FINAL REPORT

An empirical relationship between changes in headrope length and catch for the NPF fleet

A report to AFMA for the NPF RAG

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CMIS Report Number 07/80

29 June 2007

Commercial-in-confidence

FINAL REPORT

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Important notice

Use of this report

Executive Summary

- ❖ The present study presents an estimate of the average effect on catch in the NPF corresponding to a prescribed change in headrope length.
- ❖ The effect is shown to be specifyable as an expected percentage change in catch corresponding to any given percentage change in headrope length.
- ❖ The main result is given in graphical form as Figure 2, and in tabular form as Table 3 on page 11. The result is given in a way that can be applied to either decreases or increases in headrope length, with appropriate caution.
- ❖ The present report updates and extends some of the work in two previous reports to the NPF on possible input control measures for the NPF, namely Dichmont and Venables, (2001) and the Effort Trade-offs report (Venables, Dichmont, et al, 2003). The present study largely confirms the latter result.
- ❖ The study has to be done with logbook data only, which are ill-suited to this model building task due to the inevitable lack of any experimental control. Many factors will be confounded in the model and the results have to be treated with corresponding caution.
- ❖ Given these caveats, we recommend that the updated version of the catch and headrope change relationship continue to be used to inform management decisions in the NPF in the way it has been used in the past.

Contents:

Figures:

Tables:

Introduction

The present report is an updated and extended investigation of one aspect previously covered by a previous report (Bill Venables, Cathy Dichmont, *et al*, “Report to NORMAC on Effort Trade-off Proposals for the NPF”, NORMAC meeting, Darwin, 24th October 2003), which we refer to here to as the “Effort Trade-offs Report”. (The relevant extract from this report is Appendix D, and this has been attached to this report as Appendix 2 on page 16 below.) The reader is referred to this report for background, general orientation and motivation.

Using conceptually straightforward analytical techniques, the Effort Trade-offs Report offered an estimate of the average proportional effect on catch of proportional changes to the allowable headrope length for the fishery. The technique used the logbook record data to model catch rates (CPUE) in terms of the major determinants, on a per vessel basis. In addition to headrope length carried, these determinants included vessel characteristics and surrogates for changes in abundance.

There is a conceptual difficulty with trying to assess the effects of headrope changes when the only source of data available comes from the NPF fleet, for a period of time when headrope was initially limited, then relaxed in favour of A-units, and finally reinstated as the major direct instrument for management control.

In spite of these difficulties, we take the view that the best way available to us to predict the effects of changes in headrope length is to build an empirical model from the past available data and to isolate the appropriate effect. This approach was taken in a paper (Venables, W N & Dichmont, C M, “Effort control mechanisms for the NPF”, 2001) presented to NORMAC in August 2001. At that time there had been no mandatory headrope cuts in the recent NPF history, so the empirical relationship found relied on the hopeful assumption that the voluntary changes in headrope lengths that had been observed at that time would give a good indication of what the performance of the fleet would be under compulsory reductions. The Effort trade-offs study used a similar empirical approach, but had the advantage of several years’ data for which compulsory reductions in headrope length have been enacted.

The present study looks at empirical models a little more comprehensively, but adopts essentially the same empirical approach. Now, in mid 2007, there have been several rounds of quite severe reductions in the headrope unit values so the evidence available should be stronger and the message clearer. Nevertheless some fundamental difficulties remain, as they always will with studies that rely on observational evidence and no experimental control, implying that even with a very careful study there has to be some caution with interpreting and using the results. We return to this point in the discussion later in the report.

Scope

The present study is intended to provide the following:

1. A reassessment of empirical relationship models between catch and the principal determinants, in the light of a revised and extended data set over that available in 2003, and making use of improved modelling technology,
2. An investigation of the stability of the relationship over time, as the fleet size changes and the management scheme varies,

3. A recommendation on an updated empirical relationship curve to be used for management purposes within the NPF that is as safe, stable and realistic as possible in the light of the current fleet composition and gear disposition.
4. A presentation of the outcomes to AFMA via the NPF RAG as a short report.

Data

As in the previous two studies, the primary focus will be on the non-banana prawn component of the NPF. For model building and calibration purposes we have therefore restricted our data set to logbook records for the second half of the fishing year, which is overwhelmingly for tiger, endeavour and king prawns. Following advice from CSIRO staff who work intimately with the industry, we learn that in the second season most fishing is done with tiger prawn rigged nets, for logistical reasons, even on those uncommon occasions when the catch is predominantly banana prawns. (Quinton Del, CSIRO Marine and Atmospheric Research (CMAR), *personal communication*). We also understand from industry members that trawling for red-legged banana prawns in the Joseph Bonaparte Gulf (JBG) has more in common with tiger prawn fishing than with common banana prawn fishing for aggregations.

Study seasons: 1987-2006

Whereas the Effort trade-offs study was limited to second-season logbook records from the years 1991-2002, for reasons of data accuracy. The fishing power work, led by Janet Bishop, CMAR, has devoted a lot of energy and time to completing and improving the quality of the vessel characteristic database for the NPF, and we now feel it is safe to extend the series back to 1987, the first year when quad gear was banned and when fishing in the NPF became universally dual net, which it remains to the present. This gives us more time in the study when headrope length was at least limited by regulation, if not reduced as has been the case in recent years. We can also extend the series forward to 2006, the last year for which second season logbook records are currently available.

The year 2003, however, poses a problem. While the headrope record is reasonably complete, a decision was made in AFMA not to collect other vessel characteristics, such as engine power and hull size, for that year. This gap has been largely filled by subsequent survey work done in connection with fishing power, but engine power and hull units for vessels in 2003, quantities we need for this study, have had to be imputed from a variety of collateral sources. We have every reason to suppose that this process is reliable and in the few doubtful cases remaining we are confident will not significantly compromise our results.

Catch and effort

For this study we have decided to define 'Catch' as the total weight of all commercial species for any logbook record, that is, the sum of the four species groups:

$$C = B + T + E + K$$

This differs from the previous study where we took an 'economic catch', $C = T + \frac{1}{2}E$, largely for reasons of past convention. We believe the current definition is more appropriate for our purposes and we use all second-season records for model building and calibration purposes.

With this simple definition of catch, nominal effort is then appropriately defined as boat days spent in the fishery. The need to impute target and to separate 'banana' from 'tiger' effort is removed.

The primary modelling strategy used the total catch and effort for an individual vessel, for a single stock region[1], (see Appendix 1 on page 16) in any one season as the response variable. The first stock region, JBG, was excluded from the analysis, as it is largely a red-legged banana prawn fishery, but also because records from the JBG were in some seasons very few and this made the models very unstable. Thus each vessel contributes potentially six records per season to the data set for the model, but only if it visited all six tiger prawn stock regions in that season (excluding the JBG). Normally this will only be a subset of these, though.

A secondary modelling strategy, considered largely for investigative purposes, uses individual logbook records as the response.

Vessel characteristics

In addition to

- *headrope length* (fathoms),

the models we consider use the

- *engine power* (KW) and
- *hull size* (standard hull units)

of vessels as the main vessel characteristic that will contribute to catch effectiveness. However the models contain a random term for the vessel itself, to allow for other features of the vessel and crew that a model at this scale cannot otherwise capture.

This process led to 8473 complete records in the primary data set coming from 270 individual vessels. By contrast the data set used in the Effort Trade-off project had 4897 complete records from 212 individual vessels.

Trends in vessel characteristics

Over the study period, 1987-2006, the vessel configurations in the NPF have undergone many changes. For interest we present here in Figure 1 the average towed headline length (upper section, blue) and average engine power (lower section, red) for vessels in the NPF over the study period.

The headrope length is essentially accurate, as reported on the gear sheets. The engine power values contain some imputed figures for the earlier section of the record and for 2003, for reasons stated above. In addition in the period leading up to 2002 many engine power ratings have been revised through work done in the fishing power project, using a variety of elicitation techniques[2].

[1] The tiger stock regions are those as defined in the 'Risk' report in 2001, and since commonly used for many analytical purposes.

[2] In one egregious case a power rating was reported in KW but the figure quoted on the gear sheet was actually for a rating in HP!

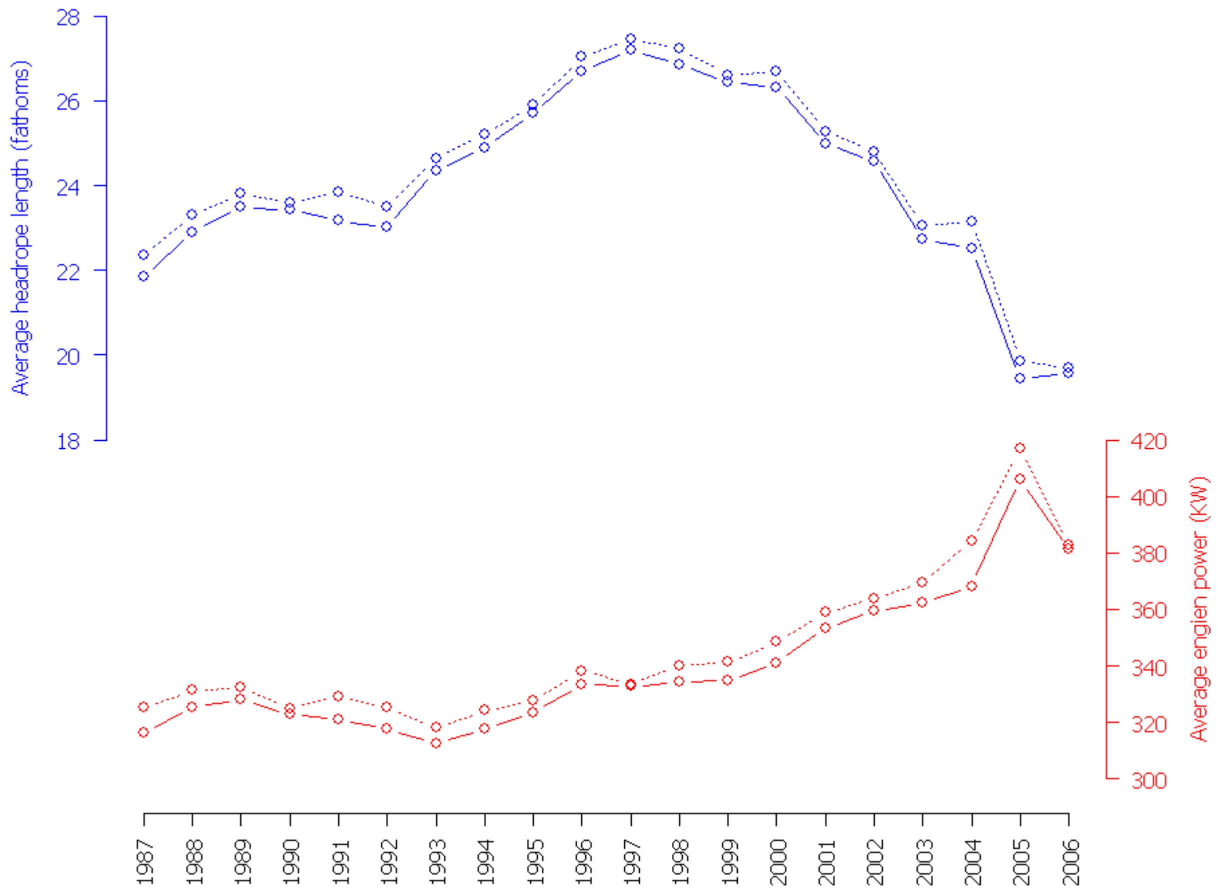

Figure 1: Average towed headline length and average engine power for vessels in the NPF. The solid lines show the vessel average, whereas the dotted lines show the figures weighted by frequency of occurrence in the logbook records.

Statistical model

Let C_{vys} and E_{vys} be the total catch and effort (boat days), respectively, for vessel v in the second season of a year, y, and stock region, s. We may assume that $E_{vys} > 0$. The vessel then has hull units U_{vy}, engine power P_{vy} and headrope length H_{vy}. Hull units generally remain fixed for the vessel from year to year during this period, but engine power occasionally changes between seasons. The statistical model we propose predicts $\log C_{vys}$ using fixed and random terms as follows

$$\log C_{vys} = \mu + \beta_H \log H_{vy} + \beta_P \log P_{vy} + \beta_U \log U_{vy} + \beta_E \log E_{vys} + \rho_s + \gamma_v + \delta_y + \tau_{ys} + \varepsilon_{vys}$$

where ρ_s is a fixed effect representing the average productivity differential for stock region s, and the final four terms are independent random effects,

- $\gamma_v \sim N(0, \sigma_\gamma^2)$ allows for catch differences between vessels (not explained by hull units, engine power and headrope length),
- $\delta_y \sim N(0, \sigma_\delta^2)$ allows for abundance differences between seasons (years),

- $\tau_{ys} \sim N(0, \sigma_\tau^2)$ allows for abundance differences between stock regions *within seasons* (as opposed to the fixed effect across seasons, ρ_s) and
- $\varepsilon_{vys} \sim N(0, \sigma^2)$ is an error term accounting for all other differences between log-catches.

The overall philosophy is that in a commercial fishery like the NPF the major differences between the catch performances of vessels, (at least those which can be attributed to objectively quantifiable factors), will be mostly explained by differences in the size and engine power . Most of the influences on catch will also be multiplicative, changing catch on average by some percentage rather than by some fixed amount. Modelling the result in the log scale, and similarly transforming the appropriate predictors, will change these multiplicative effects into additive ones, thus simplifying many complex interactions between the influencing factors. It should also greatly simplify the variance structure, making the analysis more efficient and interpretable.

Using a random effect for vessel is a parametrically economic way of allowing for other differences that are particular to the vessel, which can be important. The random effects of season and stock region within season are also a parametrically economic way of allowing for differences in abundance between seasons and between the major fishery regions within a season. The year effect will also capture, hopefully effectively, fishing power changes over the seasons, but these cannot be separated from abundance differences in this simple modelling strategy.

The random effects also have the effect of inducing correlations between catches within the same year and within the same stock region for that year, a feature that is clearly important and well in accord with observed experience. In this respect the present model is a good deal more sophisticated than the one presented in 2001, although the basic intuition is very similar.

The log scale is used for two reasons,

(a) the process is likely to be mainly multiplicative and hence additive in the log scale (and thus simpler to analyse), but more importantly

(b) the response, catch, is very likely to have approximately constant coefficient of variation rather than constant variance,

and hence the log provides a scale where the variation is approximately homogeneous.

The parameter β_H then measures the (partial) response of log-catch to changes in headrope length. Since only changes in headrope length are subject to management control, we argue that assessing the effect of management actions in this regard is best done by considering the change in log catch assuming all other variables are held constant. Where other variables are held constant we then have the relationship $C \propto H^{\beta_H}$ which in turn leads to the relative change formula

$$\Delta C = \left(1 + \Delta H\right)^{\beta_H} - 1$$

where $\Delta C = \left(C - C_0\right) / C_0$ is the proportional change in mean catch, corresponding to the change from H_0 (old) to H (new) in the headrope. Likewise $\Delta H = \left(H - H_0\right) / H_0$ is the proportional change in headrope length.

Results

The estimated coefficients, apart from fixed stock region effects, are as follows. For comparison the results from Effort Trade-offs have been repeated here as well, in Table 1:

Table 1: Parameter estimates and standard errors for the previous and present studies

	Effort Trade-offs		***Present study***	
	Value	Std Error	Value	Std Error
μ	2.0223	(0.2383)	2.2705	(0.1664)
β_H	0.3132	(0.0768)	0.3105	(0.0461)
β_P	0.1664	(0.0600)	0.1389	(0.0345)
β_U	0.1524	(0.0424)	0.1885	(0.0282)
β_E	1.1450	(0.0063)	1.1463	(0.0044)

The natural null hypothesis for β_E is 1, that is, that catch is proportional to effort with other factors remaining constant. This would be true if the resource were randomly distributed. The fact that its estimate is slightly (but significantly) greater than 1 suggests that fishers tend to remain in productive areas. Thus where effort is large, CPUE also tends to be larger than elsewhere. The fact that the coefficients for hull units and engine power are comparable but much less than unity tends to suggest that the catching capacity of a vessel is (roughly) a function of the product of hull size and engine power, but sub-proportional to it.

Finally the coefficient estimate $\beta_H = 0.3105$ provides the suggested link between headrope length and catch. This is remarkably close to the estimate obtained in Effort trade-offs, $\beta_H = 0.3132$ from a much shorter time span and with approximately half the current sample size, but larger than the previous estimate to that in Venables & Dichmont, (2001), which suggested a value near $\beta_H = 0.25$. We suspect that this is the result of having data where the headrope length changes were not voluntary and the link between headrope changes and catch is correspondingly stronger. Note, however, that this parameter is estimated only with a fairly large standard error, leading to the 95% confidence interval

$$0.2183 < \beta_H < 0.4027$$

which reflects the relative lack of information in the data for estimating this quantity. A graphical representation of the change relationship is shown in the next section below.

For completeness, the estimates of variance components (as standard deviations) are given in Table 2:

Table 2: Estimated variance component estimates from the previous and present studies.

	σ_γ	σ_δ	σ_τ	σ
Effort trade-offs	0.095406	0.000206	0.264869	0.441024
Present study	0.097933	0.192875	0.213025	0.415964

It would be unwise to read too much into these estimates since the data set is not well designed to estimate them. In particular the very small estimate for the between year component is unrealistic, but suggests that variation between stocks within seasons is more important than overall variation between year to year. Although the estimates are possibly unrealistic, it is nevertheless important to make an allowance for them in estimating the main parameters of interest.

A graphical representation of the main relationship

Figure 2 shows the main relationship between relative changes in catch and relative changes in headrope length, at least for reductions. This ignores the uncertainty in the estimate of β_H , but this could be incorporated if desired. The resulting error bounds, however, would be quite wide. For convenience a table of values is provided below as Table 3 on page 11.

We repeat the advice we gave in the Effort trade-offs report, namely that this empirical relationship has a very limited domain of applicability and should be used with caution for positive or negative percentage changes beyond the range of those seen in the calibration data, i.e. beyond $\pm 50\%$, approximately.

$$\Delta C = (1 + \Delta H)^{0.3105} - 1$$

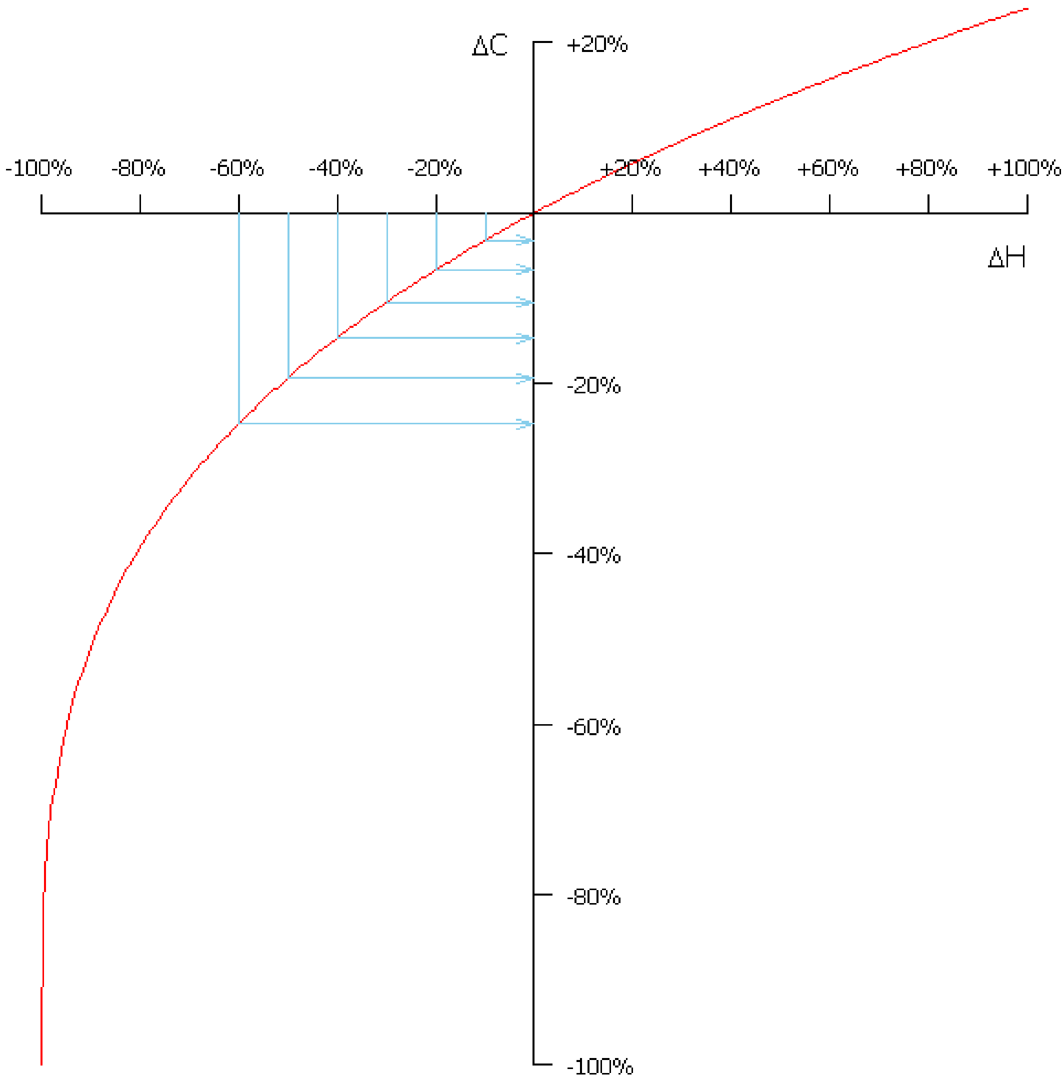

Figure 2: The relationship between relative change in catch for a relative change in headrope length.

Table 3: Expected percentage changes in catch corresponding to specified percentage changes in headrope length.

% change in H, (ΔH)	% change in C, (ΔC)	% change in H, (ΔH)	% change in C, (ΔC)
-95	-60.6	5	1.5
-90	-51.1	10	3.0
-85	-44.5	15	4.4
-80	-39.3	20	5.8
-75	-35.0	25	7.2
-70	-31.2	30	8.5
-65	-27.8	35	9.8
-60	-24.8	40	11.0
-55	-22.0	45	12.2
-50	-19.4	50	13.4
-45	-16.9	55	14.6
-40	-14.7	60	15.7
-35	-12.5	65	16.8
-30	-10.5	70	17.9
-25	-8.5	75	19.0
-20	-6.7	80	20.0
-15	-4.9	85	21.0
-10	-3.2	90	22.1
-5	-1.6	95	23.0

Discussion

Stability over time

To investigate the sensitivity of the estimate of β_H, and other parameters, to the data set used, a series of artificial model calibrations was done, each one using a 5-year window of the data set ranging from 1987-91 to 2001-06. These estimates must be treated with some caution. Short time spans make it very difficult to estimate the variance components due to year and 'stock region within year', in particular, and this will affect all other estimates to some extent. The computations were done for illustrative purposes only.

Figure 3 shows the partial estimates of β_H from this series of time windows. The estimate from the entire data set is shown as the dashed horizontal line, which is quite close to the top of the sequence. This is not in any sense a paradox but a consequence of the estimation instability allued to above.

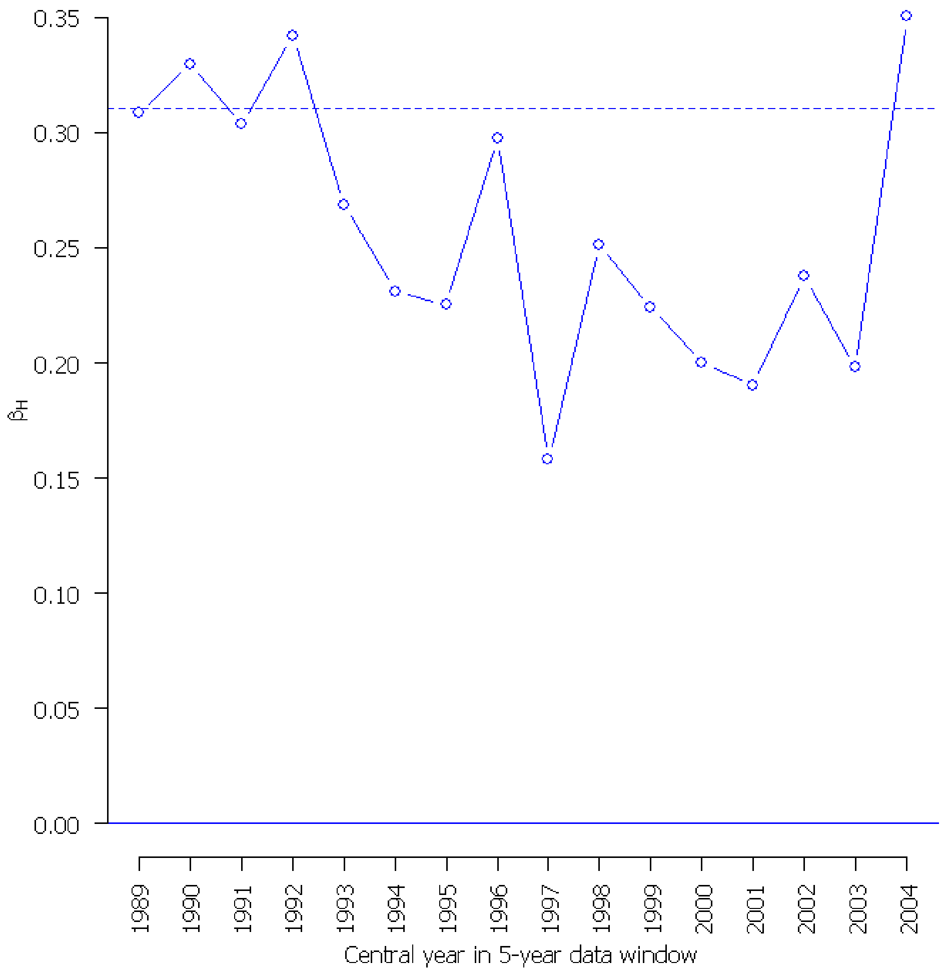

Figure 3: Estimates of β_H from a series of small datasets each covering a 5-year window, starting with 1987-91 and finishing at 2001-06. The dotted blue line shows the estimate from the complete data set.

The suggestion we take from this graph is that perhaps catch is more sensitive to changes in headrope at times when it is limited by management, as it was in the initial part of the sequence, and when it is subject to strong cuts, as in the most recent part of the sequence. At times when management is largely though alternative instruments, as in the central part of the series, the dependence is less. This interpretation is speculative, however, and would need to be checked by further research.

Sources of information and confounding

Trying to estimate the effect of headrope changes on catch from logbook records alone is an inherently difficult exercise. The main reason for this is largely the lack of any experimental control, which results in factors being confounded and an inevitable degree of volatility and even ambiguity in the results.

We note that information on the effect of changes in headrope on catch conceptually can come from two kinds of source, namely

1. Information from individual vessels which change their headrope lengths over time (intra-vessel information) and
2. Information by comparing different vessels, (inter-vessel information).

Since vessels only change their headrope between seasons (according to the gear sheet record, at least) the intra-vessel information is directly confounded with seasonal variations in abundance. It is only by comparing the intra-vessel information from two distinct vessels, one of which changes its headrope length and the other does not, that we obtain the most direct component of intra-vessel information.

We try to remove 'abundance' effects, which include spatial and temporal variations in actual abundance as well as 'availability' and 'catchability' (including fishing power) effects in two ways. We fit a systematic term for the individual stock regions, the purely spatial component, a random term for the seasonal, or purely temporal, effect and a random interaction between region and year. The fixed effect for regions is an innovation in this particular modelling approach, and appears significantly to enhance the model. The random terms are essentially markers for variance parameters, and the estimation process is geared to estimating these unknown variances (as reported in Table 2 on page 9). To estimate a variance usually requires a fairly large sample size, the larger the better. This is possibly the reason why the variance estimate for 'Seasons' is very different for the short series of 11 years in the Effort trade-offs study from that of the present study, which uses 20 years.

This is also at the core of the reason why the estimates based on the 5-year moving windows are unreliable, and only offered for investigative purposes. The short time series involved for each make the seasonal estimate somewhat unreliable, which in turn makes the ability of the model to resolve intra-vessel information confounding with seasonal effects somewhat limited.

By contrast, inter-vessel information, by definition, is confounded with vessel differences. We try to remove vessel effects in two ways. We use systematic effects for hull size, engine power and, of course headrope length, to accommodate one easily identifiable and quantifiable source of inter-vessel differences. The remaining, less tangible, differences are handled in the model by the random term for vessels.

Unlocking seasonal, spatial and inter-vessel differences, in principle, should allow the intra- and inter-vessel information to be isolated and optimally combined to furnish efficient estimates for the key parameter of interest, the headrope exponent, β_H.

Without experimental control, however, the extent to which this process succeeds must remain somewhat unknown, and hence the advice to use the results with caution.

Scale of the analysis

We have chosen to sum catch and effort on a per-vessel basis for a complete season and stock region and to model the process at this aggregated scale. As part of this study we also did an analysis at a much finer scale, based on the individual logbook record. At this scale the influences on catch that need to be taken into account in order to isolate the effect we are looking for are more numerous and *in addition* to the spatial, temporal and vessel characteristics already noted include

1. Within season effects, for example availablility patterns,
2. Depletion effects as the season progresses,
3. Moon phase, which is often claimed to have an effect on catch
4. Possible interactions between these effects and stock region and season.

This makes for a much more complex model, and not necessarily more precise estimates, even if the apparent sample size is very much larger.

Although the analysis produced what appeared to be credible estimates for most parameters, but the headrope exponent, β_H, was somewhat lower at about 0.25. We decided not to pursue the analysis at the finer scale, mainly because we were not confident that the modelling strategies available to us were sufficient to capture the dependencies (or correlations) between vessels that must exist at this scale. Aggregating to the vessel/season/stock region scale to some extent must overcome this, (if not in a very elegant way).

Nevertheless we consider it appropriate to report that this avenue of investigation was considered.

Implied link between headrope and effort changes

The empirical model we have fitted includes nominal effort as a predictor. To the extent that a change in headrope implies a change in catch, we can extend the idea to arrive at an equivalent change in effort. The model itself implies that

$$C = kH^{\beta_H} E^{\beta_E}$$

where k depends on hull size, engine power and the random terms which we here hold constant. Suppose H_0 is a changed headrope length which produces a new expected value for catch of C_0 and let E_0 be the changed value of effort which produces the same expected catch without a change to headrope. It follows that

$$kH_0^{\beta_H} E^{\beta_E} = C_0 = kH^{\beta_H} E_0^{\beta_E}$$

This in turn implies that

$$\left(\frac{H}{H_0}\right)^{\beta_H} = \left(\frac{E}{E_0}\right)^{\beta_E}$$

which can be written as

$$\Delta E = \left(1 + \Delta H\right)^{\beta_H/\beta_E} - 1$$

where, as before, ΔH is the relative change in headrope and ΔE is the analogous change in implied effort. From the fitted model we have the estimates

$$\hat{\beta}_H / \hat{\beta}_E = 0.3105/1.1463 = 0.2709$$

A graph of the relationship is shown in Figure 4 below.

$$\Delta E = (1 + \Delta H)^{0.2709} - 1$$

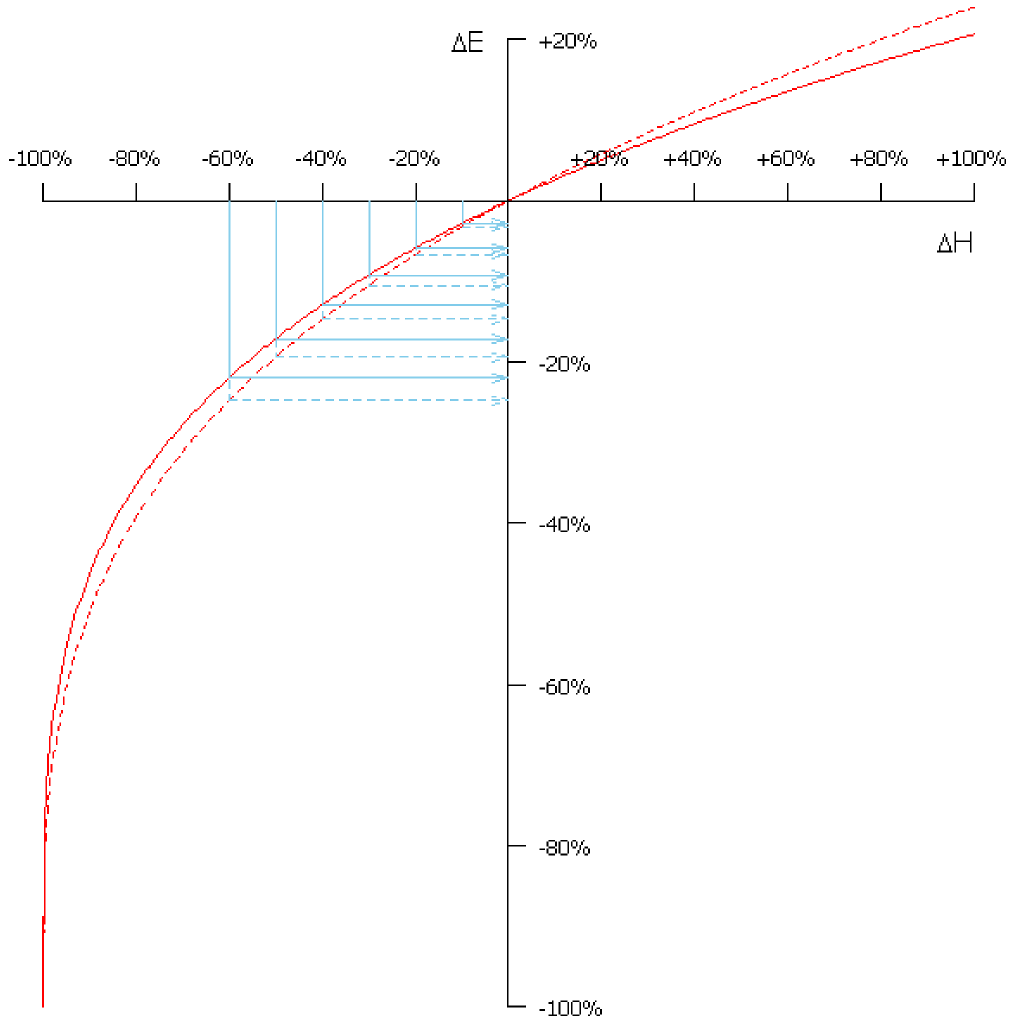

Figure 4: Relationship between relative change in headrope length and catch. For comparison the corresponding relationship between catch and headrope changes is shown as a dashed curve.

The interpretation of this relationship is somewhat subtle. The relationship between catch and headrope changes shows the expected proportional change in catch the fleet would expect corresponding to an actual proportional change in headrope length. The present relationship shows the relative change in effort that the fleet should see as equivalent to a given relative change in headrope length, in the sense that it produces the same relative change in expected catch. The important point to notice is that the actual proportional change in effort corresponding to an *imposed* change to headrope units may be somewhat different, as the fleet may elect to absorb the change in ways other than by actually cutting or extending the headrope on the vessels active in the fishery.

Appendix 1: The tiger prawn stock regions for the NPF

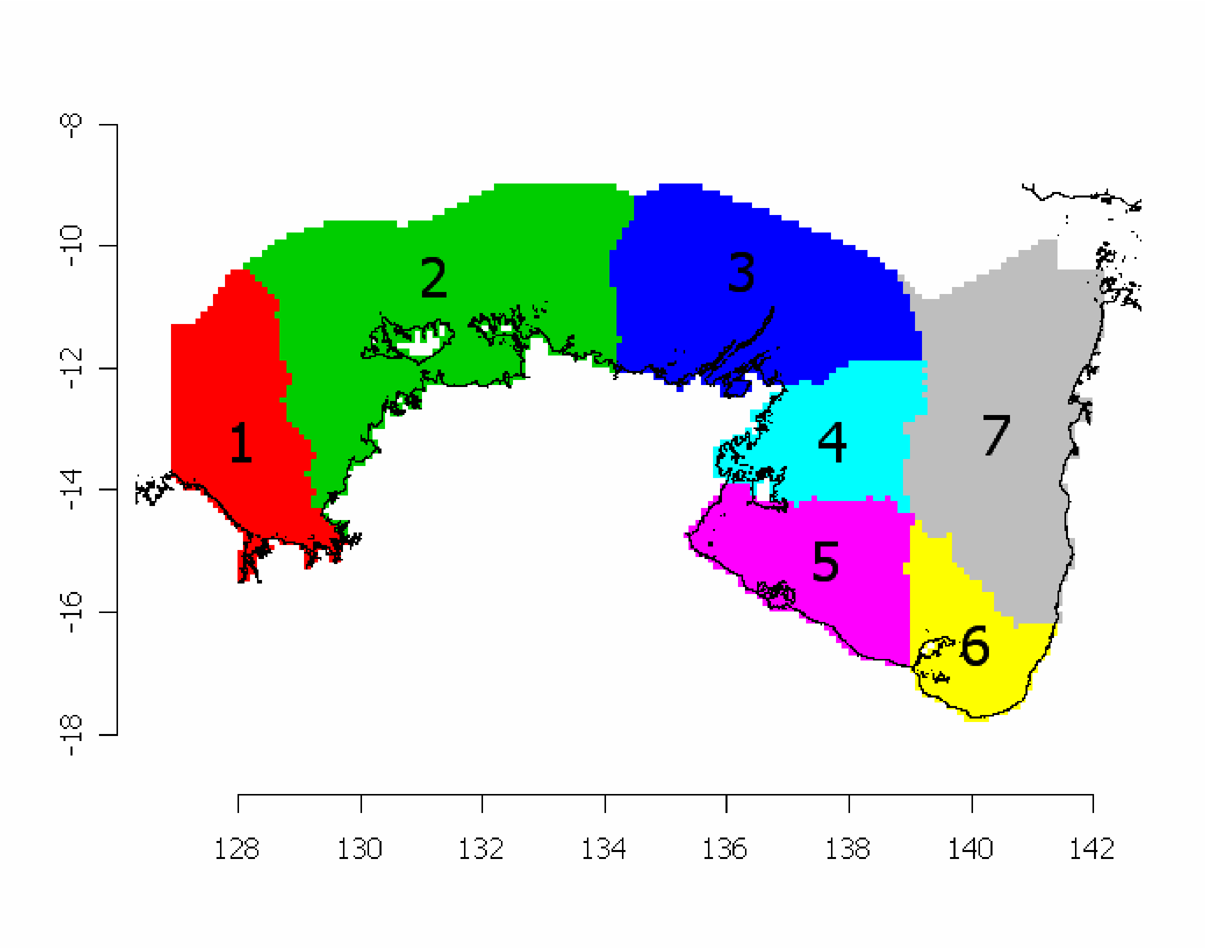

Figure 5: Tiger prawn stock regions. 1 = JBG, 2 = Melville-Coburg, 3 = Arnhem, 4 = Groote, 5= Vanderlins, 6 = Karumba, 7 = Weipa

Appendix 2: An extract from the Effort Trade-offs report

This section is a verbatim copy of Appendix D of the Effort Trade-offs report, presented to the NORMAC REC in Darwin, 24 October, 2003. It is included here for reference.

Appendix D: An empirical relationship between changes in headrope and changes in catch for the NPF

The NPF is an input-controlled fishery with the allowable headrope length (controlled through tradable gear units) as the major management instrument. The other mechanisms include spatial and temporal closures. If the headrope length on an NPF vessel is adjusted and the skipper takes no compensatory or countervailing measures, the changes in swept area performance by the vessel are to some extent mechanically predictable. This is the primary output of the Prawn Trawl Prediction Model of D J Sterling. (See Dichmont, C M *et al.* "A new approach to fishing power and its application to the NPF" Final Report, 2003.) In general, if the headrope length is shortened and the trawl gear is optimised for the new net size, the vessel will speed up. The resultant effect on swept area performance is often quite small, unless the change in headrope is very large. The key point is that the consequence of headrope cuts depends on the operator response, and as yet we have no way to predict this for the short term, although it may be reasonable to assume that gear will eventually be optimised over a number of years. It has been suggested to us that we should not assume that operator responses to future cuts would be the same as they have been until now, because after the recent cuts, vessels are now close to the limit within which the same styles of adaptations can be made.

Nevertheless, for this exercise we proceed by assuming that operator responses to future headline cuts will be similar to responses to past cuts. Elsewhere we also investigate alternatives where cuts lead to reductions in the fleet size. In 2002, when the large reduction in the headrope unit size took place, the fleet reduced in size by fifteen vessels; eleven of the remaining fleet increased their headline length, and 79 out of the 98 vessels that remained in the fleet took a headrope cut, of 6.6 metres on average.

Therefore we take the view that the best way to predict the effects of changes in headrope length is to build an empirical model from the past available data and to isolate the appropriate effect. This approach was taken in a paper (Venables, W N & Dichmont, C M, "Effort control mechanisms for the NPF", 2001) presented to NORMAC in August 2001. At that time there had been no mandatory headrope cuts in the recent NPF history, so the empirical relationship found relied on the hopeful assumption that the voluntary changes in headrope lengths that had been observed at that time would give a good indication of what the performance of the fleet would be under compulsory reductions. The present study uses a similar empirical approach, but now has the advantage of several years' data for which compulsory reductions in headrope length have been enacted.

Data

This study is primarily concerned with the effect of headrope length changes on the tiger fishery in the second season of the year. Accordingly the data used comes from the standard logbook record for the NPF, but aggregated as follows:

1. Only records from the second season for the years 1991-2002 were used.

2. Records from the first stock region (JBG) were few and excluded for stability reasons.
3. For each vessel, for each season, the total Catch, in each of the six remaining stock regions and the total nominal Effort, defined as the number of nights fished in the stock region for that season when the target was either tiger species, formed the basic data.
4. Catch for our purpose is defined as the so-called 'economic catch', that is the tiger catch plus half the endeavour and king prawn catch. (In fact the catch is arbitrarily increased by 0.5 kg to allow us to work in the log scale without excluding a very small number of zero catches.)
5. Each vessel may have up to six catch and effort values for each (second) season. Only records with positive effort are used.
6. Vessel information used included
   a) The vessel indicator (Vcode) itself,
   b) Hull units and engine power used for each season,
   c) The headrope length used in each season, (the primary predictor of interest).

This process led to 4897 complete records in the primary data set coming from 212 individual vessels.

Statistical model

Let C_{vys} and E_{vys} be the economic catch and tiger effort, respectively, for vessel v in the second season of a year, y, and stock region, s. We may assume that $E_{vys} > 0$. The vessel then has hull units U_{vy}, engine power P_{vy} and headrope length H_{vy}. Hull units generally remain fixed for the vessel from year to year during this period, but engine power occasionally changes between seasons. The statistical model we propose predicts $\log C_{vys}$ using fixed and random terms as follows

$$\log C_{vys} = \mu + \beta_E \log E_{vys} + \beta_U \log U_{vy} + \beta_P \log P_{vy} + \beta_H \log H_{vy} + \gamma_v + \delta_y + \tau_{ys} + \varepsilon_{vys}$$

where the final four terms are independent random effects,

- $\gamma_v \sim N(0, \sigma_\gamma^2)$ allows for catch differences between vessels (not explained by hull units, engine power and headrope length),
- $\delta_y \sim N(0, \sigma_\delta^2)$ allows for abundance differences between seasons (years),
- $\tau_{ys} \sim N(0, \sigma_\tau^2)$ allows for abundance differences between stock regions within seasons and
- $\varepsilon_{vys} \sim N(0, \sigma^2)$ is an error term accounting for all other differences between log-catches.

The overall philosophy is that in a professional fishery like the NPF the major differences between the catch performance of vessels will be mostly explained by differences in size and power of vessel. Using a random effect for vessel is a parametrically economic way of allowing for other differences that are particular to the vessel, which can be important. The random effects of season and stock region within season are also a parametrically economic way of allowing for differences in abundance between seasons and between the major fishery regions within a season. They also have the effect of inducing correlations between catches within the same year and within the same stock region for that year, a feature that is clearly important and well in accord with observed experience. In this respect the present model is a good deal more sophisticated than the one presented in 2001, although the basic intuition is very similar.

The log scale is used for two reasons, (a) the process is likely to be mainly multiplicative and hence additive in the log scale (and thus simpler to analyse), but more importantly (b) the response, catch, is very likely to have approximately constant coefficient of variation rather than constant variance, and hence the log provides a scale where the variation is approximately homogeneous.

The parameter β_H then measures the (partial) response of log-catch to changes in headrope length. Since only changes in headrope length are subject to management control, we argue that assessing the effect of management actions in this regard is best done by considering the change in log catch assuming all other variables are held constant. Where other variables are held constant we then have the relationship $C \propto H^{\beta_H}$ which in turn leads to the relative change formula

$$\Delta C = 1 - (1 - \Delta H)^{\beta_H}$$

where $\Delta C = (C_0 - C)/C_0$ is the relative change in catch from C_0 to C, and ΔH is the corresponding relative change in headrope length.

Results

The estimated coefficients are as follows

	Value	Std Error
μ	2.0223	0.2383
β_E	1.1450	0.0063
β_U	0.1524	0.0424
β_P	0.1664	0.0600
β_H	0.3132	0.0768

The natural null hypothesis for β_E is 1, that is, that catch is proportional to effort with other factors remaining constant. This would be true if the resource were randomly distributed. The fact that its estimate is slightly (but significantly) greater than 1 suggests that the resource is aggregatory and that fishers tend to remain at productive areas. Thus where effort is large, CPUE also tends to be larger than elsewhere. The fact that the coefficients for hull units and engine power are approximately equal but much less than unity tends to suggest that the catching capacity of a vessel is (roughly) a function of the product of hull size and engine power, but sub-proportional to it.

Finally the coefficient estimate $\beta_H = 0.3132$ provides the suggested link between headrope length and catch. This is larger than the previous estimate in Venables & Dichmont, (2001), which suggested a value near $\beta_H = 0.25$. We suspect that this is the result of having data where the headrope length changes were not voluntary and the link between headrope changes and catch is correspondingly stronger. (In fact an extended model that allows this parameter to vary with time suggests that it consistently increases with year, but the effect is not statistically significant.) Note, however, that this parameter is estimated only with a fairly large standard error, leading to the 95% confidence interval

$$0.1596 < \beta_H < 0.4667$$

which reflects the relative lack of information in the data for estimating this quantity. A graphical representation of the change relationship is shown in the next section below.

For completeness, the estimates of variance components (as standard deviations) are as follows

σ_γ	σ_δ	σ_τ	σ
0.09540554	0.0002060327	0.2648688	0.4410239

It would be unwise to read too much into these estimates since the data set is not well designed to estimate them. In particular the very small estimate for the between year component is unrealistic, but suggests that variation between stocks within seasons is more important than overall variation between year to year. Although the estimates are possibly unrealistic, it is nevertheless important to make an allowance for them in estimating the main parameters of interest.

A graphical representation of the main relationship

Figure 2 shows the main relationship between relative changes in catch and relative changes in headrope length, at least for reductions. This ignores the uncertainty in the estimate of β_H, but this could be incorporated if desired. The resulting error bounds, however, would be quite wide. Figure 7 shows the actual percentage reductions taken on NPF vessels in 2002.

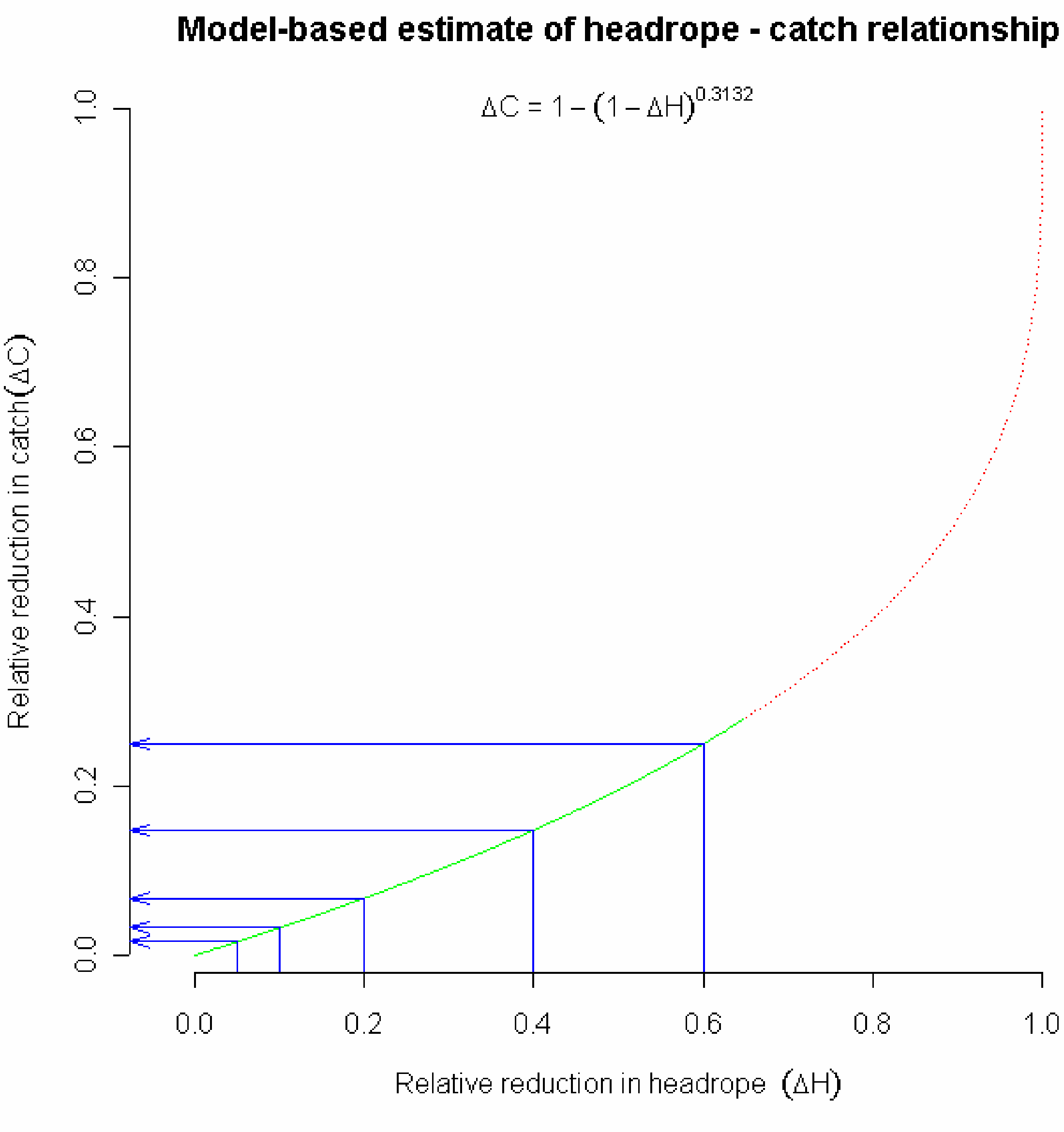

Figure 6: The estimated relative reduction in catch for a relative change in headrope length.

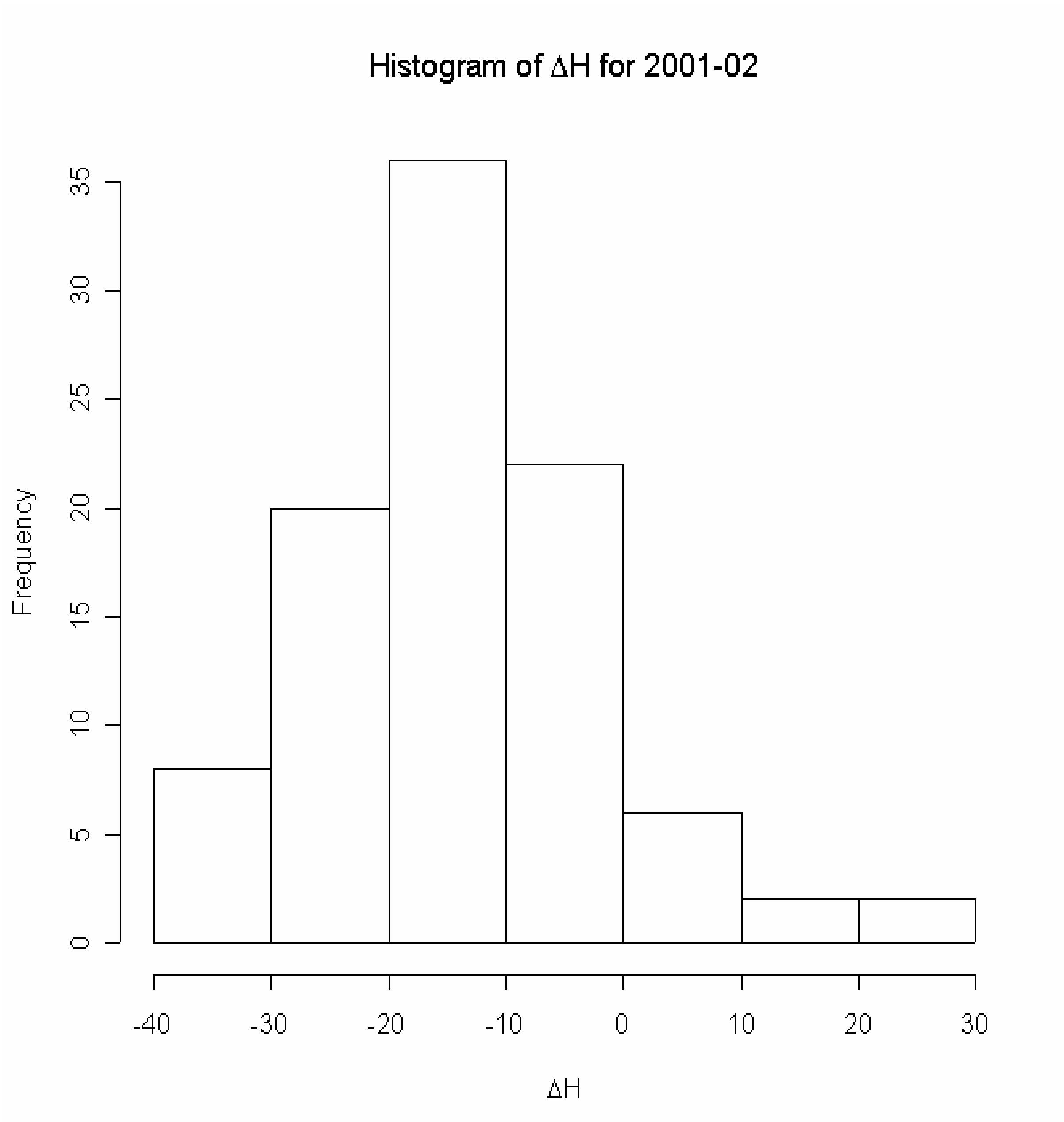

Figure 7: Histogram of actual percentage headrope length reductions made on vessels in 2002