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Modified hooks reduce incidental mortality of snapper (*Pagrus auratus*: Sparidae) in the New Zealand commercial longline fishery

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In longline fisheries, decreasing the catch of undersized fish and minimizing the rate of gut-hooking over all sizes will reduce incidental mortality, and improve the landed value of the commercial catch. In this study, standard Tainawa 16R longline hooks were simultaneously fished for snapper (*Pagrus auratus*) with the same hook pattern modified by the addition of 20-mm and 40-mm wire appendages. The experimental design also included three bait types. Gut-hooking rates were markedly lower on modified hooks relative to normal hooks. Normal hooks gut-hooked 17% and 30% (pooled across baits) of snapper caught in January and June, respectively, whereas 20-mm modified hooks gut-hooked 7% and 12%, and 40-mm hooks gut-hooked only 2% in both seasons. Overall catch rates were significantly lower on modified hooks, however most of the loss of catch comprised undersized fish and "deads" (unsuitable for export). There was no significant reduction in the weight of export-quality snapper landed using modified hooks. Modified hooks reduced both the catch rate and gut-hooking rate of undersized snapper. If it is assumed that all gut-hooked discards are likely to die, the estimated annual reduction in discard mortality at the stock level would be 78% if 20-mm hook modifications are used, and 96% if 40-mm modifications are used. These estimates are consistent for scenarios where minimum legal size is set at both 25 cm and 27 cm, however they are based on the assumption that observed catch and mortality rates are representative of the commercial fishery.

Keywords: hooks, discard mortality, longline, *Pagrus auratus*, selectivity.

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Introduction

The sparid snapper (*Pagrus auratus*) is a carnivorous, demersal fish that forms important commercial and recreational fisheries throughout its geographic range, from Japan in the north to Australia and New Zealand in the south (Paulin, 1990). High fishing pressure in northeastern New Zealand has placed the stock (SNA1) under stress, with current estimates of stock size at 66% of B_{MSY} (Davies *et al.*, 1999). To assist in rebuilding of the SNA1 stock, it is desirable to reduce incidental mortality (Chopin *et al.*, 1997) of sub-legal (<25-cm fork length, FL) snapper as far as practicable. Such mortality is not presently included in the SNA1 stock assessments but quantification of its impact on the fishery is now under investigation (Harley *et al.*, 2000a).

Presently, about 60% of the SNA1 quota is taken by longline (Davies *et al.*, 1999). Longlining has long been regarded as a size- and species-selective method of fishing (Løkkeborg and Bjordal, 1992), notwithstanding that there is limited knowledge about the precise shape of hook size-selection curves (Millar and Fryer, 1999) other than the general belief that these curves are typically broad (Pope *et al.*, 1975). The broadness of the selection curves prohibits the possibility of achieving size-selectivity that is close to "knife edge" at the minimum legal size. So, while larger hooks of a given pattern can be very effective at reducing the catch of undersized fish, they will typically incur a substantial loss of the smaller legal-sized fish (Ralston, 1990; Otway and Craig, 1993). This loss may be offset by an increase in catch of the largest sizes of fish on the larger hook, though this is by no means certain as there have been some studies which showed smaller hooks to be equally effective at catching the largest sizes (e.g. Erzini *et al.*, 1996; Sousa *et al.*, 1999).

The likelihood of post-release mortality of discards or bycatch from commercial hook fisheries has been sparsely examined, although there is a substantial literature associated with recreational (angling) fisheries (e.g. Muoneke and Childress, 1994; Chopin and Arimoto, 1995). In the snapper longline fishery, discard mortality is highly dependent on the location at which the hook is embedded inside the fish (McKenzie, 1999). Lip-hooked snapper are generally alive when brought on board (pers. obs.), are easily removed from the hook, and suffer low discard mortality. In contrast, fish that ingest the hook ("gut-hook") are usually moribund or dead when brought on board and discards are highly likely (>98%) to die as a result of damage to the gills or viscera (McKenzie, 1999).

Hook location is also relevant to the value of the landed catch because the highest economic value of snapper is obtained when legal-sized fish are boated alive and killed by the "iki jime" method (brain spiked). Snapper boated dead or in moribund condition suffer a rapid decrease in flesh quality, making them unsuitable for the export market. Overall value of the total allowable commercial catch (TACC) will therefore be increased by reducing the gut-hooking rate of legal-sized fish. Moreover, snapper mature at ± 23 cm FL (Scott, 1991), and capture stress in snapper can often result in gonadal atresia post-release (Carragher and Pankhurst, 1991), so reduction in catch of unwanted size classes may also have the indirect advantage of reducing losses in annual spawning biomass.

Increasing hook size would be one possibility for decreasing the catch of undersized snapper and the rate of gut-hooking. However, preliminary evidence (Ministry of Fisheries, 1997) suggested that the use of a modified hook could achieve these goals with little reduction in overall catch rate of legal-sized fish, and hence require little increase in fishing effort to achieve the TACC. The modified hooks (the "Barnes" hook) are made by the addition of a wire appendage to the standard hook. The wire projects posteriorly from the hook eye at an angle of approximately 45° to the shank. The appendage is thought to form a physical barrier to ingestion by small snapper, and the sharp point may also inhibit swallowing of the hook by larger fish.

This paper documents experimental trials designed to test the effects of modifications to standard longline hooks on gut-hooking (and hence incidental mortality)

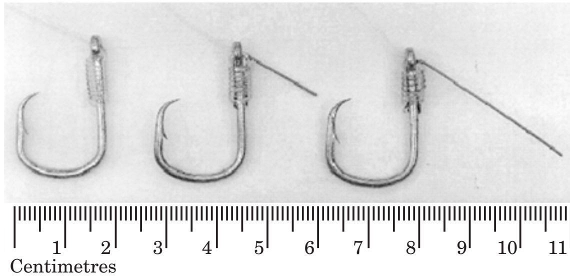

Figure 1. Photograph of the three hooks fished in this study. From left to right: a normal 16R pattern hook, hook fitted with a 20-mm appendage, hook fitted with a 40-mm appendage.

rate, catch rate, and relative (indirect) size selectivity in the snapper fishery. This was done by simultaneously fishing the normal hook with two variants of modified hook and recording the size, hook site and physical condition of all snapper caught. Three bait types were used to determine whether there were any interactions between hook modifications and baits commonly used in the fishery. This is the first scientific study to experimentally test an innovation to longline gear technology in the New Zealand snapper fishery.

Materials and methods

Fishing operations

Modified hooks were tested by fishing all treatments simultaneously from the 18-m commercial longline vessel "Oceana". The mainline was 100-kg breaking strain (bs) monofilament with hook spacers at 3 m intervals. The line was weighted during deployment at 25 hook intervals with 1 kg lead weights. All hooks tested were the Tainawa 16R pattern, used almost universally in the SNA1 longline fleet (Figure 1). These were tied to a 55 cm snood of 36.5 kg bs. Surface floats were attached to the line at 150 hook intervals, to minimize the likelihood of gear loss in the event of mainline breakage.

The line was shot at a boat speed of 6 kt, and deployment time for each shot was approximately 30 min. Soak time after deployment was 1 h before retrieval commenced, and retrieval time was 1.5–2 h.

Sampling design

Three hook configurations were tested: normal hooks, hooks with a 20-mm long appendage, and hooks with a 40-mm long appendage. To attempt to encompass some of the between-vessel variability in fishing strategy, we also tested three baits: arrow squid *Notodarus sloanii*, pilchard *Sardinops neopilchardus*, and blue mackerel *Scomber australasicus*. The hooks and baits were incorporated into a factorial design so that nine treatment combinations were fished.

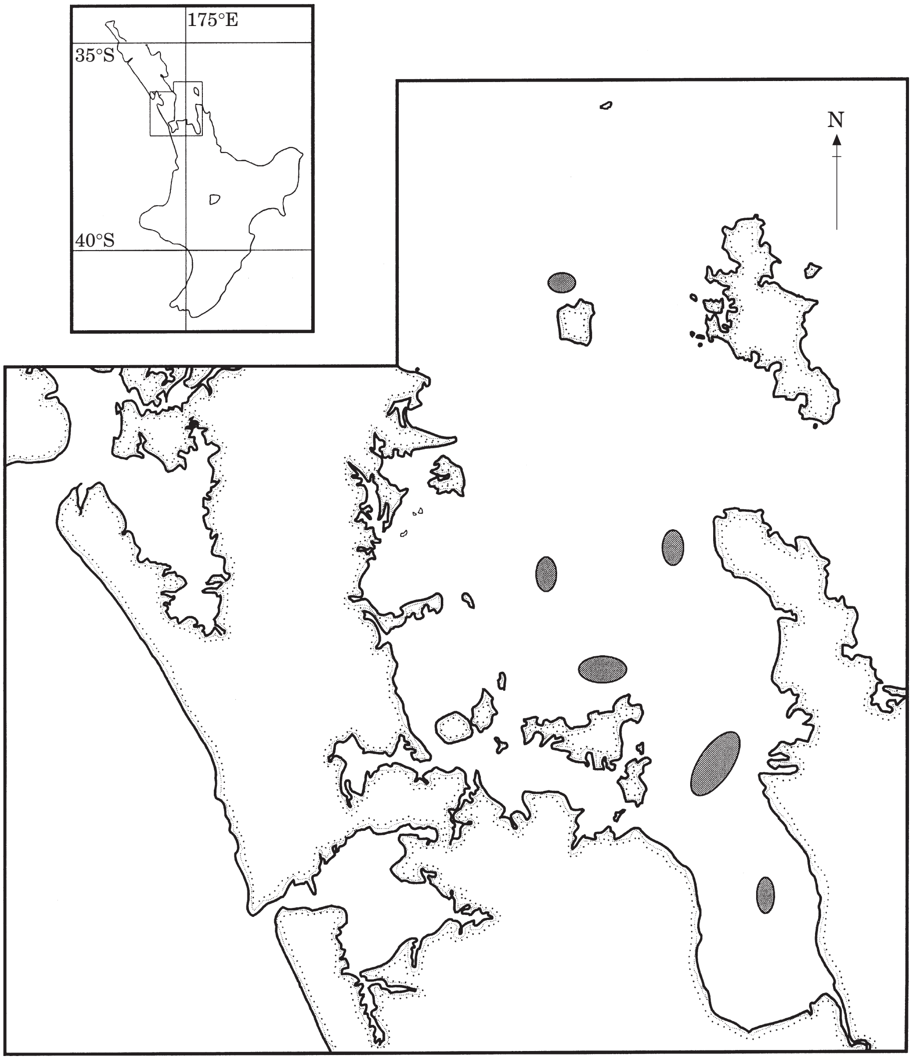

Figure 2. Map of the Hauraki Gulf. Shaded ellipses indicate approximate locations of fishing trials. The inset shows the North Island of New Zealand with the map area defined.

It was impracticable to completely randomize the treatments by individual hooks, so the nine treatments were set as three replicate blocks of 50 hooks, giving 1350 hooks per shot. The order of treatments was determined randomly before sailing. Treatments were identified by clipping plastic tags (marked with the appropriate treatment number) to the lead weight preceding each treatment block.

To determine whether seasonal effects might affect gut-hooking rate or catch rate, two series of cruises were completed in January (summer) 1999, and June (winter) 1999. Thirteen shots were completed in summer, and twelve in winter. These were distributed around the Hauraki Gulf so as to encompass any geographical variation in the response of snapper to baits or hooks (Figure 2).

Data collection

The position (from the ship's GPS), depth, and the time of each shot were recorded at the beginning of deployment, after 450 hooks, after 900 hooks, and once all hooks were deployed.

The fate of each hook was recorded by the skipper as gear was retrieved (catch, bait present, bait absent, bait partial, hook bitten or broken off) using a dictaphone. The catch was then transferred to the scientific staff, where it was identified, measured (to nearest cm below fork length) and mode of hooking described (lip, side mouth, foul, gills, gut). Measurements and hooking mode were recorded both by dictaphone and on paper.

During data entry, the three data sources (skipper's dictaphone, researcher's dictaphone, and researcher's paper recording) were cross-checked to eliminate errors. On a few occasions there was conflict in classification of hook site as lip vs. side and of gut vs. gills. To negate this conflict and to simplify the analysis, in what follows, lip-hooked refers to fish that were hooked in the mouth (lip or side-hooked) and gut-hooked refers to fish that swallowed the hook (gill or gut-hooked).

Data analysis

Catches were analysed with respect to both numbers and weight. Numbers are more relevant to quantification of pre-recruit mortality and weight is more relevant to quantification of commercial catch rates.

The analyses described below utilize mixed models, that is, models having both fixed and random effects. Hook type, bait type and season correspond to fixed effects because the levels of these effects (three hooks, three baits, and two seasons) represent all levels about which we wish to make inference (Verbeke and Molenberghs, 1993). However, shot is a random effect because the 25 shots should be regarded as a random sample from a much larger "population" of shots, and it is with respect to this large population that we wish to make inference about catch rates.

Numbers

The number of snapper caught by a treatment (hook-bait combination) is observed over a fixed number of deployments of that hook-bait combination. That is, the counts of snapper can be considered the number of "successes" out of a fixed number of trials (hooks retrieved). Thus, it is appropriate to model the counts as binomial, or more generally, as over-dispersed binomial to take into account the effect of patchiness in the spatial distribution of snapper.

When only fixed effects are present then binomial data are routinely fitted using logistic regression, which is a particular case of a generalized linear model. In the presence of both fixed and random effects the application of logistic regression then corresponds to the use of a generalized linear mixed model (GLMM). For example, the logistic regression model containing only the main effects of hook, bait and season and the random shot effect is of the form:

$$\mathrm{logit}(p_{ijkl}) = \log\left(\frac{p_{ijkl}}{1-p_{ijkl}}\right) = \mu + \alpha_i + \beta_j + \delta_k + \varepsilon_l \quad (1)$$

where p_{ijkl} denotes the probability of catching a snapper on the hook of type i (i=1,2,3) using bait j (j=1,2,3) in season k (k=1,2) and shot l. The levels of the main effects, μ, α_i, β_j, and δ_k are unknown parameters to be estimated. The random effects of shot, ε_l, are assumed to be independent and identically distributed as normal random variables with mean 0.

The right-hand side of Equation (1) is a standard linear mixed model and can be altered to include any interactions of interest. Model selection was performed by using backward model fitting whereby the full model (three-way interactions of fixed effects) was fitted and then non-significant interactions progressively removed. The fits were implemented using the GLIMMIX[1] macro (Littell *et al*., 1996) for SAS (version 6.12).

The analysis of snapper numbers can equally well be applied to a subset of the snapper catch. In addition to modeling the numbers of snapper, the numbers of snapper in the following categories were also modeled using the GLMM approach presented above:

(i) Gut-hooked undersized (<25 cm FL) snapper
(ii) Lip-hooked undersized snapper
(iii) Gut-hooked legal-sized snapper
(iv) Lip-hooked legal-sized snapper
(v) Export quality legal-sized snapper (irrespective of hooking mode)

Weights

Snapper weights (kg) were estimated from fork length (cm) using the formula of Paul (1976):

$$W = (0.0447 \times L^{2.793})/1000$$

Weights were examined on the multiplicative scale (whence an effect is quantifying a percentage change in weight) by employing log-linear models. Here, this is again a particular case of a generalized linear mixed model with, for example, the log-linear regression model containing only the main effects of hook, bait and season and the random shot effect being of the form:

$$\log(w_{ijkl}) = \mu + \alpha_i + \beta_j + \delta_k + \varepsilon_l \quad (2)$$

where w_{ijkl} denotes the expected weight of snapper caught on hook type i (i=1,2,3) using bait j (j=1,2,3) in season k (k=1,2) and shot l. The right-hand side of Equation (2) is interpreted analogously to that of Equation (1).

Analysis of catch weights was restricted to legal-sized snapper and was also applied to the following categories of catch:

(i) Gut-hooked legal-sized snapper
(ii) Lip-hooked legal-sized snapper
(iii) Export quality legal-sized snapper

Stock-scale discard mortality estimates

Stock-scale (SNA1) estimates of the number of undersized snapper released alive and discarded dead annually

[1]Available from ftp://ftp.sas.com/techsup/download/stat/glmm612.sas

in the longline component of the fishery were made. This was done by extrapolating observed catch and gut-hooking rates as a proportion of the current total allowable commercial catch (TACC). In the 1998–1999 fishing year, the landed catch from SNA1 was 4124 t, giving an estimated longline take of 2474.4 t (60%). Estimates of annual changes to discard mortality using the two Barnes hook configurations were made relative to observed normal hook rates. These estimates assume that post-release mortality of gut-hooked fish is 100% (McKenzie, 1999). Because fishers do not have time to measure snapper accurately during longline retrieval, they tend to err on the side of caution by discarding fish of at least 1 cm more than the minimum legal size (MLS) (pers. obs.). Absolute incidental mortality and percent reduction estimates were therefore calculated for scenarios of effective MLS of 25 cm FL (assuming fishers retain all legal-size fish) and 27 cm FL.

Results

A total of 33 750 hooks were set, of which 33 309 were successfully retrieved. The loss of 441 hooks was mainly due to occasional gear breakage caused either by fouling of the line on the bottom, or entanglement of large sharks (usually school sharks *Galeorhinus galeus*, hammerheads *Sphyrna zygaena*, or makos *Isurus oxyrinchus*) in the mainline.

Numbers

Over the 13 shots performed in January 1999, 14.6% of hooks caught snapper (2504 snapper from 17 174 hooks). A slightly higher catch rate of 15.1% was observed in June 1999 (2440 snapper from 16 135 hooks).

Normal hooks gut-hooked 17% and 30% (pooled across baits) of snapper caught in January and June, respectively, whereas 20-mm modified hooks gut-hooked 7% and 12%, and 40-mm hooks gut-hooked only 2% in both seasons. Twenty-two snapper (0.4%) were foul-hooked but all of these were boated in lively condition. We felt that the foul-hooked fish would suffer similar mortality to lip-hooked fish and so, rather than analysing this tiny minority of fish separately, they were added to the lip-hooked category.

The percentage catch of gut-hooked snapper was noticeably higher in winter (Figure 3) and the catches across all categories other than lip-hooked legal-sized snapper tended to decrease as appendage size increased. These features suggest the likely present of strong seasonal and hook effects. The lack of interaction between hook and bait enables quantification of hook effects without regard to the bait used.

GLMMs were applied to each of the six categories of snapper catch. Backward model fitting was used with significance at the 5% level required for a term to remain in the model. On no occasion was any of the interaction terms significant. Season and bait main effects were significant for at least one response category. The hook main effect was significant for all response categories except lip-hooked legal-sized snapper. Thus, the best model was taken to be the main effects only model specified in Equation (1).

Results from the GLMMs show that the probability of snapper capture by the modified hooks is lower for all response categories, with a very dramatic decline in gut-hooked snapper (Table 1). The odds of capture of lip-hooked sublegal snapper, lip-hooked legal snapper and export quality fish were not significantly lower on the 20-mm appendage hook relative to the normal hook. On the 40-mm appendage hook, only the odds of capture for lip-hooked legal snapper were not significantly different from that of the normal hook. (See the Appendix for explanation of how to interpret the relative odds from Table 1.)

The effect of bait was not of primary interest in this study, but is worthy of brief mention. The bait effect was significant at the 5% level in the "lip-hooked legal" and "export quality" response categories. Mackerel outperformed pilchard, which in turn outperformed squid. Compared to squid, mackerel gave relative odds of capture of 1.20 for the lip-hooked legal and export quality categories. For the same two categories, pilchard gave odds relative to squid of 1.07.

Weights

The average catch weight of snapper (all size classes) per hook retrieved was 0.111 kg in January 1999 and 0.098 kg in June 1999. Restricting attention to legal-sized snapper, these catch weights were 0.107 kg and 0.092 kg, respectively. As length of hook appendage increases there is a dramatic decrease in the weight of gut-hooked legals, but there is no clear systematic difference in the weight of lip-hooked legals (Figure 4). The difference in mean weights per hook retrieved between seasons is explained by the size distribution of the catch (Figure 5). Although catch rates were higher in winter, this was offset by the catch of larger fish in summer.

GLMMs were used to fit the log-linear models for each of the four categories of catch weight. At the 5% level, bait was significant for three categories, hook for two categories, and the bait × season for one category and so the model having main effects of season, hook and bait, and the interaction term of bait × season was used.

Results from the GLMMs show that catch weight of legal-sized snapper is significantly lower on the modified hooks (Table 2), but that the loss is attributable to a

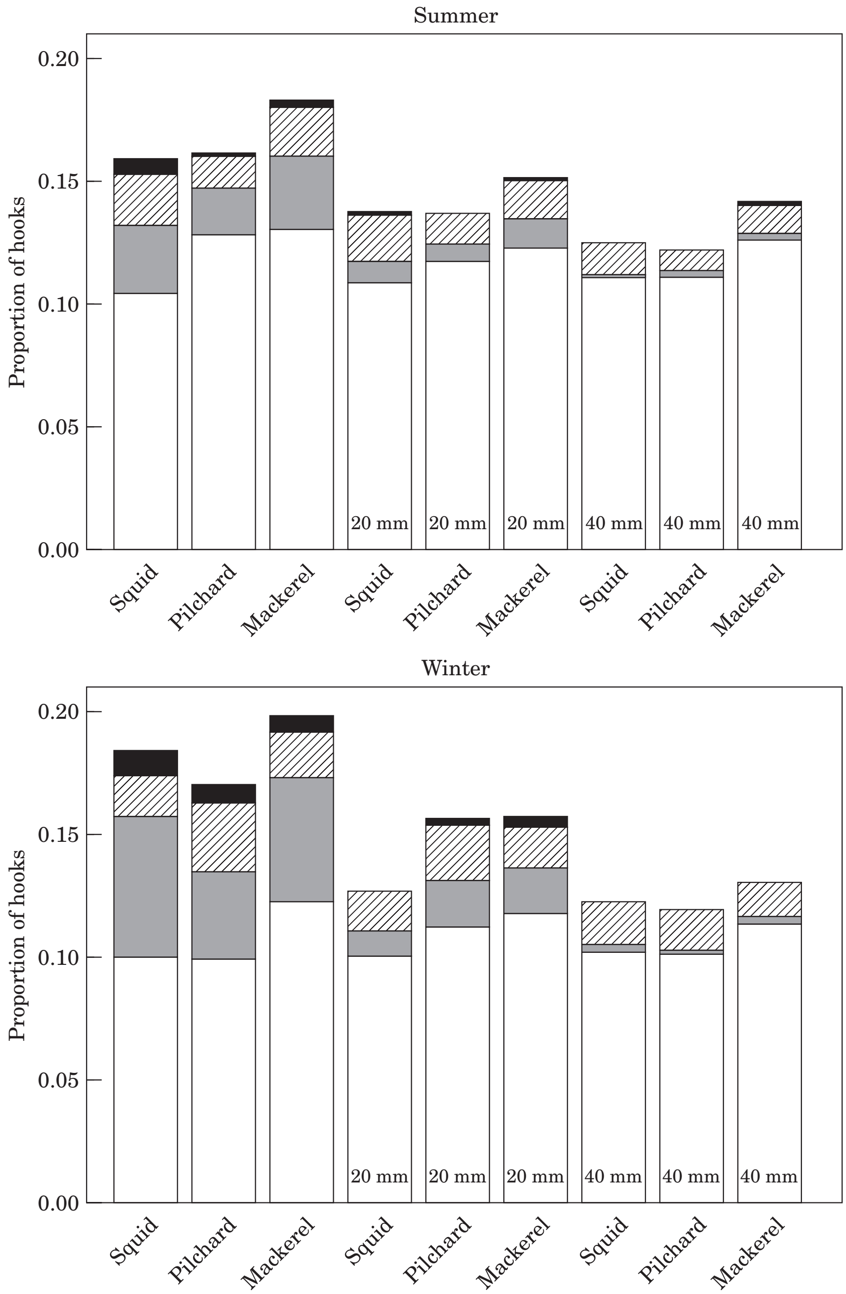

Figure 3. Bar graphs showing the proportion of each category of *Pagrus auratus* catch for each combination of season, hook and bait type. □, lip-hooked legal; ▨, gut-hooked legal; ▨, lip-hooked sublegal; ■, gut-hooked sublegal.

highly significant reduction in the weight of gut-hooked fish. Modified hooks show a slight (non-significant) increase in weight of lip-hooked fish and a slight (non-significant) reduction in weight of export quality fish. The increase in the landed weight of lip-hooked fish on modified hooks occurred despite lower numbers caught. This was due to modified hooks having higher catch rate of large fish than the normal hook. Plots of the relative contribution of each hook type to the number of fish caught in each 2-cm size class (Figure 5) indicated that normal hooks had a higher catch rate of snapper <30 cm in both summer and winter, and a lower catch rate of snapper >35 cm in summer. Conversely, hooks with 40-mm appendages had lower catch rate of fish <30 cm, and greater rate for snapper >35 cm in both seasons. Hooks modified with 20-mm appendages in general

Table 1. Relative odds of capture relative to normal hooks. The p-value is for the null hypothesis of no difference between hooks, corresponding to H_0: relative odds = 1.

Catch category	Relative odds of capture	s.e.	p-value
20-mm appendage			
All snapper	0.78	0.04	<0.0001
Gut-hooked sublegal	0.19	0.06	<0.0001
Lip-hooked sublegal	0.87	0.09	0.1772
Gut-hooked legal	0.33	0.04	<0.0001
Lip-hooked legal	0.99	0.06	0.8745
Export quality	0.91	0.05	0.1551
40-mm appendage			
All snapper	0.67	0.04	<0.0001
Gut-hooked sublegal	0.03	0.02	<0.0001
Lip-hooked sublegal	0.67	0.08	0.0005
Gut-hooked legal	0.06	0.02	<0.0001
Lip-hooked legal	0.96	0.06	0.5200
Export quality	0.86	0.05	0.0142

performed intermediately between the normal and 40-mm hooks.

Main effects of bait type were confounded by interaction with season. This is evident in the bar graphs (Figure 4) where, for example, squid returned the lowest catch rate of lip-hooked snapper over all hooks in summer. However, in winter it had higher catch than pilchard on the normal and 40-mm modified hooks.

Stock-scale discard mortality estimates

The potential reduction of incidental discard mortality of snapper on longlines (caused by reductions in both catch and gut-hooking rates of fish <MLS) was estimated to be approximately 78% and 96% for 20-mm and 40-mm modified hooks, respectively, under both MLS scenarios (Table 3).

Discussion

The use of hooks modified by the addition of a wire appendage has the potential to significantly lower unaccounted discard mortality in the snapper longline fishery. The modified design alters catch selectivity to substantially reduce the catch rate of undersized fish (Table 1) while incurring a modest loss of catch weight of legal-sized snapper (Table 2). More importantly, the modified hooks dramatically lower the incidence of "gut-hooking" in all size classes.

Previous attempts to manipulate longline gear have generally been directed towards increasing species or size selectivity (see review of Løkkeborg and Bjordal, 1992), either by changing hook type (Huse and Fernö, 1990) or size (Ralston, 1982, 1990; Otway and Craig, 1993), or bait type or size (Løkkeborg, 1990). The only studies (of which we are aware) that utilized artificial additions to normal hook structure were those conducted by Løkkeborg and Bjordal (1995), and Huse and Soldal (2000). They tested hooks with the addition of a plastic body attached to the shank, with the stated aim of increasing apparent bait size to reduce the catch of undersized gadoids off Norway, with only limited success. The current study is therefore the first to formally report marked changes to longline catch structure and gut-hooking rate by use of an artificial appendage.

The behavioural response of fish to baited hooks is likely to have significant effects on the selectivity of various hook types (Løkkeborg *et al*., 1989; Huse and Fernö, 1990; Kaimmer, 1999). During these trials, modified hooks generally had higher catch rates of larger (40–50 cm FL) snapper (Figure 6). Underwater video observations show that smaller snapper (<30 cm) tend to approach baits more rapidly than larger, more cautious individuals, but then toy with the bait rather than ingesting it immediately (T.J.W., unpubl. data). Reduction in the catch of smaller fish is probably due to the physical barrier to ingestion presented by the hook appendage. Conversely, increased catch of large fish on modified hooks may be caused by a combination of stimuli induced by feeding behaviour of small fish, as well as the increase in time over which the bait is presented that results from the inability of small fish to ingest it.

The probability of gut-hooked fish dying on the line is substantially increased by soak time (J. R. McKenzie, NIWA, Auckland, unpubl. data), but lip-hooked snapper can survive for 18 h or more (Chopin *et al*., 1996) with few ill effects. Commercial longline soak times in the snapper fishery are generally longer than the 1 h we used and hence the 100% gut-hooked mortality scenario

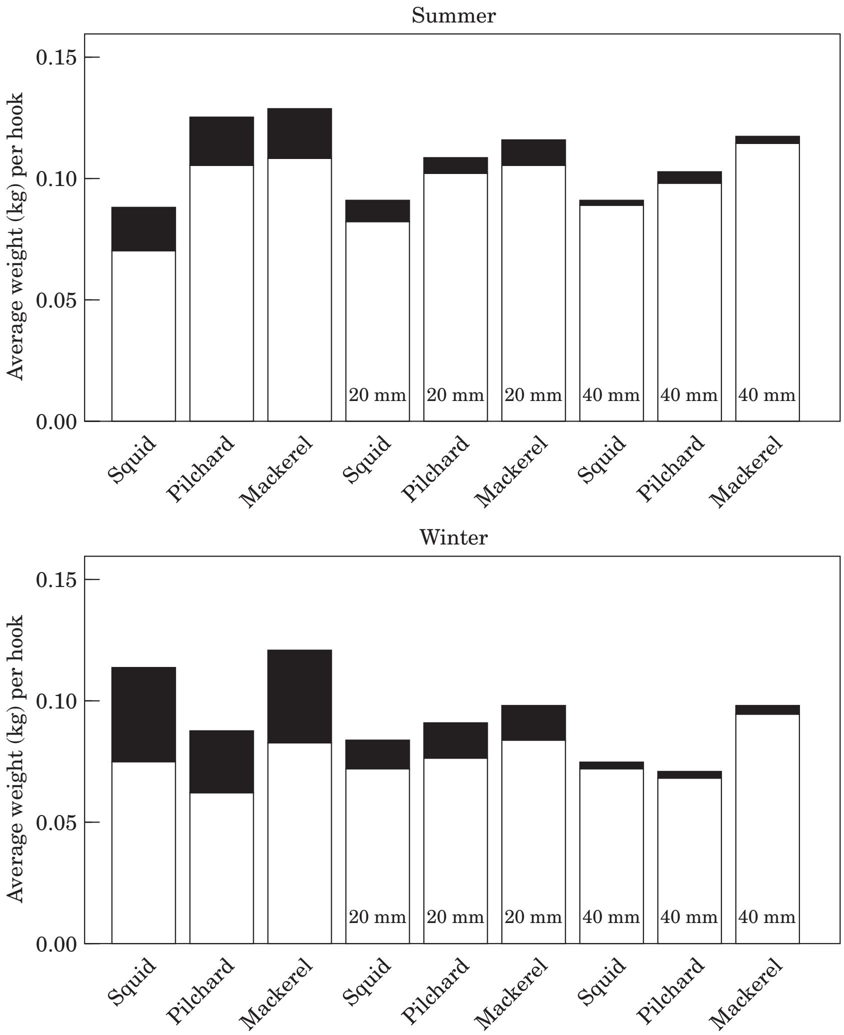

Figure 4. Bar graphs showing the average weight per hook of each category of legal sized *Pagrus auratus* catch for each combination of season, hook and bait type. □, lip-hooked legal; ■, gut-hooked legal.

was used here. This also implies that the relative performance of modified hooks with regard to catches of export quality fish will be somewhat higher in the commercial fishery than given by our estimates (Table 2).

In the commercial fishery, the need to err on the side of caution, and some deliberate "high-grading" (discard of small legal-size fish) will result in an effective MLS somewhat above 25 cm. The deliberate discard of small legal-sized fish was not taken into acount in our analyses. Thus, the higher relative catch rate of 25–30 cm fish on unmodified hooks (Figure 6) may not translate into similar differences in landings, due to the behaviour of the fishers.

Extrapolation of the observed catch and gut-hooking rates to the stock-scale (SNA1) gives estimates of the annual number of undersized snapper released alive and discarded dead that would result from use of modified hooks in the current longline fishery. These predictions assume: (i) that longliners capture 60% of the SNA1 TACC (Davies *et al.*, 1999); (ii) observed incidental mortality rates reflect those of the SNA1 fishery; (iii) all gut-hooked discards die post-release; (iv) observed catch size structure on unmodified hooks is representative of the fishery; (v) use of bait types is proportional to those we used; (vi) fishing strategy of "Oceana" does not differ from the rest of the fleet. Some of these assumptions are almost certainly violated (particularly the latter two), but in the absence of comparative catch data representative of the whole fleet, the exercise provides an indicative assessment of the potential annual reduction in discard waste.

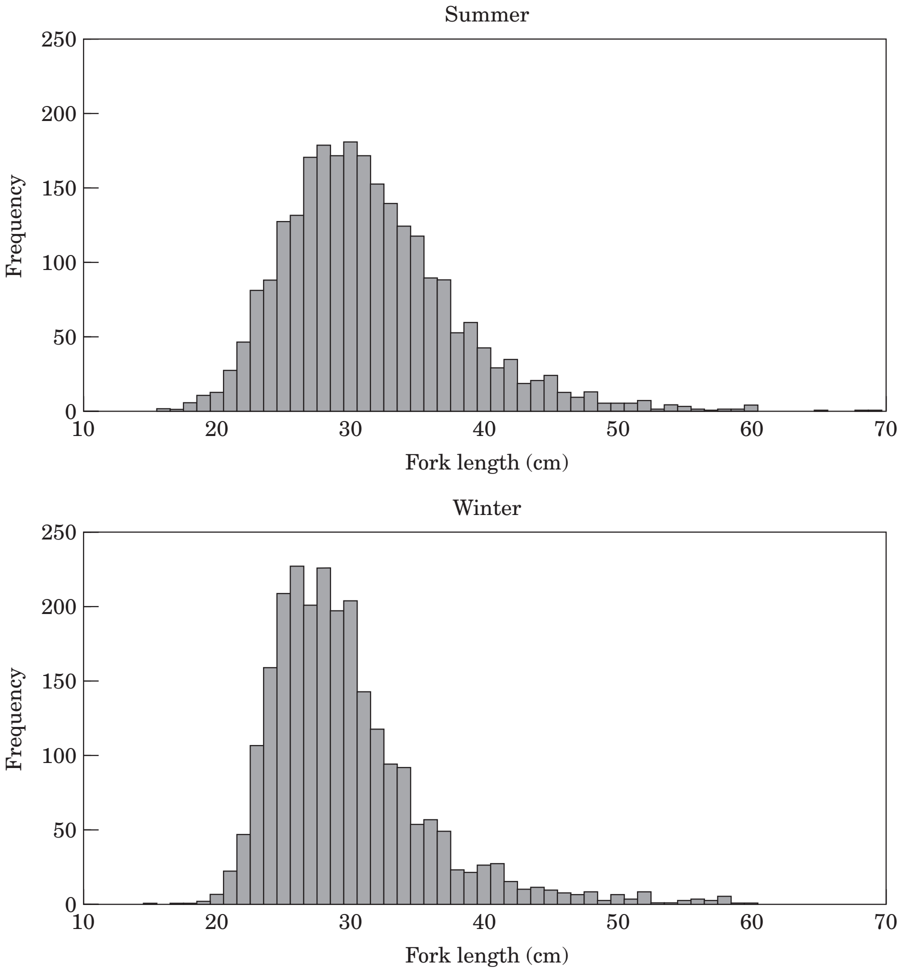

Figure 5. Length distributions of longline-caught *Pagrus auratus* by season (catch of all hook types combined).

The potential benefits of modified hooks to the fishery are dependent on economic variables. Presently about 40% of SNA1 quota is landed by trawlers, and estimated catch rates of undersized snapper in the 1998–1999 fishing year was 10–14% (Akroyd-Walshe Ltd, Auckland, unpubl. data). The probability of snapper post-release survival after trawling is not accurately known, but a value of 37.5% has been used in recent modeling of snapper mortality (Harley *et al.*, 2000b). If the export price of "iki jime" snapper is low, trawl fishing becomes more cost effective than longlining, and a correspondingly greater proportion of the TACC will be captured by trawl. This may reduce the biological benefits of modified hook use.

Table 2. Percentage change in catch weight relative to normal hooks. The p-value is for the null hypothesis of no change.

Catch category	Percentage change	s.e.	p-value
20-mm appendage			
Legal	− 12	5	0.0383
Gut-hooked legal	− 59	5	<0.0001
Lip-hooked legal	+3	6	0.6417
Export quality	− 4	6	0.4546
40-mm appendage			
Legal	− 17	5	0.0023
Gut-hooked legal	− 91	2	<0.0001
Lip-hooked legal	+6	6	0.3735
Export quality	− 6	6	0.3318

Sullivan *et al.* (1988) suggested that yield-per-recruit of snapper would be increased by raising the size at recruitment to the fishery (i.e. raising the minimum legal size), but the dynamic model of Harley *et al.* (2000b) found that the required increase in effort and discarding would negate this increase. The use of modified hooks requires only a modest increase in effort to maintain catch but the reduction in incidental mortality could be dramatic. For example, the 20-mm appendaged hook catches 0.88 of the legal catch weight of the normal hook

Table 3. Estimated annual reduction in incidental mortality of undersized snapper for the longline component of the stock (SNA1) using modified hooks, based on extrapolation of observed catch and gut-hooking rates.

Effective size limit	Hook	Number of undersized snapper caught	Number of undersized snapper gut-hooked	% reduction in discard mortality
25 cm	Normal	574 301	118 880	
	20 mm	478 858	25 858	78.2
	40 mm	383 644	4 987	95.6
27 cm	Normal	1 280 369	290 643	
	20 mm	1 082 575	63 872	78.0
	40 mm	916 359	10 996	96.2

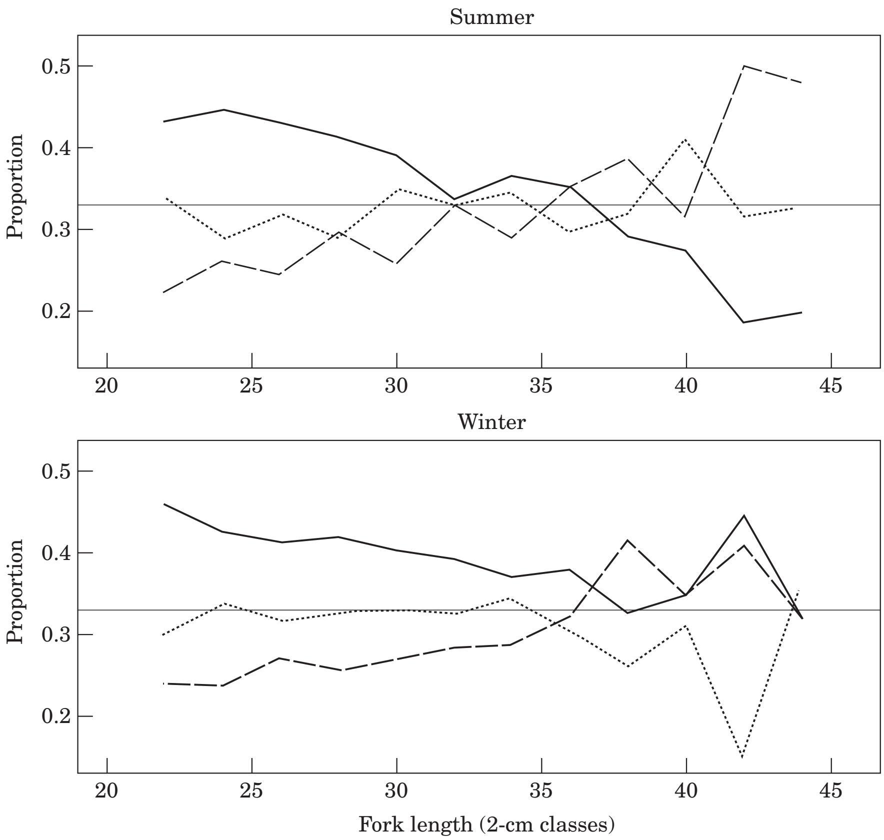

Figure 6. Relative proportion of *Pagrus auratus* in each 2-cm size class caught on the three hook types in summer and winter. The horizontal line represents the expected proportion if there were no difference between hook types. ——, unmodified hook; · · · ·, 20-mm appendage; – – –, 40-mm appendage.

(Table 2) and so would require $0.88^{-1}=1.13$ times the effort, but the odds of catching a gut-hooked sublegal fish are only 19% (Table 2) relative to the normal hook. For the 40-mm appendage hook, a 20% increase in effort is required, but the odds of catching a gut-hooked sublegal fish are a mere 3% relative to the normal hook. It is for these reasons that the stock-scale discard mortality estimates were reduced by 78% and 96% for the 20-mm and 40-mm modified hooks.

Future work will incorporate the results from this study into a dynamic model similar to that of Harley *et al*. (2000a) for the purposes of assessing the long-term consequences to the fishery of legislating a hook modification. This will require inference about the selection curves of the modified hooks. These can be obtained by using the relative catches by size class (Figure 6) as an adjustment to the assumed selection curve for the normal hook.

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Appendix

Interpreting odds

The odds of an event occurring is simply the ratio of the probability of occurrence over the probability of non-occurrence. This gives the expected ratio of occurrence to non-occurrence if the experiment were to be repeated a large number of times. Formally, if an event has probability p of occurring, then

odds of event = $p/(1-p)$ to 1

So, if the event has probability 0.5 of occurring then its odds are 1-to-1. If it has probability 0.75 then the odds are 3-to-1, etc.

Note that

$p = \text{odds}/(1 + \text{odds})$

Interpreting relative odds

By way of example: relative to the normal hook, the odds of catching a snapper are 22% lower on a 20-mm appendage hook and 33% lower on a 40-mm appendage hook. (These values correspond to the relative odds values of 0.78 and 0.67 from Table 1.) If, for a particular shot, the probability of catching a snapper on a normal hook was 1/6 (corresponding to odds of 0.2-to-1) then the odds of a snapper on the 20-mm appendage hook would be 0.156-to-1, and on the 40-mm appendage hook would be 0.134-to-1. These two odds correspond to probabilities of capture of 0.135 and 0.118, respectively.