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ScienceDirect

Fisheries Research 90 (2008) 289–295

FISHERIES RESEARCH

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Capture depth related mortality of discarded snapper (*Pagrus auratus*) and implications for management

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Received 9 August 2007; received in revised form 31 October 2007; accepted 2 November 2007

Abstract

Variables affecting the short-term survival of snapper (*Pagrus auratus*) captured using commercial fish traps and subsequently released were investigated by holding the fish in cages. A logistic regression model showed that capture depth had the greatest affect on short-term survival of snapper, with no mortalities observed from depths of less than 21 m and ∼2% from depths of less than 30 m. Mortality of snapper increased rapidly after 30 m and was ∼39% between capture depths of 30 and 44 m and ∼55% between capture depths of 45 and 59 m. Survival was also effected by fish length, with smaller fish being more likely to die. The rate of ascent of captured snapper and the density of fish in cages were kept reasonably constant and did not appear to affect survival. The number of snapper swimming upside-down prior to being returned to the sea floor in cages was not a good predictor of mortality. Future studies that use cages to assess discard mortality rates would benefit from underwater video observations of fish behaviour. The results demonstrate that the discard mortality of snapper should be considered when managing the fishery in New South Wales, Australia.

Keywords: Pagrus; Mortality; Release; Depth

1. Introduction

Snapper (*Pagrus auratus*) is an iconic species in the waters of Australia and New Zealand and support substantial commercial and recreational fisheries (Hutchins and Swainston, 1986; Kailola et al., 1993). In Australia, snapper are distributed in coastal waters from north Queensland (∼18°S) around the south of the continent to Western Australia (∼20°S) and several discrete stocks have been identified (Johnson et al., 1986; Donnellan and McGlennon, 1996). The east coast snapper stock is in a depleted state. In New South Wales (NSW) and Queensland snapper are listed as being growth-overfished and there is increasing evidence that the stock is over-exploited (Allen et al., 2006). In NSW, commercial landings have declined from ∼600 tonnes per annum during the early 1990s to ∼200 tonnes per annum in 2005/2006. The most recent estimate of the annual recreational harvest of snapper in NSW is similar to the commercial harvest (Henry and Lyle, 2003). Landings are dominated by fish within five cm of the minimum legal length (MLL) of 30 cm total length (TL) and ∼75% are less than four years old (NSW DPI unpublished data). The commercial fishery for snapper in NSW is mostly an offshore trap fishery (Stewart and Ferrell, 2003) while the recreational fishery is mostly a line fishing one.

Large numbers of snapper are captured and released each year due to MLLs and recreational bag limits. The rate of discarding of snapper in the NSW commercial trap fishery was reported as being >30% during 1999/2000 (Stewart and Ferrell, 2003). Since that time the MLL has been increased and based on the known catch composition of fish traps (Stewart and Ferrell, 2003) the discard rate is now estimated to be >50%. Such high rates of discarding of snapper may represent a substantial risk to the sustainability of the stock if there is an associated high rate of mortality. Unfortunately, there exists very little information on the fate of discarded snapper and current assessments and management controls do not incorporate information on discard mortality. Rather, management arrangements implicitly assume that discard mortality is negligible.

In NSW there is much debate about appropriate management arrangements to promote recovery and sustainability of the snapper stock. Information on the discard mortality of snapper would aid in reducing the level of debate. The commercial trap fishery has recognized that it may have a snapper discard problem

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0165-7836/$ – see front matter
doi:10.1016/j.fishres.2007.11.003

and is planning to introduce ‘escape panels’ of larger mesh to reduce the number of under legal-sized snapper retained in traps (Stewart and Ferrell, 2002). The problem in this multi-species fishery is that any increases in mesh size may result in losses of valuable species other than snapper. Knowledge of rates of mortality of snapper discarded from fish traps, and how it varies with depth, will enable industry and management to adjust ‘escape panel’ regulations so as to minimize losses of secondary species while minimizing mortality of discarded snapper. In addition, there are strong arguments to increase the current MLL, including increasing the spawning potential (snapper in NSW mature at around 30 cm fork length and three years of age (Kailola et al., 1993)) and yield per recruit. An increase in MLL may also reduce the risk of a fishery collapse after years of poor recruitment. However, if discard mortality is high then any increase in MLL will not achieve the desired results.

Discard mortality has been studied in many species of finfish and is generally species-specific and influenced by many physical and environmental factors (see reviews by Muoneke and Childress, 1994; Bartholomew and Bohnsack, 2005). Capture depth has a major influence on survival of fish that are discarded and there is an inverse relationship between capture depth and survival (Rummer and Bennett, 2005; St. John and Syers, 2005). The physiological cause of capture depth related mortality relates to barotrauma resulting from rapid depressurization (Rummer and Bennett, 2005; St. John and Syers, 2005). Given the life-history dynamics of snapper, with small juveniles inhabiting shallow bays and estuaries and older juveniles and adults being found in offshore waters up to 200 m deep (Kailola et al., 1993), barotrauma injuries related to capture depth are most likely to occur in those older juveniles and adults.

The aim of this study was to provide a first step in assessing the discard mortality of snapper caught in fish traps and to identify factors that may contribute to this mortality. The findings are used to discuss further studies and how they may be incorporated into management action.

2. Materials and methods

This experiment was done near Sydney, NSW (33°35′S) during November and December 2006. The work was done by chartering an ex-commercial trap fisher with extensive knowledge of the area.

Snapper were captured using standard commercial practices: rectangular fish traps covered with 50 mm hexagonal wire mesh and baited with pilchards, bread and striped tuna (see Stewart and Ferrell, 2003 for a description of the fishery). Four individually numbered traps were used, each measuring ∼90 cm × 120 cm × 165 cm.

Traps were baited and set, usually overnight but sometimes longer because of bad weather, on known snapper grounds. Information on date, trap number, depth and sea conditions was recorded. Traps were lifted using a hydraulic winch at a relatively constant rate and were hauled onboard using a trap-tipper. Any snapper captured were quickly placed in a tub of water (∼75 l) and other fish and old bait were cleared from the trap. The empty trap had its entrance nozzle closed, was put into the water beside the vessel and the snapper placed into it using a knotless mesh net. The density of snapper was set at a maximum of 20 per trap and these were chosen haphazardly from the holding tub when more than 20 fish were caught. The trap was then lowered back to the sea floor in the same depth as it was retrieved from. Information recorded included: the rate at which the trap was raised (m/s), the number of snapper placed in the trap, the number of snapper floating upside-down prior to being lowered, and the time between the trap being hauled onboard and lowered again. Caged fish were generally left overnight, except when bad weather precluded retrieval. Snapper retrieved from closed traps were measured (TL), their fate recorded (alive or dead) and notes made on the survivors’ condition.

2.1. Data analyses

A logistic regression model was used to test the effect of five continuous variables on the binary variable fate (Y_i) of individual snapper. These variables were: depth (capture depth in m); ascent (rate of ascent when captured m/s); cage (the time that experimental fish were caged on the sea floor in h); density (the number of experimental snapper in the trap when lowered to the sea floor) and fish length (TL in cm).

The model was:

$$\mathrm{logit}(Y_i) = a + b \times \mathrm{depth}_i + c \times \mathrm{ascent}_i + d \times \mathrm{cage}_i + e \times \mathrm{density}_i + f \times \mathrm{fish\ length}_i + \epsilon_i$$

where a to f are constants.

The model was calculated using the freeware statistical package “R” (R Development Core Team, 2006). General linear models predicting fate using the above variables were fitted within “R” using the glm(family = binomial) function.

The significance of each variable to the model was tested using the null hypothesis that they were significantly different from 0 using partial z-tests. Variables that were non-significant were removed and a reduced model refitted. The influence of each variable on the reduced model was assessed using the drop1( ) function within “R”. This function calculates an Akaike Information Criteria (AIC) value for the reduced model and for the model without each variable. Variables with the greatest corresponding AIC value influence the model the most.

3. Results

Information was recorded from 21 trap sets and 334 snapper. Capture depths ranged between eight and 57 m and overall 88 fish died and 246 fish survived (Table 1). The average (±S.E.) time that snapper spent in the holding tub between being captured and lowered back to the sea floor was ∼9 min (±0.05).

3.1. The model

In the full logistic regression model, rate of ascent and density were non-significant ($P > 0.05$, Table 2). A reduced model was fitted with the variables of depth and fish length (Table 3). The variable cage was not included because there were only three

Table 1
Summary of information from each experimental trap set

Date set	Trap number	Depth (m)	Ascent (m/s)	Density	Cage (h)	Mean length (cm)	Number of fish floating	Number of fish alive	Number of fish dead
28/11/2006	1	8.3	0.38	9	23.92	25.67	0	9	0
28/11/2006	2	9	0.41	12	24.00	24.81	0	12	0
28/11/2006	3	9	0.39	10	24.00	27.55	0	10	0
29/11/2006	4	12	0.39	15	21.67	22.71	0	15	0
30/11/2006	1	21	0.42	20	24.08	26.24	0	20	0
30/11/2006	3	20	0.38	20	22.92	24.78	8	20	0
1/12/2006	4	31	0.39	20	49.42	24.57	3	5	15
2/12/2006	1	41	0.41	19	22.42	26.44	8	16	3
2/12/2006	3	27	0.36	20	22.25	26.66	8	19	1
4/12/2006	2	31.5	0.47	18	23.92	25.27	4	15	3
4/12/2006	4	30	0.45	19	24.42	26.42	8	15	4
5/12/2006	3	24	0.51	18	22.92	24.89	8	17	1
6/12/2006	1	43	0.37	6	22.28	29.25	0	1	5
6/12/2006	2	47	0.39	18	23.20	28.62	5	13	5
6/12/2006	4	37	0.36	7	23.12	28.46	1	4	3
7/12/2006	3	24	0.43	20	72.10	26.29	-	19	1
8/12/2006	4	38	0.44	13	47.25	28.67	1	4	9
11/12/2006	1	42	0.45	16	24.97	27.06	3	12	4
11/12/2006	2	45	0.49	20	24.00	27.93	4	11	9
11/12/2006	3	57	0.46	19	24.03	28.46	10	6	13
13/12/2006	4	56	0.45	15	23.80	27.78	3	3	12
Means		31.09	0.42	15.90	28.13	26.45			
Totals	21						74	246	88

Table 2
Parameter estimates for the full logistic regression model

Variable	Coefficient	Value	S.E.	z-Value	P
Intercept*	a	2.83	2.86	0.992	0.32
Depth	b	0.15	0.02	7.99	<0.001
Ascent*	c	−3.53	4.04	−0.87	0.38
Cage	d	0.04	0.01	3.90	<0.001
Density*	e	−0.09	0.08	−1.15	0.25
Fish length	f	−0.28	0.06	−4.45	<0.001

* Denotes non-significant at $P > 0.05$.

observations of greater than one day. In the reduced model, depth and fish length were significant and the influence of each variable to the model was examined by comparison of the AIC values for the model without each variable. Depth had by far the greatest effect on predicting the fate of individual snapper (Table 4).

3.2. Capture depth

Capture depth had the greatest affect on survival of snapper (Table 4). There were no mortalities of snapper from capture depths less than 21 m and only three from capture depths less than 30 m. The proportion of snapper that died in each experimental trap was variable, but generally increased with capture depth (Fig. 1). Overall <2% of snapper captured from <30 m died, ∼39% died between 30 and 44 m and ∼55% died between 45 and 59 m. It was noted that surviving fish from the two deep-

Table 3
Parameter estimates for the reduced logistic regression model

Variable	Coefficient	Value	S.E.	z-Value	P
Intercept*	a	1.66	1.41	1.18	0.24
Depth	b	0.13	0.02	8.0	<0.001
Fish length	f	−0.27	0.06	−4.40	<0.001

* Denotes non-significant at $P > 0.05$.

Table 4
Influence of each variable on the reduced model

	d.f.	Deviance	AIC
Two variables		282.78	288.78
Depth	1	387.19	391.19
Fish length	1	305.21	309.21

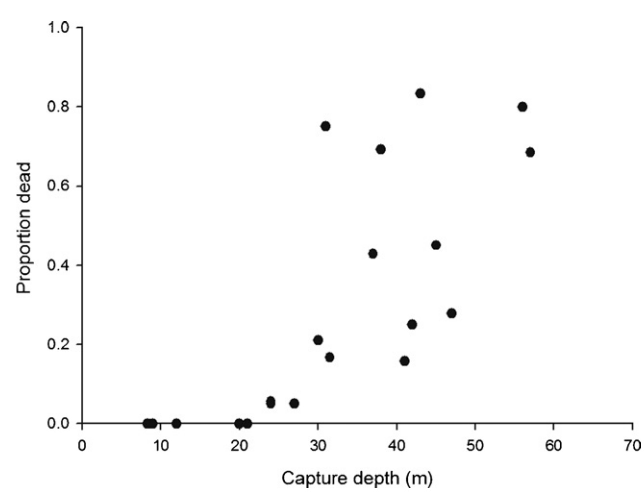

Fig. 1. Mortality rates for snapper from different capture depths.

est capture depths (56 and 57 m) were in poor condition after ~24 h and appeared unlikely to have survived for much longer.

3.3. Ascent rate

Trap ascent rate was kept reasonably constant (mean ± S.E. of 0.42 ± 0.01 m/s) but ranged between 0.36 and 0.51 m/s. Trap ascent rate did not affect survival of snapper in the full model (Table 2) and there was no trend of increasing mortality with ascent rate (Pearson's correlation coefficient $r = 0.10$, 19 d.f., $P > 0.05$).

3.4. Cage time

The time that experimental fish were caged on the sea floor (cage time) significantly affected their survival in the initial model (Table 2). The coefficient value for cage time (d) was slightly positive, indicating that fish caged for longer had a slightly worse chance of surviving. However, there was no apparent trend for increased mortality with increased cage time (Table 1) and the significant affect may have been due to having only three observations of greater than one day. Eighteen of the 21 trap sets were left for one day, two were left for two days and one was left for three days. The longest time that fish were caged was for three days (~72 h) from a capture depth of 24 m, yet only one of these 20 fish died.

3.5. Density

The number of experimental snapper in the trap when lowered to the sea floor (density) did not affect survival of snapper in the full model (Table 2). There was no apparent relationship between density and the proportion of snapper surviving, and some of the highest mortality rates were observed in traps with relatively low densities; however, these were associated with some of the deepest capture depths (Table 1).

3.6. Fish length

Fish length significantly affected survival of snapper (Tables 2 and 3), but had a substantially lower influence in predicting survival than capture depth in the reduced model (Table 4). The coefficient value for fish length (f) was negative (Table 3) indicating that larger fish had a slightly greater chance of survival.

Fish length was related to capture depth during this experiment, with those from <30 m being, on average, smaller than those from capture depths of ≥30 m (Fig. 2, Kolmogorov–Smirnov test, $P < 0.01$).

For snapper from capture depths ≥30 m the distribution of lengths of fish that died was significantly smaller than those that survived (Kolmogorov–Smirnov test, $P < 0.01$).

3.7. Floating fish

There was a positive correlation between increasing capture depth and the number of snapper observed to be floating upside-

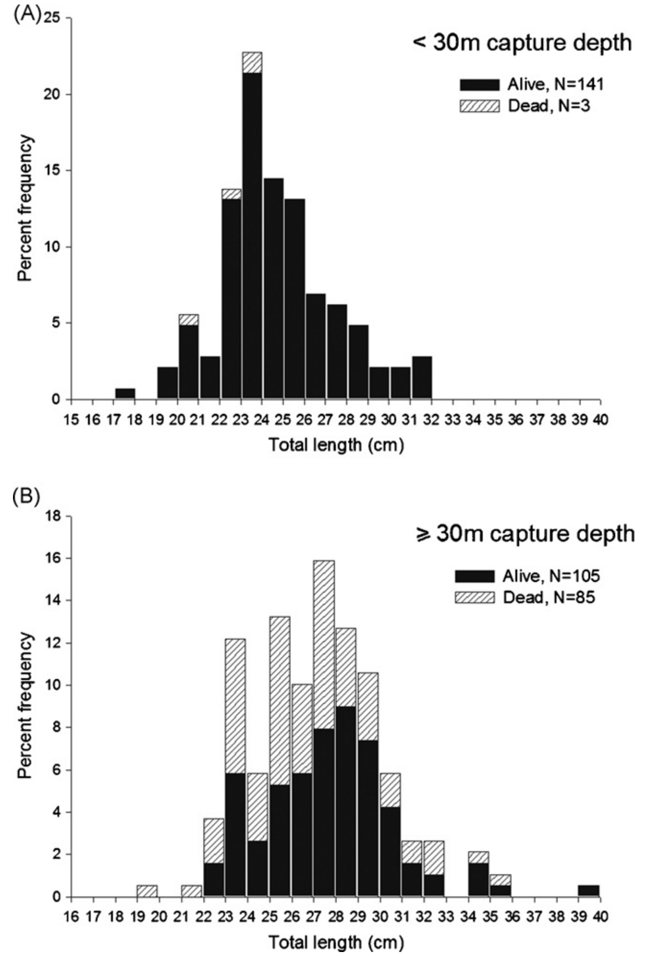

Fig. 2. The lengths of snapper from (A) <30 m and (B) ≥30 m capture depths that survived and died.

down before being lowered to the sea floor (Table 1; Pearson's correlation coefficient $r = 0.46$, 19 d.f., $P < 0.05$). However, there was no correlation between the number of snapper observed to be floating and the number of snapper that died in each trap (Pearson's correlation coefficient $r = 0.21$, 19 d.f., $P > 0.05$).

4. Discussion

The major finding from this study is that the mortality of snapper discarded from fish traps with capture depths of greater than 30 m may be high. This mortality appears to be largely attributable to capture depth and rapid depressurization during capture. Rates of mortality of more than 20% are considered problematic (Muoneke and Childress, 1994), and ~45% of snapper from capture depths of greater than 30 m died during the present study. Most of the NSW demersal trap fishery targets snapper in waters of greater than 50 m (Ferrell and Sumpton, 1997) and, given that discard rates are currently in the order of 50% the mortality of these discards is of concern. Given that ~66% of all recreationally caught snapper are also discarded (Henry and Lyle, 2003) it is likely that the mortality of recreationally caught and released snapper may also be an issue.

The short-term mortality rates from waters greater than 30 m reported here are consistent with other research done on snapper. Broadhurst et al. (2005) reported a mortality rate of >30% in a fishery where barotrauma is likely to be negligible due to shallow (<6 m) capture depths. Our estimates of short-term mortality are likely to be under-estimates of those from normal fishing operations because the standard one day cage time in the present study may have been too short to span all mortalities resulting from capture and release. This is supported by the observation that the surviving fish from the two deepest capture depths (56 and 57 m) were in poor condition and seemed close to death after ∼24 h. These findings, and those from other studies (Gitschlag and Renaud, 1994; St. John and Syers, 2005), suggest that fish from deeper capture depths may die more quickly than those from shallower depths.

The finding during the present study that smaller fish had a higher chance of dying is in contrast to that of Collins et al. (1999), who used cage experiments to assess post-release survival of black sea bass (*Centropristis striata*) and vermilion snapper (*Rhomboplites aurorubens*). They reported that mortality was not related to fish size of either species. Gitschlag and Renaud (1994) reported no significant difference in mortality between sub-legal and legal-sized red snapper, but their data indicated that the larger fish in their study all survived. However, Beyer et al. (1976) theorized that smaller fish would be more susceptible to barotrauma because of their smaller blood vessels being more likely to become blocked by gas bubbles. The relatively short nature of the present study precludes any definitive conclusion concerning length-related mortality; however this issue is very important for fisheries managers if they are to assess the potential effects of increases in MLL of snapper and associated post-release mortality.

The ascent rate (or rate of depressurization) was kept relatively constant during the present study (∼0.4 m/s) and this was a likely reason why it was a non-significant variable in the logistic regression model. Nevertheless, the rate of ascent is an important contributing factor in barotrauma-related injuries (Carturan et al., 2002) and its affect on snapper should be investigated. The ascent rate used during the present study was typical of that used in the NSW demersal trap fishery, but anecdotal evidence is that some fishers use faster trap hauling rates so as to have time to haul more traps in a day. Rummer and Bennett (2005) simulated 'normal' recreational angling ascent rates when examining decompression injuries in red snapper and used a rate of 10 kPa/s (1 m/s). At this rate of ascent red snapper suffered potentially catastrophic injuries from simulated depths of 30 m and greater. If an ascent rate of ∼1 m/s is 'normal' for recreationally caught fish, and ascent rate is an important contributing factor to mortality rates after release, then barotrauma-related mortality from recreationally caught and released snapper may be substantial and warrants study.

The number of snapper that were floating upside-down prior to release increased with capture depth, but was not a good predictor of mortality. This correlation was confounded by the caging experiment because floating fish were protected from predation on the surface, and physical damage due to the sun and heat, by being lowered to the sea floor. However, other studies have also reported a lack of correlation between physical damage and mortality (Gitschlag and Renaud, 1994). An interesting observation during the present study was that the number of snapper floating upside-down in the holding tub prior to release often increased with time. While the extent of this increase was not quantified, this observation agrees with the findings of Feathers and Knable (1983) who observed a delay of ∼5 min before depressurized largemouth bass (*Micropterus salmoides*) became bloated at the surface. They assumed that the delay was due to the peritoneum and dense connective tissue initially impeding swim-bladder expansion before being ruptured. The average time that snapper spent on the surface before being lowered in a cage during the present study was ∼9 min, while during normal fishing operations fish are discarded much more quickly (within a few minutes, personal observation). This slightly longer time at sea level may have resulted in greater damage due to inflated swim bladders than would occur under normal trapping operations.

4.1. Implications for future studies

The use of cages that are returned to the sea floor to examine post-release mortality of demersal fish is a method that has been successfully used previously (Gitschlag and Renaud, 1994; Collins et al., 1999; St. John and Syers, 2005). Nevertheless, it is important to consider the potentially confounding effects of this artificial situation where fish are: (i) protected from predation; (ii) quickly re-pressurized by being returned to depth; and (iii) subjected to additional stresses associated with being caged. Being protected from predators and quickly re-pressurized may have resulted in under-estimates of the mortality rate associated with capture and discarding. Keeping snapper in cages and lowering them to the sea floor may have protected them from predation by birds while on the surface and by predators such as dolphins, sharks and larger fish below the surface. One method to quantify the confounding effects of using cages is to use underwater video to observe fish behaviour. Hannah and Matteson (2007) successfully used release cages lowered to depth coupled with underwater video observations of fish behaviour to assess the effect of barotrauma on *Sebastes* spp. and a similar approach may be useful for snapper. The mortality rates of snapper from capture depths of >30 m during the present study were quite variable (see Fig. 1) and underwater video observations may have been useful in understanding this variation.

While it is difficult to assess the effect of being caged on mortality of snapper, it was likely to have been minor during the present short-term study. Snapper should be ideal for caging experiments because of their suitability for intensive aquaculture in pens (Bell et al., 1991). In addition, the fact that no snapper died in six trap sets in less than 21 m suggests that any short-term effects were small. Some fish did show signs of damage after being caged, such as frayed tails and damaged heads, presumably from brushing against the wire mesh. Others showed signs of muscle wasting overnight, a symptom that may be associated with elevated plasma cortisol levels resulting from stress (Pankhurst and Sharples, 1992). Future studies should examine the potential for these additional injuries and stresses to cause mortalities when fish are caged for longer than a few days; however, these experimental artefacts are difficult to control for.

Future studies should examine the short-term survival of snapper captured from deeper depths (>60 m) because the bulk of the commercial fishery operates beyond this depth. Their longer term survival also needs to be examined. However, given that the short-term survival rates found during the present study were high, future efforts may be better used in examining ways of mitigating such mortality. Variables to be examined may include: varying the ascent rate; using decompression stops during the ascent; and venting the fish prior to release. Investigating the mortality of line-caught snapper from different capture depths using cages would also be useful to management. Finally, similar studies should be done on other valuable demersal species that are heavily exploited.

4.2. Implications for management

This study has provided sufficient information on the mortality rates of snapper that are captured and released to aid managers in their efforts to promote the recovery of the snapper stock and the sustainability of the fishery. The rates of discarding by commercial and recreational fishers are very high (>50% in each sector) and the present study has demonstrated that the mortality of these discards may be unacceptably high. There is a current management initiative to increase the MLL of snapper in NSW from 30 to 32 cm, but the results presented here suggest that such an increase may not fully achieve the predicted increases in yield and egg production because of high rates of discard mortality. It has been previously demonstrated that MLLs for snapper in New Zealand may not be effective in increasing stock size if discard mortality is high (Harley et al., 2000).

One management option to mitigate the effects of discard mortality would be to reduce the capture of snapper smaller than their MLL. This may be achieved in the commercial trap fishery through implementing escape panels of larger mesh to allow small snapper to escape. The problem for industry and management is that by using mesh of dimensions that allows snapper of ∼30 cm to escape, substantial quantities of valuable secondary species may at times be lost (Stewart and Ferrell, 2002). This problem would be exacerbated if the MLL was increased to 32 cm and escape panel mesh increased accordingly. The solution may require trade-offs between increasing the mesh size in traps and an appropriate MLL. Such arrangements could vary with depth with different gear configurations and MLLs for snapper in shallow (<30 m) and deep (≥30 m) waters. Options may include having a larger MLL in shallow waters (where discarded fish are likely to survive) and traps with smaller sized escape panel mesh that still retain valuable secondary species. Fishing in deeper waters may require traps configured to minimize the catch of sub-legal snapper and this may be achieved by either larger sized escape panel mesh or a smaller MLL in these waters.

Acknowledgements

Thanks to Chris Judd who skippered the fishing vessel and provided the expertise in catching snapper. Matthew Lockett and Julian Hughes assisted with the fieldwork. Drs. James Scandol, Kevin Rowling, Doug Ferrell, Doug Rotherham, Geoff Liggins and Charles Gray provided useful comments on the design of the study and drafts of this manuscript.

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