Effects of hooking damage and hook type on post-release survival of sand flathead (*Platycephalus bassensis*)

Jeremy M. Lyle[A,E], *Natalie A. Moltschaniwskyj*[B], *Alastair J. Morton*[A],
Ian W. Brown[C] *and David Mayer*[D]

[A]Marine Research Laboratories, Tasmanian Aquaculture and Fisheries Institute, University of
  Tasmania, Private Bag 49, Hobart, Tas. 7001, Australia.
[B]School of Aquaculture, Tasmanian Aquaculture and Fisheries Institute, University of Tasmania,
  Private Bag 1370, Launceston, Tas. 7250, Australia.
[C]Southern Fisheries Centre, Department of Primary Industries and Fisheries, PO Box 76,
  Deception Bay, Qld 4508, Australia.
[D]Animal Research Institute, Department of Primary Industries and Fisheries,
  665 Fairfield Road, Yeerongpilly, Qld 4105, Australia.
[E]Corresponding author. Email: jeremy.lyle@utas.edu.au

Abstract.   This study examined post-release survival in sand flathead (*Platycephalus bassensis*) and whether there were survival benefits from the use of circle hooks over conventional hook patterns. Anatomical hooking location was the major factor contributing to mortality, with an almost 100% survival rate for fish hooked in the lip, mouth or eye (shallow-hooked) compared with around 64% for fish hooked in the throat or gut (deep-hooked). Mortality in deep-hooked fish was generally associated with injuries to vital organs (gills, heart, liver) and survival was significantly lower if bleeding was associated with injury (54% compared with 85% for non-bleeders). Circle hooks resulted in significantly lower deep-hooking rates (1%) compared with conventional hook types (4–9%) and, based on catch rates, were at least as effective as conventional hook patterns. Estimated survival rates for line-caught sand flathead were high, over 99% for circle hooks and between 94 and 97% for conventional hooks. These findings support the efficacy of management strategies based on size and bag limits and the practice of catch-and-release fishing for sand flathead, as well as a potential conservation benefit from the use of circle hooks.

Additional keywords: bait fishing, circle hooks, conventional hooks, deep hooking, hooking injury, hooking mortality, recreational fishing in Tasmania.

Introduction

Recreational fishing is a popular pastime around the world, and in Australia about one-fifth of the resident population fish at least once a year (Henry and Lyle 2003). Recreational catches can be divided into retained and released components and, for many species, the released component represents a significant part of the catch. Whether fish are released in accordance with fisheries regulations, due to the practice of catch-and-release fishing or for other ethical reasons, it is assumed that the majority will survive. Survival depends on several factors including the nature of the hooking injury, fishing and handling practices, and environmental conditions (see reviews by Muoneke and Childress 1994; Bartholomew and Bohnsack 2005). Anatomical hooking location is the most important factor influencing survival, with throat, oesophagus, stomach, and in some instances eyes representing critical locations. Terminal tackle (bait or lure), hook type and size, fishing practices (active or passive fishing) and fish size influence the probability of deep hooking (i.e. throat, oesophagus or stomach). This in turn influences the risk of damage to vital organs, and subsequent survival. As well as hook-induced

injuries, factors such as water temperature, depth of capture, and playing and handling times influence the level of physiological stress experienced by fish, further affecting the potential for survival.

By estimating post-release survival, it is possible to evaluate the impact on fish populations of regulations that require fish to be released (size and bag limits, closed seasons), as well as to account for fishery-induced mortality in stock assessments. Such information can also help promote awareness among anglers of their impacts on fish stocks, and identify potential improvements in fishing practices. To date there have been relatively few post-release survival studies in Australia, but a review by McLeay *et al.* (2002) and the establishment of the National Strategy for the Survival of Released Line Caught Fish (www.info-fish.net/releasefish, accessed 1 March 2007) have recently focused attention on this issue.

Flatheads (family Platycephalidae) constitute the most commonly caught finfish group taken by recreational anglers in Australia, with an estimated 13.5 million fish captured nationally during 2000–01, 6.0 million or 45% of which were released

(Henry and Lyle 2003). Although there are several species commonly taken by recreational fishers, two species – sand flathead (*Platycephalus bassensis*) and dusky flathead (*P. fuscus*) – dominate catches from estuarine and sheltered inshore waters. Sand flathead are distributed around south-eastern and southern Australia and are commonly captured by anglers in Tasmania and Victoria. Dusky flathead are found off eastern Australia, being the dominant flathead species taken in New South Wales and Queensland (Kailola *et al*. 1993).

Sand flathead accounted for over 90% of the recreational catch of flathead in Tasmania during 2000–01, with an estimated 1.2 million fish retained and 0.7 million (36% of total catch) released (Lyle 2005). Creel surveys conducted at the time indicated that almost 30% of retained fish were smaller than the legal minimum size of 30 cm total length (J. Lyle, unpub. data). Strict observance of the size limit would have resulted in a substantial increase in the proportion of the catch that could have been released.

In the present study, we examined the relationships between hooking injury and survival, and hook type (including circle hooks) and hooking injury in sand flathead. Circle hooks have been promoted widely in the recreational angling media and by some management agencies, particularly in North America, as a conservation measure to reduce mortality rates in released fish. However, even if survival benefits of circle hooks can be demonstrated, anglers still need to be convinced that they at least match the performance of conventional hooks if they are to be adopted. Recognising this important point, we compared catch rates for circle hooks with more conventional hook types.

Material and methods

Post-release survival

The primary objective of the post-release survival experiments was to determine the relationship between hooking location and survival in sand flathead. Three separate experiments were conducted, two during the austral summer (January and February 2005) and one in winter (June 2005). Fish handling protocols were applied consistently for each experiment and survival was assessed over a four-day post-capture holding period.

Sand flathead were captured on hook types commonly used by recreational anglers in Tasmania (J-style and octopus hooks, sizes 1/0 to 2/0), which were baited with fish or squid flesh. For each experiment, boat-based fishing was undertaken over two consecutive days in the Derwent Estuary, south-eastern Tasmania (42°57′S, 147°21′E). Once hooked, fish were landed quickly (mean play time, 10 ± 6 s [s.d.]) and unhooked or line-cut, and total length was measured to the nearest centimetre rounded down. A system of dorsal spine clips was used to identify the location of final hook penetration and whether bleeding was observed from the wound site. Hooking sites were classified as lip, mouth, eye (where the hook had penetrated the eye socket or the eye itself from inside the mouth), throat or gut. Externally hooked fish were classified as foul hooked. Not all hooked fish were retained. Targets for the number of fish for each combination of hooking site and size group (<30 cm and ≥ 30 cm) were established for each experiment. All sand flathead hooked in the eye, throat and gut regions were retained.

Fish were held initially in plastic tubs containing $\sim$40 L of aerated seawater that was refreshed periodically. Up to eight fish were held in each tub, with a maximum holding period of about 1 h, before transfer to shore and a larger tank containing $\sim$250 L of aerated seawater. Fish were then transported to an aquarium facility and transferred to one of four 4000-L tanks, each filled with $\sim$1500 L of seawater. This process generally took less than 15 min to complete. A flow-through sea water system was maintained with supplementary aeration, providing ambient conditions of salinity and temperature. The maximum stocking density was 43 fish per tank (with an overall mean of 35 fish per tank). Water temperature was monitored continuously during the holding period using a temperature logger.

Within about 6 h of capture, the tanks were inspected and dead fish removed. Tanks were inspected twice daily thereafter (morning and afternoon) during the holding period and dead fish removed. Dead fish were measured to the nearest millimetre, hook location (based on spine clips) noted and the fish autopsied to determine the extent and location of any obvious hook damage. All surviving fish were anaesthetised using clove oil (1 mL per 30 L) at the end of the four-day holding period, measured to the nearest millimetre, inspected for hook damage and either revived and released or euthanased with an overdose of clove oil. Just under half (46%) of all survivors recorded as throat or gut hooked were euthanased and autopsied. For the purpose of analysing fish-size effects, final length measurements were used because these were considered more accurate than those obtained at the time of capture.

On completion of the second experiment (February 2005), all anaesthetised fish were revived and held for a further 25 days, representing a minimum post-capture holding period of 29 days. During this time, fish were fed commercially available salmonid pellets and inspected daily. At the end of this period the fish were anaesthetised, measured and again examined for evidence of hooking damage.

In an attempt to provide experimental controls, sand flathead were collected using beach seine (haul) nets fished in shallow water (<2 m) over sand/seagrass substrate. Fish were removed from the net while still in the water and handled in a manner similar to the hook-caught fish (including spine clips), being transferred into holding tanks along with experimental fish.

Fishing trials

Two fishing trials were conducted in North West Bay, south-eastern Tasmania (43°04′S, 147°16′E) in order to compare catch rates and hook damage for a range of hook types, including circle, J-style, octopus and wide-gap hooks. Both trials were conducted during summer (January and December 2005), with three hook types compared in each trial. Experienced anglers and research staff were provided with a standard paternoster rig and asked to fish for specified periods with a single hook baited with squid.

A total of 20 anglers participated in the first trial: three per boat for all but one vessel, which had two anglers. Within each boat, anglers were randomly allocated one of three hook types – circle, J-style or wide-gap – and asked to fish for 2.5 h, recording all fish caught, their length and hooking site (lip, mouth, eye, throat, gut or foul). The second trial involved 12 anglers, three per boat, with circle, J-style and octopus hooks compared. In

this trial, anglers were instructed to fish in three 45-min sessions using each of the three hook types in succession in such a way that at any given time all three hook types were fishing. Allocation of the initial hook type to an angler was undertaken in the manner of the first fishing trial. For the second fishing session, the angler was randomly allocated one of the two remaining hook types and in the final session the unused hook type was fished.

Circle (Mustad Demon circle 39951 NPBLN 5/0), J-style (Mustad O'Shaughnessy 34007 2/0), wide-gap (Gamakatsu Shiner 51411 1/0) and octopus (Gamakatsu Octopus 02311 1/0) hooks were compared in the fishing trials. Octopus hooks had a 15° offset, whereas the other hook types were non-offset.

Fishing diary

Volunteer anglers, identified through angler networks and clubs, were invited to participate in the study. Anglers were issued a diary, measuring tape and hooks (circle, J-style and wide-gap identical to those used in the fishing trials), and asked to report the following details for any sand flathead captured: fishing method (bait, lure or fly), hook type, fish length, and hooking site (lip, mouth, eye, throat, gut, foul). Anglers were encouraged to use the hook types provided as well as terminal tackle they would normally use to target sand flathead. Twenty-two diarists reported fishing activity for 128 fishing trips between December 2004 and January 2006.

Data analysis

For the purpose of data analysis, hooking location was categorised as 'shallow' (lip, mouth, eye or foul hooked) or 'deep' (throat or gut) following conventions used by other authors (e.g. Skomal *et al*. 2002; Millard *et al*. 2003; Jones 2005). In addition, fish were classified as sub-legal or legal sized, based on the minimum legal size limit of 30-cm total length for sand flathead in Tasmania.

A binomial generalised linear model (GLM) with logit link (McCullagh and Nelder 1989) was used to examine effects of hooking location (deep-hooked, shallow-hooked or seine-caught), experiment number (1, 2 or 3) and size group (sub-legal or legal) on survival (GenStat 2005). Treatment was fitted first, and then step-forward selection of main effects was employed. Interaction terms were tested but removed if non-significant, the exception being two-way interactions that involved significant main effects. Pair-wise significance testing using Student's *t*-test was undertaken to compare probabilities (adjusted means) of survival for the significant factors.

Similarly, the influence of bleeding and hook removal on survival was evaluated for deep-hooked fish using GLM analysis, with fish size and experiment as additional fitted terms. The decision to restrict this analysis to deep-hooked fish was based on the low incidence of bleeding in shallow-hooked fish (7%) compared with deep-hooked fish (71%) and the fact that there were no mortalities among shallow-hooked fish in which bleeding was observed. Furthermore, the decision to cut the fishing line, leaving the hook in place, applied only to deep-hooked fish.

The effect of hook type on catch rates determined from the fishing trials was examined using a one-way ANOVA. Catch rates were calculated as the combined catch of sand flathead taken by a given hook type for each vessel, with vessels treated as replicates. Size-frequency distributions were compared using a Kolmogorov-Smirnov two-sample test.

In examining the effect of hook type on hooking location, hooking location (deep- or shallow-hooked) was treated as the response variate, with the fitted GLM terms being data source (fishing trial or diary), hook type (circle, J-style, wide-gap or octopus) and fish size (legal or sub-legal). Data for the two fishing trials were combined and only bait fishing information from the fishing diary was used in this analysis.

Odds ratios were also examined to interpret the lack of independence among selected factors.

Results

Post-release survival

In total, 369 hook-caught and 46 seine-caught sand flathead were held in aquaria to examine post-release survival (Table 1). Overall, 28 hook-caught sand flathead died within the four-day holding period, 21 (75%) within the first six hours and a further 6 within 24 h of capture (i.e. 96% within 24 h). The remaining mortality occurred during the fourth day. With the exception of a single mouth-hooked fish, all mortalities occurred among fish that had been hooked in the throat or gut regions, and most were associated with obvious puncture wounds to the gills, heart or internal organs, including the liver. Six mortalities occurred amongst the seine net sample, all within 24 h of capture (Table 1).

External evidence of hook-related damage was apparent at the completion of the holding period in some survivors. For instance, 14 (32%) of 44 fish hooked in the eye region manifested injuries that included haemorrhaging and/or swelling of the eye. Twelve (13%) of 95 lip-hooked fish had obvious lip damage that included extensive tearing of the buccal membrane and dislodgement of the maxilla, and 19 (13%) of 147 mouth-hooked fish had obvious puncture wounds in the snout region, some ulcerated. In addition, eye injuries were evident in one mouth-hooked and one throat-hooked sand flathead.

There were no further mortalities within the extended holding period (an additional 25 days) at the completion of the second experiment. All fish were re-examined at the end of this period and most exhibited no obvious injuries or at least evidence of wound healing. However, eye injuries (haemorrhaging and/or swelling) were still evident in a small number of fish: 7 (25%) of 28 eye hooked and 2 non-eye hooked individuals.

Survival rates based on raw scores for each of the shallow-hooked locations, i.e. lip, mouth, eye and foul hooked, were effectively 100%. In contrast, survival rates of throat- and gut-hooked fish were 65 and 67% respectively (Table 1). Post-mortem examination of the 23 dead fish classified as throat-hooked revealed that 4 (17%) had obvious puncture wounds to the upper oesophagus. Furthermore, amongst 16 throat-hooked survivors that were euthanased at the end of the holding period, 3 (19%) also had puncture wounds in the oesophagus. These observations suggest some difficulty in distinguishing between throat- and gut-hooking when the hook was lodged in the upper oesophagus as opposed to well into the stomach (when little of the hook would have been visible). Notwithstanding this potential confusion, throat and gut categories were combined for analysis. Overall survival rates for deep-hooked fish were 58

Table 1. Number of sand flathead by size group and treatment (including hooking location) for post-release survival experiments, with mean experimental water temperatures indicated (temperature range in parentheses)

Values in parentheses represent the number of mortalities within the 4-day holding period

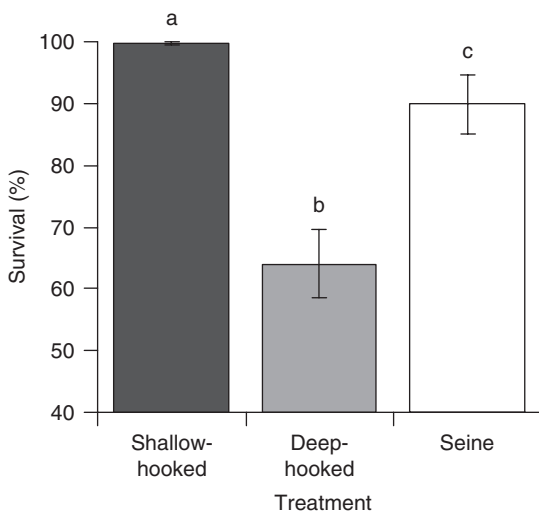| Treatment | Experiment 1 | | Experiment 2 | | Experiment 3 | |
| | 16.7°C (15.0–18.0) | | 16.8°C (14.5–19.4) | | 11.4°C (10.5–11.9) | |
	Sub-legal	Legal	Sub-legal	Legal	Sub-legal	Legal
Shallow-hooked	55 (1)	31 (0)	54 (0)	53 (0)	37 (0)	62 (0)
Lip	20	17	8	12	12	26
Mouth	28 (1)	11	20	35	22	32
Eye	7	3	24	4	3	3
Foul	0	0	2	2	0	1
Deep-hooked	14 (6)	11 (6)	9 (5)	21 (5)	10 (3)	12 (2)
Throat	13 (6)	8 (4)	9 (5)	15 (4)	10 (3)	10 (1)
Gut	1	3 (2)	0	6 (1)	0	2 (1)
Seine net	18 (1)	3 (1)	18 (4)	7 (0)	–	–

Fig. 1. Adjusted mean survival rates (±s.e.) for shallow-hooked, deep-hooked, and seine-caught sand flathead. Means with different letters are significantly different from one another.

and 70% for sub-legal and legal sized sand flathead respectively (Table 1). Survival rates for seine-caught sand flathead ranged between 86% for sub-legal and 90% for legal-sized individuals.

The GLM revealed that survival was highly dependent on treatment ($\chi^2 = 43.26$; d.f. = 2, $P < 0.001$), but size group, experiment and interaction terms were non-significant at the 95% probability level. Mean survival rates, adjusted for all other terms in the model, were effectively 100% for shallow-hooked fish, 64% for deep-hooked fish, and almost 90% for seine-caught fish (Fig. 1). Significance testing established that adjusted means were different ($P < 0.05$) for each pair-wise comparison, and odds ratios indicated that shallow-hooked sand flathead were 157 times (95% confidence interval [CI] = 20.9–1182.7) more likely to survive than deep-hooked fish.

Across the three experiments, 77 sand flathead were deep-hooked, 55 (71%) had bleeding injuries and in 12 (16%) the line had been cut leaving the hook embedded (Table 2). For deep-hooked fish, the GLM indicated that survival was dependent

Table 2. Number of deep-hooked sand flathead by bleeding and hook removal status, and size group for the combined data set of post-release survival experiments

Values in parentheses represent the number of mortalities

| Bleeding | Hook removed | | Hook left in | |
	Sub-legal	Legal	Sub-legal	Legal
Yes	26 (12)	21 (11)	1 (0)	7 (2)
No	5 (2)	13 (0)	1 (0)	3 (0)

on whether or not the individual was bleeding ($\chi^2 = 10.57$; d.f. = 1, $P = 0.001$), with adjusted mean survival rates for non-bleeding fish of almost 85% compared with 54% for bleeding fish (Fig. 2*a*). However, there was also a size group × bleeding interaction ($\chi^2 = 6.07$; d.f. = 1, $P = 0.014$) (Fig. 2*b*). Adjusted mean survival rates for sub-legal bleeders and non-bleeders were not significantly different. By contrast, survival rates for legal-sized non-bleeders were significantly higher (~100%) than for bleeders (51%), indicating that the effect of bleeding on survival was a result of survival differences in the legal size group. Overall, the odds of survival for deep-hooked fish were 8.3 times (95% CI = 1.8–39.2) greater for non-bleeders than for fish that had obvious bleeding injuries. Of the remaining factors, hook left in, size group and experiment emerged as non-significant factors.

Although not a primary objective of this study, it was possible to make some observations about the practice of not removing hooks in deep-hooked fish. Two of the fish died with hooks still intact: in one the point of the hook had passed through the upper oesophageal wall, back into the mouth and penetrated the gill arch, while in the second the stomach wall was punctured. Of the remaining ten survivors, five still had hooks embedded at the end of the experimental period, one of which had rotated the hook such that the shank of the hook was in the stomach. Three fish expelled the hook, while in another the hook was free (unattached) within the stomach. The status of one other survivor was uncertain because it was not autopsied at the completion of the experiment.
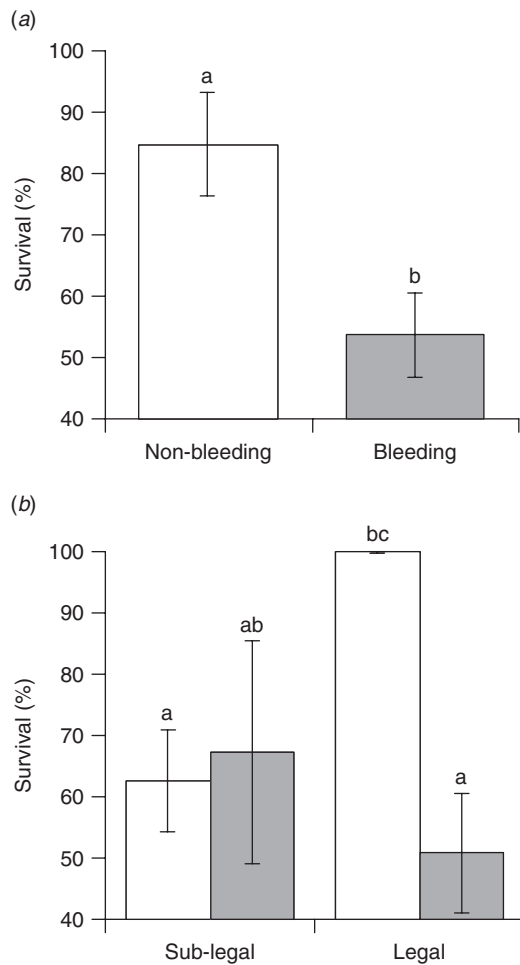
Fig. 2. Adjusted mean survival rates (±s.e.) for bleeding (shaded) and non-bleeding (white) deep-hooked sand flathead for (*a*) all size classes and (*b*) sub-legal and legal size groups. Means with different letters are significantly different from one another.

Hook types – catch rates and deep hooking

In the two fishing trials, a total of 551 sand flathead were caught, 55% of which were sub-legal (Table 3). Within the diary data set, information was available for 1126 bait-caught sand flathead, 46% of which were sub-legal (Table 3). There was some variability in the size of J-style and octopus hooks used by diarists, though in each case most sand flathead were taken with hook sizes consistent with those used in the fishing trials. Hook size was not included as a factor in these analyses.

A key objective of the fishing trials was to compare the performance of circle hooks against conventional hook types. Given minor differences in sampling protocols between trials, data were treated separately. Mean catch rates (flathead per boat) in the first trial varied from 16.2 for J-style to 17.3 for wide-gap and 22.0 for circle hooks. In the second trial, mean catch rates were 13.8 for circle and J-style hooks, and 17.3 for octopus hooks. Standard errors associated with these means were relatively high (17–46% of mean values), with no significant differences in catch rates

among hook types in either trial (ANOVA: Trial 1 $F_{2,17} = 0.41$; $P = 0.672$; Trial 2 $F_{2,9} = 0.12$; $P = 0.885$).

Size compositions by hook type for the combined fishing trial data set revealed unimodal distributions, with mean lengths varying by just over 1 cm: 28.5 cm for J-style, 28.7 cm for octopus, 29.6 cm for circle and 29.9 cm for wide gap hooks. Kolmogorov-Smirnov tests failed to detect significant differences in length-frequency distributions.

Hook type ($\chi^2 = 7.27$; d.f. $= 3$, $P < 0.001$) and size group ($\chi^2 = 6.94$; d.f. $= 1$, $P = 0.008$) significantly influenced the rate of deep hooking in sand flathead, but the effect of data source (fishing trial or diary) was not significant ($\chi^2 = 2.71$; d.f. $= 1$, $P = 0.100$). The lack of significance in the hook type × size group interaction ($\chi^2 = 0.68$; d.f. $= 3$, $P = 0.56$) indicated that with respect to deep hooking, these two factors acted independently. The adjusted mean deep-hooking rate for circle hooks (1%) was significantly lower than for any of other hook types tested (Fig. 3*a*). Deep-hooking rates for the other hook were not significantly different, ranging between 5 and 9%. The size effect indicated that there was a significantly greater probability of deep hooking in legal-sized flathead than sub-legal fish (Fig. 3*b*). In order to examine this relationship in more detail, the model was re-run with length as a continuous variable, and again hook type ($P < 0.001$) and length ($P = 0.004$) emerged as significant factors. The deep-hooking rate increased non-linearly with size, from ~3% at 20 cm to 4.5% at 30 cm and 9% at 40 cm (Fig. 4).

Discussion

In the present study, virtually all hook-related mortalities were associated with deep hooking, the survival rate for shallow-hooked fish being effectively 100% compared with 64% for deep-hooked fish. Anatomical hooking location, specifically deep hooking, has been identified as the most important factor influencing survival in hook-caught fish (refer to reviews by Muoneke and Childress 1994; Bartholomew and Bohnsack 2005).

The inclusion of controls is important in order to correctly estimate survival rates in post-release survival studies (Wilde *et al*. 2003). In the present study, seine-caught sand flathead were to be treated as a non-hook control. However, because survival rates were significantly lower than for shallow-hooked flathead, we conclude that they were not effective in this context. Rather, the high survival rate of the shallow-hooked fish (~100%) implies that mortality, when observed in the hook-caught flathead, was unlikely to have been confounded by factors such as handling and confinement. Previous studies have demonstrated that post-release survival of seine-caught fish can be low, especially when fish become meshed in the net (Kennelly and Gray 2000). There have been no studies in Tasmania to assess sand flathead by-catch levels in seine nets, but our results suggest that there may be unaccounted mortality (~10%) associated with the method.

Most post-release survival studies have determined that hooking-related mortality occurs very soon after capture, typically within 24 h (Muoneke and Childress 1994; Schill 1996; Taylor *et al*. 2001; Bartholomew and Bohnsack 2005). Our findings were consistent with this observation, with 96% of sand

Table 3.   Number of sand flathead caught by hook type and size group for the two fishing trials and bait fishing reported in the fishing diary
Values in parentheses indicate the number of deep-hooked individuals

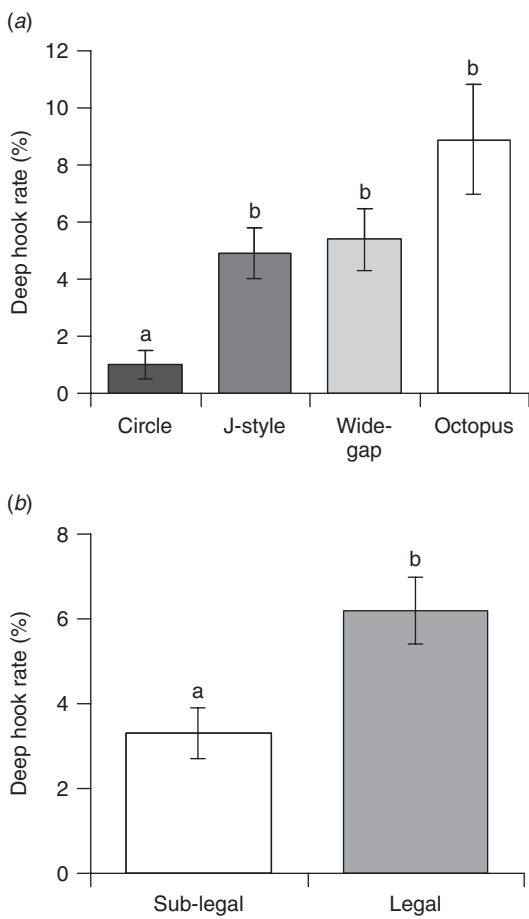| Hook type	Trial 1		Trial 2		Diary	
	Sub-legal	Legal	Sub-legal	Legal	Sub-legal	Legal
Circle	75 (2)	79 (1)	31 (0)	24 (0)	67 (0)	84 (1)
J-style	66 (2)	48 (7)	41 (2)	14 (1)	225 (6)	277 (14)
Wide-gap	50 (2)	54 (4)	–	–	152 (4)	162 (12)
Octopus	–	–	41 (3)	28 (3)	70 (6)	89 (8)
Total	191 (6)	181 (12)	113 (5)	66 (4)	514 (16)	612 (35)

(*a*)

(*b*)

Fig. 3.   Adjusted mean deep-hooking rates (±s.e.) for sand flathead based on (*a*) hook type and (*b*) size group. Means with different letters are significantly different from one another.

Fig. 4.   Deep-hooking rate by length for sand flathead; solid line is adjusted mean, dotted lines represent upper and lower 95% confidence limits.

flathead mortalities recorded within 24 h (and most within 6 h). Broadhurst *et al.* (2005) reported up to 10% mortality in dusky flathead within four hours of capture, presumably a consequence of hooking-induced trauma. Delayed mortalities also occurred 4–10 days after capture, with overall mortality rates of 28–47% after ten days. Their study was, however, confounded by problems with confinement, and most subsequent mortalities
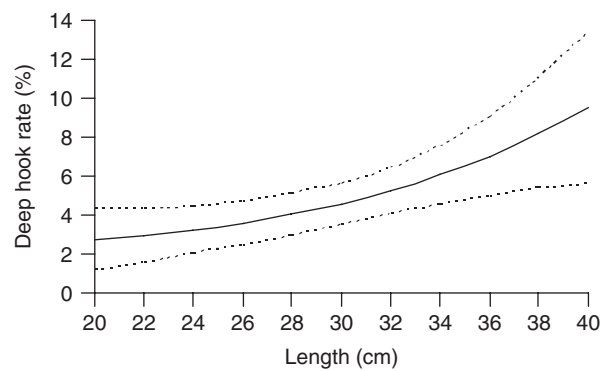
appeared to be a result of non-hook-related injuries. In our second survival experiment, sand flathead were held in aquaria for almost 1 month with no additional mortalities after the initial holding period. Delayed mortalities, at least within this time frame, are unlikely to be a significant problem for sand flathead.

Although there was no relationship between size group and survival in sand flathead based on hooking location, our data did suggest that deep-hooking rates in legal-sized fish (6%) were double those in sub-legal fish (3%). Because most legal-sized fish are not released, the higher deep-hooking rate would have limited overall impact on the level of incidental hooking mortality in sand flathead. Based on other studies, the relationship between fish size and survival appears to be species-specific, with survival rates either increasing with size, decreasing with size, or remaining unaffected by size (see reviews by Muoneke and Childress 1994; Bartholomew and Bohnsack 2005).

Bleeding is a significant factor affecting the survival of released fish (Wertheimer 1988; Vincent-Lang *et al.* 1993; Schisler and Bergersen 1996; Nelson 1998; Lindsay *et al.* 2004), and is usually associated with deep hooking (Skomal *et al.* 2002; Cooke *et al.* 2003*a*). Our findings were consistent with these observations, with bleeding injuries more frequent in deep-hooked fish, and lower survival rates for bleeders. However, this pattern was only evident in legal-size fish: survival of sub-legal individuals was less affected by whether or not there was bleeding associated with deep-hooking. Because our sample sizes

were small, further research would be necessary to establish the robustness of this observed size × bleeding interaction in sand flathead.

Cutting line rather than removing the hook can increase survivorship in deep-hooked fish (e.g. Schill 1996; Schisler and Bergersen 1996; Taylor *et al*. 2001; Tsuboi *et al*. 2006), with some hooks eventually being shed, often shortly after release (Bugley and Shepherd 1991; Schill 1996; Schisler and Bergersen 1996; Diggles and Ernst 1997; St John and Syers 2005; Tsuboi *et al*. 2006). Our analyses indicated that cutting the line and leaving the hook in was not a significant factor influencing survival in sand flathead. Nevertheless, based on raw frequencies, there was some evidence that cutting the line may have a survival benefit in deep-hooked sand flathead, with 10 of the 12 fish (83%) in which the hook was not removed surviving. We also observed evidence that survivors were able to expel hooks, with at least four survivors having dislodged hooks. Schisler and Bergersen (1996) demonstrated that cutting the line significantly improved survival rates from 45 to 79% in deep-hooked rainbow trout (*Oncorhynchus mykiss*). Similarly, Schill (1996) observed an increase in survival of deep-hooked rainbow trout from 26 to 53% when line was cut, with almost three-quarters of line-cut survivors having shed hooks within two months. Based on recaptures, Tsuboi *et al*. (2006) established very high survival rates (93%) for deep-hooked white-spotted charr (*Salvelinus leucomaenis*) that had the line cut. Furthermore, about one-third of these fish had evacuated the hooks before recapture, while in others there was clear evidence of substantial *in situ* corrosion of the hooks.

By virtue of a dorso-ventrally flattened head and large mouth, sand flathead are susceptible to hooking damage to the eye and eye socket from ingested hooks. Hooking injuries to the eye may contribute to mortality because of a reduced capacity to avoid predators and feed successfully (DuBois and Dubielzig 2004). In our study, none of the flathead hooked through the eye region died within the holding period; however, obvious eye injuries, including haemorrhaging and swelling, were observed in about one-third of individuals at the completion of the experimental period. Extra-orbital and choroidal haemorrhage has been shown to be reversible within a short period in some species of salmonids (DuBois and Dubielzig 2004). The comparatively low rate of obvious eye injuries in our study corroborates this observation for sand flathead. Further research would be required to formally investigate the nature and extent of eye damage and healing in flathead, as well as to investigate possible sub-lethal effects on long-term survival and growth.

Of the three survival experiments conducted in this study, two were carried out during summer within very similar temperature ranges (mean 17°C), whereas the third experiment was conducted during winter (mean 11°C). The lack of a significant experimental effect on survival implies that, within the range of temperatures examined, temperature was not an important factor in sand flathead survival. This is consistent with findings for common snook (*Centropomus undecimalis*) (Taylor *et al*. 2001). By contrast, water temperature has been identified as a major factor for several other species, with survival typically inversely related to temperature (e.g. Muoneke and Childress 1994; Schisler and Bergersen 1996; Nelson 1998; De Lestang *et al*. 2004).

Internationally and nationally there is considerable interest in the use of circle hooks as a 'fish friendly' tackle. Circle hooks are promoted on the expectation that post-release survival rates are higher than for other hook types, owing largely to the low incidence of deep hooking (Cooke and Suski 2004). Our findings support this conclusion, with a significantly lower deep-hooking rate for circle hooks than for conventional hooks. Because most hook-induced mortalities result from injuries owing to deep hooking, it can be inferred that circle hooks have the potential to produce higher survival rates for released sand flathead. With the exception of St John and Syers (2005), who examined post-release survival in dhufish (*Glaucosoma hebraicum*), there have been no previous Australian studies to examine the effectiveness of circle hooks. Unfortunately, because very few individuals were caught on circle hooks, the effect of hook type on dhufish survival was inconclusive.

If anglers are to accept circle hooks, it is important that they perceive that the capture efficiency of circle hooks is at least as effective as that of conventional hook types. In this respect the performance of circle hooks has proven variable, with several studies finding that circle hooks do not perform as effectively as other hook types (e.g. Orsi *et al*. 1993; Cooke *et al*. 2003*a*, 2003*b*; Meka 2004; Jones 2005). Capture efficiency has two components: hooking efficiency (proportion of strikes that result in a hook-up) and landing efficiency (proportion of hook-ups that are landed) (Cooke and Suski 2004). Meka (2004) compared artificial flies with circle and J-style hooks and established that circle hooks had a lower landing efficiency than did J-style hooks for rainbow trout. Jones (2005) noted that both hooking and landing efficiencies were lower for walleye (*Stizostedion vitreum*) taken on circle hooks than on octopus hooks. In our study, capture efficiency was assessed directly as catch rate (fish per unit time) and indicated that circle hooks were at least as effective as conventional hook types for sand flathead. Their successful adoption would, however, require some modification to fishing techniques. Constant tension rather than a vigorous strike on the bite is required to hook fish when using circle hooks (Cooke and Suski 2004), and it is this aspect that is likely to result in some resistance to their uptake, particularly from experienced anglers.

By combining information on hooking location and survival rates, and hook type and hooking location, we conclude that post-release survival in sand flathead is likely to be high, greater than 99% for circle hooks and between 94 and 97% for conventional hook types. Comparable survival rates have also been found for several other Australian coastal fish species of recreational significance: ∼97% for tailor (*Pomatomus saltatrix*) (Ayvazian *et al*. 2002) and King George whiting (*Sillaginodes punctata*) (Kumar *et al*. 1995), and 94% for sand whiting (*Sillago ciliata*) (Butcher *et al*. 2006). By contrast, survival rates as low as 64–72% have been reported for yellowfin bream (*Acanthopagus australis*), pink snapper (*Pagrus auratus*) and silver trevally (*Pseudocaranx dentex*) (Broadhurst *et al*. 2005).

High survival rates for sand flathead support the efficacy of current management strategies, which are based on size and bag limits, and the practice of catch-and-release fishing. Our data also indicate that there would be some conservation benefit from the use of circle hooks and, importantly, that the performance of circle hooks is at least comparable with that of conventional hook types.

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