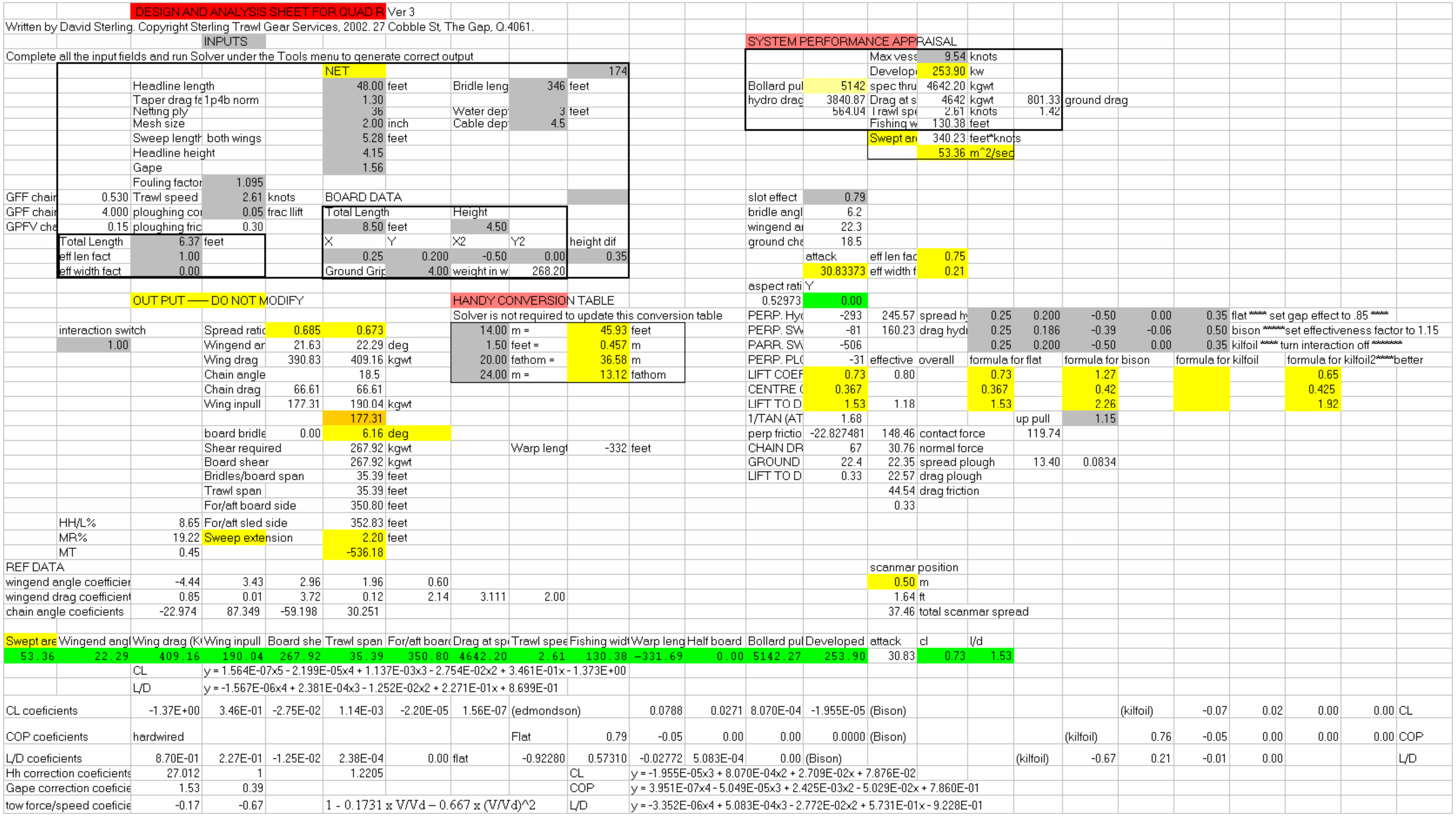
$F8_{=} = \mu_k F8_{\perp} \mathrm{Cos}\ \psi$ where $\mu_{pn} = 21$ and $\mu_k = 0.2$

Swept area rate calculation

Once the trawl speed and spread ratios for all nets in the system are known the swept area rate (SAR) is calculated using equation 10.

$$\mathrm{SAR} = \mathrm{V} \sum_{n=1}^{Nn} (\mathrm{SR}_n \ \mathrm{Hl}_n) \tag{10}$$

Input - output screen for the PTPM ver3 (Standard Quad)



		DESIGN AND ANALYSIS SHEET FOR QUAD R				Ver 3																		
Written by David Sterling. Copyright Sterling Trawl Gear Services, 2002. 27 Cobble St, The Gap, Q.4061.																								
			INPUTS									SYSTEM PERFORMANCE APPRAISAL												
Complete all the input fields and run Solver under the Tools menu to generate correct output														Max vess	9.54	knots								
					NET				174					Develop	253.90	kw								
		Headline length			48.00	feet	Bridle leng	346	feet			Bollard pul	5142	spec thru	4642.20	kgwt								
		Taper drag fa	1p4b norm		1.30							hydro drag	3840.87	Drag at s	4642	kgwt	801.33	ground drag						
		Netting ply			36		Water dep	3	feet				564.04	Trawl spe	2.61	knots	1.42							
		Mesh size			2.00	inch	Cable dep	4.5						Fishing w	130.38	feet								
		Sweep length	both wings		5.28	feet								Swept ar	340.23	feet*knots								
		Headline height			4.15										53.36	m^2/sec								
		Gape			1.56																			
		Fouling factor	1.095																					
GFF chair	0.530	Trawl speed	2.61	knots	BOARD DATA							slot effect	0.79											
GPF chair	4.000	ploughing co	0.05	frac llift	Total Length		Height					bridle angl	6.2											
GPFV cha	0.15	ploughing fric	0.30		8.50	feet	4.50					wingend a	22.3											
	Total Length	6.37	feet		X	Y	X2	Y2	height dif			ground cha	18.5											
	eff len fact	1.00			0.25	0.200	-0.50	0.00	0.35				attack	eff len fac	0.75									
	eff width fact	0.00			Ground Grip	4.00	weight in w	268.20					30.83373	eff width f	0.21									
												aspect rati	Y											
		OUT PUT —— DO NOT MODIFY					HANDY CONVERSION TABLE					0.52973	0.00											
							Solver is not required to update this conversion table					PERP. Hy	-293	245.57	spread hy	0.25	0.200	-0.50	0.00	0.35	flat **** set gap effect to .85 ****			
	interaction switch		Spread ratio	0.685	0.673		14.00	m =	45.93	feet		PERP. SW	-81	160.23	drag hyd	0.25	0.186	-0.39	-0.06	0.50	bison *****set effectiveness factor to 1.15			
	1.00		Wingend ar	21.63	22.29	deg	1.50	feet =	0.457	m		PARR. SW	-506			0.25	0.200	-0.50	0.00	0.35	kilfoil **** turn interaction off ********			
			Wing drag	390.83	409.16	kgwt	20.00	fathom =	36.58	m		PERP. PL	-31	effective	overall	formula for flat		formula for bison		formula for kilfoil		formula for kilfoil2****better		
			Chain angle		18.5		24.00	m =	13.12	fathom		LIFT COEF	0.73	0.80		0.73		1.27				0.65		
			Chain drag	66.61	66.61							CENTRE (	0.367			0.367		0.42				0.425		
			Wing inpull	177.31	190.04	kgwt						LIFT TO D	1.53	1.18		1.53		2.26				1.92		
					177.31							1/TAN (AT	1.68				up pull	1.15						
			board bridle	0.00	6.16	deg						perp frictio	-22.827481	148.46	contact force		119.74							
			Shear required		267.92	kgwt		Warp lengt	-332	feet		CHAIN DR	67	30.76	normal force									
			Board shear		267.92	kgwt						GROUND	22.4	22.35	spread plough		13.40	0.0834						
			Bridles/board span		35.39	feet						LIFT TO D	0.33	22.57	drag plough									
			Trawl span		35.39	feet								44.54	drag friction									
			For/aft board side		350.80	feet								0.33										
	HH/L%	8.65	For/aft sled side		352.83	feet																		
	MR%	19.22	Sweep extension		2.20	feet																		
	MT	0.45			-536.18																			
REF DATA														scanmar position										
wingend angle coefficier		-4.44	3.43	2.96	1.96	0.60								0.50	m									
wingend drag coefficient		0.85	0.01	3.72	0.12	2.14	3.111	2.00						1.64	ft									
chain angle coeficients		-22.974	87.349	-59.198	30.251									37.46	total scanmar spread									
Swept are	Wingend angl	Wing drag (K	Wing inpull	Board she	Trawl span	For/aft boar	Drag at sp	Trawl spee	Fishing widt	Warp leng	Half board	Bollard pul	Developed	attack	cl	l/d								
53.36	22.29	409.16	190.04	267.92	35.39	350.80	4642.20	2.61	130.38	-331.69	0.00	5142.27	253.90	30.83	0.73	1.53								
		CL	y = 1.564E-07x5 - 2.199E-05x4 + 1.137E-03x3 - 2.754E-02x2 + 3.461E-01x - 1.373E+00																					
		L/D	y = -1.567E-06x4 + 2.381E-04x3 - 1.252E-02x2 + 2.271E-01x + 8.699E-01																					
CL coeficients		-1.37E+00	3.46E-01	-2.75E-02	1.14E-03	-2.20E-05	1.56E-07	(edmondson)		0.0788	0.0271	8.070E-04	-1.955E-05	(Bison)					(kilfoil)	-0.07	0.02	0.00	0.00	CL
COP coeficients		hardwired						Flat	0.79	-0.05	0.00	0.00	0.0000	(Bison)				(kilfoil)	0.76	-0.05	0.00	0.00	0.00	COP
L/D coeficients		8.70E-01	2.27E-01	-1.25E-02	2.38E-04	0.00	flat	-0.92280	0.57310	-0.02772	5.083E-04	0.00	(Bison)				(kilfoil)	-0.67	0.21	-0.01	0.00			L/D
Hh correction coeficients		27.012	1		1.2205				CL	y = -1.955E-05x3 + 8.070E-04x2 + 2.709E-02x + 7.876E-02														
Gape correction coeficie		1.53	0.39						COP	y = 3.951E-07x4 - 5.049E-05x3 + 2.425E-03x2 - 5.029E-02x + 7.860E-01														
tow force/speed coeficie		-0.17	-0.67		1 - 0.1731 x V/Vd – 0.667 x (V/Vd)^2				L/D	y = -3.352E-06x4 + 5.083E-04x3 - 2.772E-02x2 + 5.731E-01x - 9.228E-01														

APPPENDIX C SCATTER-PLOT MATRIX AND REGRESSION OUTPUTS FOR SENSITIVITY EVALUATION BETWEEN DOUBLE RIG CONFIGURATION AND QUAD RIG BENEFIT

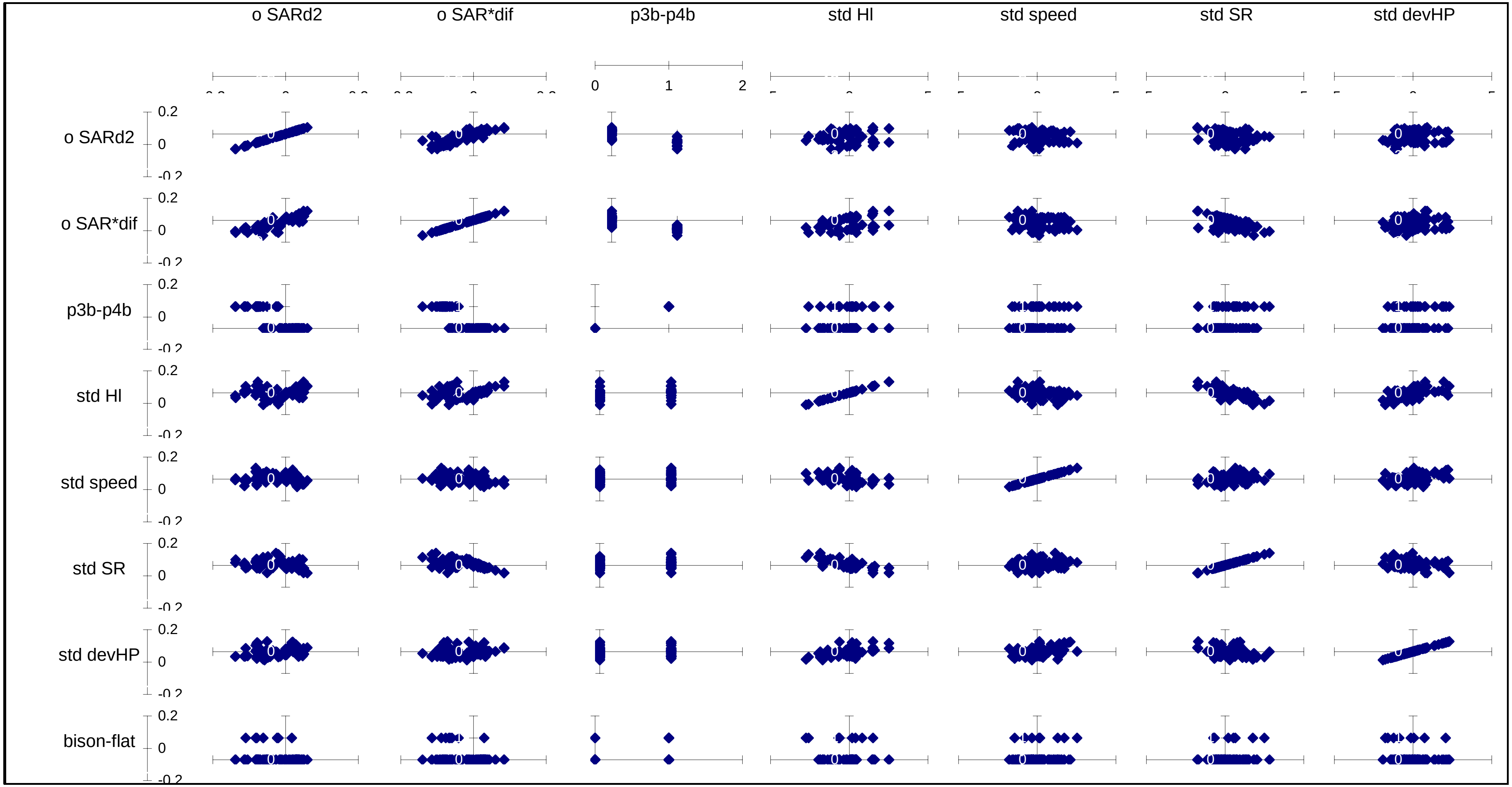


Figure 30. Scatter-plot matrix for SAR and SAR* quad rig benefits, and double rig configuration variables.

Regression Summary for Dependent Variable: SAR_DIFF
R= .91487826 R^2= .83700222 Adjusted R^2= .82308778
F(7,82)=60.153 p<.00000 Std.Error of estimate: .02349

		St. Err.		
	B	of B	t(82)	p-level
P4B	-.088539	.006454	-13.7183	.000000
STD_HL	.006762	.006658	1.0157	.312754
P3B	.014441	.003069	4.7051	.000010
STD_SR	.011265	.005400	2.0862	.040064
FLAT	.025718	.009603	2.6780	.008944
STD_SPEE	-.022529	.004577	-4.9220	.000004
STD_DEVH	.023502	.005208	4.5123	.000021

Regression Summary for Dependent Variable: SAR_DIFF
R= .87287139 R^2= .76190447 Adjusted R^2= .75359881
F(3,86)=91.733 p<.00000 Std.Error of estimate: .02773

		St. Err.		
	B	of B	t(86)	p-level
P4B	-.082914	.005191	-15.9738	.000000
STD_HL	.014970	.002988	5.0105	.000003
P3B	.014166	.003609	3.9254	.000174

Regression Summary for Dependent Variable: SAR_DIFF
R= .85490422 R^2= .73086123 Adjusted R^2= .71819588
F(4,85)=57.706 p<.00000 Std.Error of estimate: .02965

		St. Err.		
	B	of B	t(85)	p-level
P4B	-.074782	.005738	-13.0336	.000000
P3B	.013030	.003845	3.3886	.001067
STD_SR	-.007926	.003672	-2.1588	.033683
STD_SPEE	-.007477	.003612	-2.0699	.041493

Regression Summary for Dependent Variable: SAR_DIFF
R= .88481604 R^2= .78289943 Adjusted R^2= .76997678
F(5,84)=60.583 p<.00000 Std.Error of estimate: .02679

		St. Err.		
	B	of B	t(84)	p-level
P4B	-.089856	.006177	-14.5466	.000000
STD_HL	.023497	.005237	4.4871	.000023
P3B	.014440	.003488	4.1398	.000082
STD_SR	.013355	.005788	2.3075	.023489
STD_SPEE	-.005985	.003280	-1.8246	.071614

Regression Summary for Dependent Variable: STD_SR
R= .77341121 R^2= .59816489 Adjusted R^2= .59354610
F(1,87)=129.51 p<.00000 Std.Error of estimate: .57881

		St. Err.		
	B	of B	t(87)	p-level
Intercpt	.192860	.061385	3.1418	.002295
STD_HL	-.698775	.061403	-11.3801	.000000

Regression Summary for Dependent Variable: STD_SPEE
R= .25844481 R^2= .06679372 Adjusted R^2= .05606721
F(1,87)=6.2270 p<.01447 Std.Error of estimate: .88299

		St. Err.		
	B	of B	t(87)	p-level
Intercpt	.080117	.093644	.85555	.394597

STD_HL	-.233748	.093672	-2.49539	.014469

Regression Summary for Dependent Variable: SAR_D2
R= .88481604 R^2= .78289943 Adjusted R^2= .76997678
F(5,84)=60.583 p<.00000 Std.Error of estimate: .02679

		St. Err.		
	B	of B	t(84)	p-level
P4B	-.089856	.006177	-14.5466	.000000
STD_HL	.015564	.002903	5.3620	.000001
P3B	.014440	.003488	4.1398	.000082
DELSR:HL	.013355	.005788	2.3075	.023489
DELSPEED:HL	-.005985	.003280	-1.8246	.071614

Regression Summary for Dependent Variable: SARXDIFF
R= .97048829 R²= .94184751 Adjusted R²= .93688328
F(7,82)=189.73 p<0.0000 Std.Error of estimate: .01403

		St. Err.		
	B	of B	t(82)	p-level
P4B	-.081908	.003853	-21.2578	.000000
STD_HL	.014798	.003975	3.7231	.000360
P3B	.014004	.001832	7.6430	.000000
STD_SR	-.011090	.003224	-3.4401	.000917
FLAT	.012678	.005733	2.2113	.029796
STD_SPEED	-.004921	.002733	-1.8007	.075419
STD_DEVH	.003521	.003109	1.1323	.260804

Regression Summary for Dependent Variable: SARXDIFF
R= .96154188 R²= .92456279 Adjusted R²= .92193126
F(3,86)=351.34 p<0.0000 Std.Error of estimate: .01560

		St. Err.		
	B	of B	t(86)	p-level
P4B	-.087381	.002920	-29.9226	0.000000
STD_HL	.025521	.001681	15.1832	.000000
P3B	.014363	.002030	7.0742	.000000

Regression Summary for Dependent Variable: SARXDIFF
R= .95581919 R²= .91359033 Adjusted R²= .90952399
F(4,85)=224.67 p<.00000 Std.Error of estimate: .01679

		St. Err.		
	B	of B	t(85)	p-level
P4B	-.069224	.003249	-21.3035	.000000
STD_SR	-.026444	.002079	-12.7171	.000000
P3B	.013246	.002178	6.0826	.000000
STD_SPEED	-.003277	.002046	-1.6019	.112897

Regression Summary for Dependent Variable: SARXDIFF
R= .96825439 R²= .93751657 Adjusted R²= .93379732
F(5,84)=252.07 p<0.0000 Std.Error of estimate: .01436

		St. Err.		
	B	of B	t(84)	p-level
P4B	-.079440	.003312	-23.9840	.000000
STD_HL	.015925	.002808	5.6715	.000000
P3B	.014202	.001870	7.5929	.000000
STD_SR	-.012021	.003103	-3.8735	.000212
STD_SPEED	-.002266	.001759	-1.2883	.201186

Regression Summary for Dependent Variable: SARXDIFF
R= .96825439 R²= .93751657 Adjusted R²= .93379732
F(5,84)=252.07 p<0.0000 Std.Error of estimate: .01436

		St. Err.		
	B	of B	t(84)	p-level
P4B	-.079440	.003312	-23.9840	.000000
STD_HL	.024854	.001556	15.9690	.000000
P3B	.014202	.001870	7.5929	.000000
DELSR:HL	-.012021	.003103	-3.8735	.000212
DELSPEED:HL	-.002266	.001759	-1.2883	.201186

APPENDIX D - Summarised responses to survey questions.

Year	**Gear change**	Implemented Y/N	**Reasons**
70's 80's	Otter boards: • larger v's smaller various sized flat boards were tried, fairly conservatively though, resulting in a SR ±10% • design change brief experimentation with Bisons	N	No perceived gain, trawling difficulties.
	Net design: • modified flats for double rig • new design flyers tried in 1980		Dawn, Stebeinhousen, Drynan (single rig, mud-rope with scallopchain), double rig went to the flats Witlof flats, to Lainge flats. See Bob regarding tapers changes. Thomo tried flyers, net distortion after a few weeks caused catch to drop off and eventually reach the catch level of the flats in use.
	Netting: • larger mesh-size few attempts, Garth tried 2.5 and happy • twine dia. 29ply, • twine type dynex, spectra tried, gundry tried and good but $		2.5 inch body tried, standard net 2 inch.
	Other: •		

2.What attempts were made to improve the catching efficiency of DR systems prior to the first appearance of a QR system?

Year	**Gear change**	Implem-ented Y/N	Reasons
	Trawl speed: •		
	Net design: • modified		

	• new design		
	Ground gear: • tickler chain		Good for maintaining catching efficiency, especially during periods when prawns are down (ie moon up and morning-shots)

3. How optimised do you feel the DR system was prior to the introduction of the first QR system?

4. What management-induced adjustments have been made to prawn-trawling effort in EG over the last two decades?

Year	**<u>Change</u>**
1967	First appearance of single rig trawler
1968	Double –rigged made an appearance
1969	3 x K-trawlers with double rig
1970's	Most vessels towing 7 fathom (7 x 3), with around 25% on 8 fathom (8 x 3).
1999	2 trawlers tried double 9's with same sized boards, not viable.

5. Have alternative management regimes been considered for the EG prawn trawl fishery at any stage in the past?

Possibly?

Management progressed towards the current arrangement, which works well.

- fishing season: 200 night maximum
- duration of season is contingent on catch-rates (>17 kg) and favourable catch-composition (incidence of small prawn-next years recruits coming through) being maintained towards the end of the season (April1 to Nov 30).
- each trawler has a fixed upper catch-limit of 1200 kg per vessel per night, which corresponds with their RSW capacity and ability to maintain catch-quality.

6. Is their any literature covering the history of prawn trawling in Exmouth Gulf?

7. Around the time when QR was introduced in 1999, what were the comparative daily catch-rates between similar HL DR trawlers, similar HL QR trawlers, and between DR and QR trawlers with similar total HL.

Rig types	Vessel details	Trawl Details	Landed catch	Relative catch
DR : DR				
QR : QR	Small vessels Larger vessels later on			25% 25%
DR : QR				

8. Did you find that similar vessels towing similar gear generally end up catching similar amounts by the end of the season, despite noticeable differences in daily-catch?

If not, how much catch-variance would you conservatively put down to skipper-skill?
Reduced to about 10% on average based on data from recent years (Smart-prawn)

9. What do you perceive as the likely cause(s) for similar QR and DR trawlers (when QR first introduced) having consistent differences in catch?

Rig types	SAP related	CE related	Other
QR : DR Similar trawlers Similar total HL	Sea-trials indicated: Inc. factor of between 1.16 & 1.22, and 1.25 was used as the HL adjustment factor for conversion based on using upper limit plus 2% extra for CE, and 1% for ?	Inc. factor 1.02	

10. Are the larger QR vessels currently catching relatively better than the smaller QR vessels once an adjustment for HL difference is made? Please provide details.

Rig types	Vessel details	Trawl Details	Landed catch	Relative catch
QR : QR	Refer sheet 1 Essentially, 3 trawl gear sizes in use (4.5, 5 & 6 fathom), and when adjusted per fathom over 30 nights, catch variation was 25 to 34kg/fthm, with a mean of 30kg/fthm. NB. some boats targeting different prawn species, & $/kg of species.			

11. How much potential for improvement in SAP and CE do you foresee with the current large and small QR trawlers?

(Note: not much to be had in the way of skipper prowess. It seems to be SAP driven.)

In regards to CE unless something very novel comes along, it is unlikely that any substantial gains are to be had.

On a full-cost benefit analysis, there is nothing overly attractive out there at the moment. This is partly because of a lack of demonstrable evidence relating to drag-saving options.

12. In light of the recent changes (trawl gear and trawler) in the EG fishery, are you considering a different management approach? If so, please provide details.

13. Do your large QR trawlers catch a kg of prawn more efficiently ($ / kg) compared to the smaller QR trawlers?

When all costs (vessel & gear maintenance, wages, fuel expense) are factored in, there is no stark difference. That said, the company is nevertheless trying to tether out some of the efficiencies that may be present with certain gear: vessel combinations to make a future decision on optimum trawl-size for a given vessel hp.

Are you able to provide some relative indices based on a seasons fishing?

14. Are there any noticeable differences in catch-composition between trawl rigs?

Rig types	Vessel details	Trawl Details	Landed catch	Relative catch
DR : QR_s QR_s : QR_L	HL ht at 3ft for most rigs, therefore no apparent HL ht effect on selectivity. After 1yr TED &FED were phased in which meant bycatch went down, making it difficult to ascertain further selectivity effects. One vessel (Sea fury) continues with 3.5 feet board ht, without any noticeable differences in cacth-composition.			

15. What do you put these differences down to?