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Tini a Tangaroa

Recommended release mortality estimation methods for species commonly caught by recreational fishers in New Zealand

New Zealand Fisheries Assessment Report 2020/17

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EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report 2020/17.* 42 p.**

This report identifies species commonly caught and released by recreational fishers in New Zealand and proposes experimental methods that could be used to estimate release mortality rates for four high priority species, based on national and international experience and published literature.

In New Zealand, recreational fishing is open access and bag limits and size limits are the main management tools used to limit overall landed catch. However, the actual impact of management changes on total fishing mortality also depends on the number of fish released and their vulnerability to release mortality. Some fishers may have to fish longer and catch more fish to land a satisfactory catch of legal size fish. Several components are required to estimate total release mortality for a species and area.

- An estimate of the proportion of fish released vs. retained from a cross section of fishers.
- An associated characterisation of the incidence of factors that may influence release mortality for that species (e.g., capture depth, hook site, size of fish, predation).
- Experimental estimates of the release mortality rates associated with those factors or combinations of factors.
- Survey estimates of the total recreational landed catch for that species and area to scale up the proportion released and their likely fates.

Five criteria or metrics were used to prioritise which species future recreational release mortality research could focus on. These criteria were: species with large recreational harvest estimates; the associated commercial catch tonnage; the proportion of the total catch that was taken by the recreational sector; data on the proportion of the recreational catch by species that is returned to the sea; and priority species identified by inshore fisheries managers. All five criteria suggest that the four species that future research into recreational release mortality estimation should focus on are: snapper, blue cod, kingfish, and kahawai.

Recreational fishers currently land over 4000 t of snapper annually, accounting for over half of the national recreational harvest of all species and 40% of the combined snapper landed catch of all sectors. Recreational release rates have steadily increased in most areas, as the abundance of snapper stocks has gradually increased, and larger minimum legal size limits and smaller daily bag limits have been introduced in most management areas. Most of the snapper that have been released by recreational fishers have been below the minimum legal size limit in force at that time, with the majority of this catch taken by rod and line fishing methods in water depths less than 30 to 40 m.

Snapper release mortality studies in New Zealand and Australia all suggest that hook damage to the gills, oesophagus, and other vital organs, and barotrauma (damage caused by expanding gases), are the most likely causal factors for release mortality. Australian studies have shown that the swim bladder of a snapper will almost certainly burst if it is caught in more than 12 m depth, which may lead to loss of buoyancy control and exhaustion, and that snapper caught in 30 m depth or more may suffer additional barotrauma caused by gases coming out of solution and forming bubbles when the fish is hauled to the surface. A holding net experimental design is proposed to assess release mortality rates associated with these and other potential causal factors.

Release rates for blue cod, kingfish, and kahawai in the recreational fishery have also increased over the past 20 years, and there is, therefore, a growing need to account for any incidental recreational fishing mortality rates for these commonly caught species. Blue cod are endemic to New Zealand. There

has been only one blue cod release mortality study to date, which focused on mortality rates for sub-legal cod caught by two different hook types. The holding pot design used for this study could be further extended to investigate other factors that may influence mortality. Early indications are that barotrauma is unlikely to be a significant causal factor for this species, which does not have a functional gas-filled swim bladder. There is only one published study that has investigated kingfish release mortality, and this suggested that fish hooked in the jaw survived and that hook damage to the gills was the main factor associated with mortality. Kingfish are able to vent their swim bladders when they rapidly ascend to the surface, and barotrauma is therefore unlikely to be an issue for this species, which can easily swim back down to its capture depth when released. Pop-up satellite tags are recommended to monitor kingfish release survival, rather than a holding net, post- release monitoring experimental design, given the highly mobile nature of this species. No work has been done on recreational release mortality for kahawai, and none is proposed because the need is far greater for the other three species discussed.

Regular data collection is also required on the incidence of factors that will influence release mortality rates, such as fish size, capture depth, and hook location. A citizen science catch and release app has also been developed and trialled as part of this study, to see whether this self-reporting approach could be used to augment creel survey-based release mortality factor characterisation surveys. The use of these and other data sources on recreational release mortality to inform fisheries management is also discussed.

1. INTRODUCTION

Reliable methods have now been developed to estimate the harvest landed by recreational fishers from the main inshore fish stocks in New Zealand (Hartill & Edwards 2015, Holdsworth et al. 2018), but there is growing recognition of the need to quantify all sources of fishing mortality, including recreational post-release mortality. Although some research has already been conducted on recreational release mortality in New Zealand (McKenzie & Holdsworth 1997, Holdsworth & Boyd 2008a, 2008b), the few studies that have been done have focused primarily on snapper (*Pagrus auratus*) in Fisheries Management Area 1 (SNA 1). The only available estimates of recreational snapper release mortality rates and associated tonnage estimates are based on characterisation surveys and mortality rate experiments conducted decades apart, both here and in Australia. These estimates have much reduced relevance now given changes in the recreational catch composition in SNA 1, following changes to recreational daily bag and minimum legal size limits in 2014 and the population structure and abundance of this stock.

A more concerted approach is therefore required, so that fisheries managers have a better understanding of the consequences of any changes that they make to daily bag and minimum legal size limits that are used to constrain recreational harvests. Information on release mortality could also be provided to recreational fishers which they could use to improve fishing methods and handling practices to maximise fish welfare and survival. Estimates of release mortality at size could also be used to inform the stock assessments that management decisions are based on.

This report identifies and prioritises recreationally caught species that should be the focus of future research into release mortality. Relevant release mortality studies conducted on these species, both here and in Australia, are also reviewed, as well as generic experimental methods that could be used to assess release mortality rates. Experimental approaches and designs are then proposed for the highest priority species.

This is the final reporting requirement for Fisheries New Zealand research project MAF2018-04.

Overall Objective:
To review the need for estimates of total fishing mortality from recreational fishing and design methods to meet those needs.

Specific Objectives:
1. To review the need for estimates of total fishing mortality from recreational fishing in consultation with MPI fisheries managers.
2. To recommend designs for trials or other approaches to estimate the number of fish released and their fate in selected recreational fisheries.

2. PRIORITISING SPECIES WHERE RECREATIONAL RELEASE MORTALITY IS AN ISSUE

Recreational fishers catch a wide variety of species from New Zealand's coastal waters but, for most of these species, the number of fish caught by recreational fishers is low relative to the number of fish landed by all sectors combined. Fishers participating in the 2017–18 National Panel Survey reported catches of almost 80 finfish and shellfish species, but there are only 12 species with an estimated national recreational catch greater than 65 t (Wynne-Jones et al. 2019). The first stage of this study focused on these 12 species, because they potentially have the most significant levels of associated recreational release mortality.

Five criteria or metrics were used to determine which of these 12 species most warranted future research into recreational release mortality (Table 1). These criteria were:

- the tonnage of each species landed by the recreational sector, as estimated by the 2017–18 National Panel Survey,
- the tonnage of each species landed by the commercial sector in 2017–18 from Fisheries Plenary Reports,
- the proportion of the combined 2017–18 commercial and recreational catch taken by the recreational sector,
- estimates of the proportion of the recreational catch of each species that is released, derived from creel survey data collected nationally in 2017–18 and Amateur Fishing Charter Vessel (AFCV) return data reported since 2011,
- a management utility ranking based on conversations with fisheries managers who were asked to identify priority species from a management perspective.

Table 1: Criteria used in conjunction with discussions with fisheries managers to prioritise the species that future research on release mortality should focus on. The top four species for which new information would be of most utility could be ranked relatively easily but, for the remaining eight species, tied ranks were allocated. Management utility rankings were assigned by Fisheries New Zealand.

Species	Recreational harvest in 2017–18 (t)	Commercial landings in 2017–18 (t)	% of catch recreational	% released creel data	% released AFCV data	Rank on recreational harvest (t)	Rank on % recreational catch	Rank on % released	Management utility rank
Snapper	4 270	6 490	40	62	42	1	5	2	1
Blue cod	293	2 049	12	55	38	4	8	3	2
Kingfish	738	255	74	63	79	3	2	1	3
Kahawai	1 702	2 139	44	39	18	2	3	6	4
Striped marlin	66	0	100	33	52	12	1	5	5=
Rock lobster	158	2 748*	5	30	58	9	9	4	5=
Hapuku/bass	228	1 250	15	05	03	5	7	12	9=
Trevally	210	3 759	5	23	16	7	10	7	9=
Butterfish	82	103	44	2	9	11	4	10	9=
Red gurnard	195	3 855	5	17	13	8	11	8	9=
Tarakihi	225	5742	4	13	10	6	12	9	5=
Paua	141	812*	15	6	4	10	7	11	5=

*in 2016–17.

All four species that fisheries managers have prioritised for further work on release mortality are ranked fourth or better in at least two of the three other ranking assessment criteria (Table 1). Snapper account for almost half of the national recreational catch, with a relatively high associated release rate. The number of snapper released annually by recreational fishers probably exceeds releases of all other species combined. Over half of the recreational blue cod (*Parapercis colias*) catch is released, and although most of the national catch of this species is landed by commercial fishers, there are some areas where the recreational catch may exceed the commercial catch, such as in the Marlborough Sounds. Almost three-quarters of the kingfish (*Seriola lalandi*) caught from private boats and charter boats is also released, with three quarters of the overall annual catch taken by recreational fishers. The fourth priority species is kahawai (*Arripis trutta*), which is commonly caught by recreational fishers around most of New Zealand and over a third of this catch is released.

Recreational release mortality for snapper is often attributed to the barotrauma that a fish may experience when it is retrieved from depth. Barotrauma is less obvious in blue cod, kingfish, and kahawai. Most of the recreational catch of the four key species identified above is taken from recreational boats fishing shallow coastal waters (under 100 m) around New Zealand. The depth distribution of recreational boat-based fishing in FMA 1, for example, can be inferred from boat location data collected during an aerial survey of this fishery in 2017–18 (Hartill et al. 2019) (Figure 1). ArcMap GIS software was used to determine the depth at the location of each boat, and the cumulative distribution of these fishing depths is shown in Figure 2. This analysis suggests that 77% of the stationary boat fishing effort observed during this survey occurred in depths of 30 m or shallower, with 89% of effort occurring in 40 m or shallower. Pelagic species are also sometimes caught from vessels trolling lures close to the surface, so the capture depth of these fish is usually shallow and not related to bottom depth.

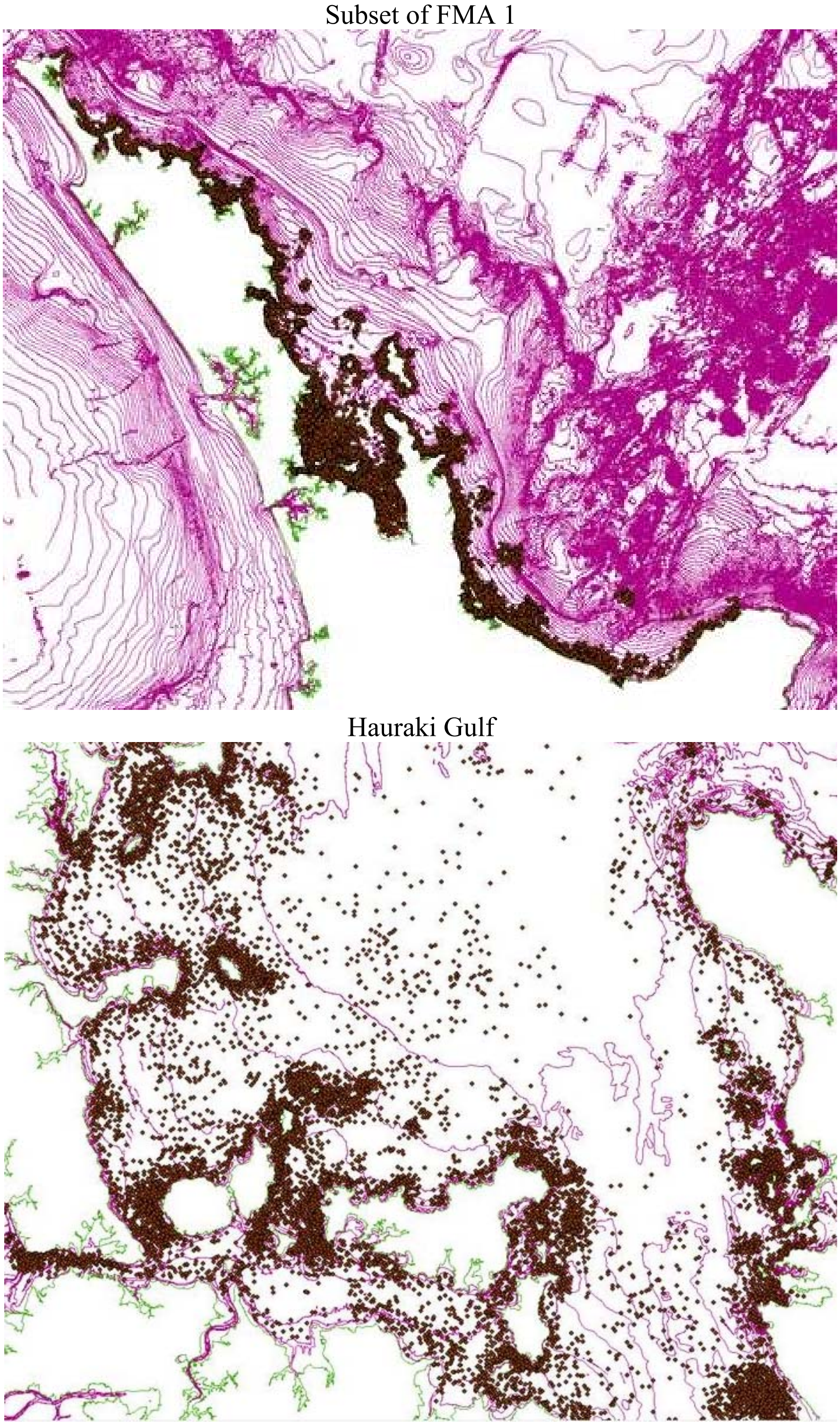

Figure 1: Location of recreational fishing vessels observed during the 2017–18 aerial-access survey, relative to 10-m depth contours, in FMA 1 (upper panel) and in the Hauraki Gulf (lower panel).

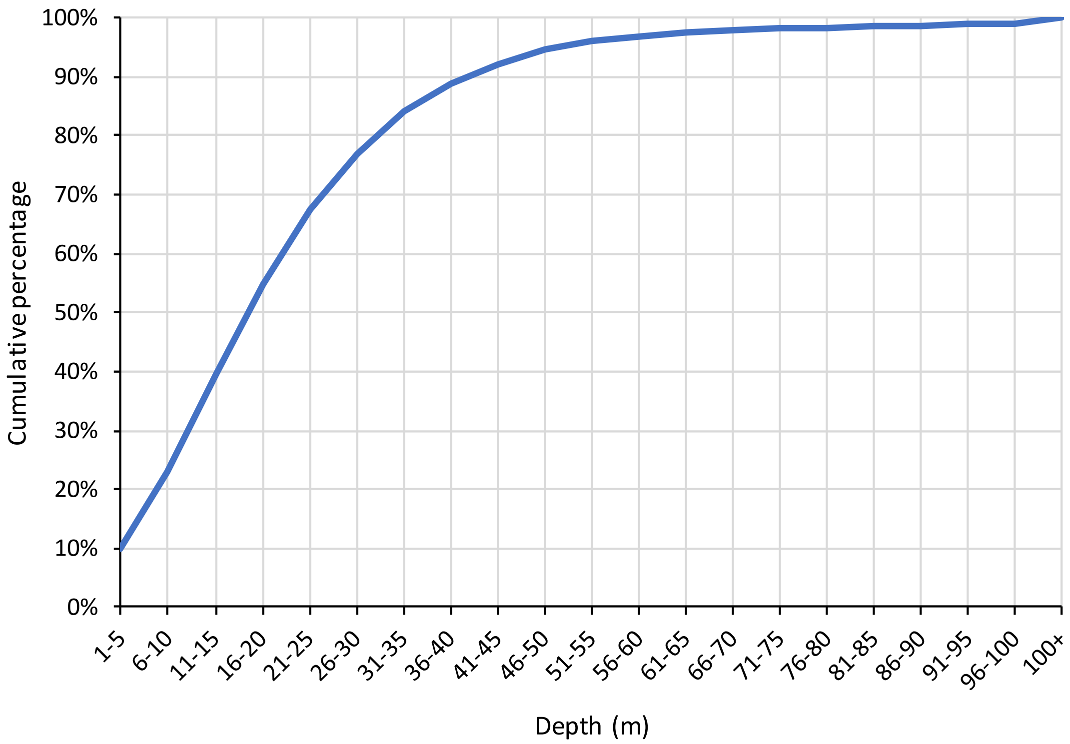

Figure 2: Cumulative depth distribution of boats observed during a 2017–18 aerial-access survey of the recreational boat-based fishery in FMA 1, in 2017–18.

Barotrauma is only one possible cause of release mortality, however, and other factors such as fishing gear related injuries and excessive or rough handling can be more of an issue for some species (Bartholomew & Bohnsack 2005). The following sections of this report will therefore review available literature on snapper, kingfish, blue cod, and kahawai release mortality studies, and propose methods that could be used to understand and quantify this issue for each species.

3. PREVIOUS SNAPPER RELEASE MORTALITY STUDIES

3.1 New Zealand recreational snapper release rates

Snapper stocks support substantial recreational and commercial fisheries around the North Island and upper South Island. There are more data on recreational snapper fisheries than for any other species, but understanding of release mortality for this species is limited. Recreational fishers often release more snapper than they land, but the current extent of mortality associated with released catches is largely unknown.

The main regulatory tools used to manage recreational snapper harvests are method restrictions, minimum legal size (MLS) limits, and daily bag limits. Increases to the snapper MLS in the large SNA 1 fishery over the past four decades have increased the likelihood of a recreational fisher releasing a fish back to the sea. Many fishers also prefer to keep snapper well above the MLS and will fish in a way that targets larger fish. Recreational minimum legal size limits and/or daily bag limits for each of the snapper management areas have been adjusted at some time since 1985 (Table 2). These adjustments to regulation settings have primarily been undertaken to constrain annual recreational harvest, regardless of any potential consequential increase in release mortality.

Table 2: Changes to minimum legal size limits (MLS) and daily bag limits used to constrain recreational harvest in snapper stocks.

Stock	MLS	Bag limit	Introduced
SNA 1	25	30	01/01/1985
SNA 1	25	20	30/09/1993
SNA 1	27	15	01/10/1994
SNA 1	27	9	13/10/1995
SNA 1	30	7	01/04/2014
SNA 2	25	30	01/01/1985
SNA 2	27	10	01/10/2005
SNA 3	25	30	01/01/1985
SNA 3	25	10	01/10/2005
SNA 7	25	3	01/01/1985
SNA 7 (excl Marlborough Sounds)	25	10	01/10/2005
SNA 7 (Marlborough Sounds)	25	3	01/10/2005
SNA 8	25	30	01/01/1985
SNA 8 (FMA 9 only)	25	20	30/09/1993
SNA 8 (FMA 9 only)	27	15	01/10/1994
SNA 8	27	10	01/10/2005

Most of the surveys of New Zealand's recreational fisheries have been conducted to characterise or estimate the landed catch (harvest), but other information has been collected during the course of these surveys, including reported estimates of undersize and legal size fish released by interviewed fishers. Counts of released fish are often reported as approximate estimates based on recalled catches that fishers had little interest in, but these data can still be used to broadly characterise trends in release rates over time (Figure 3).

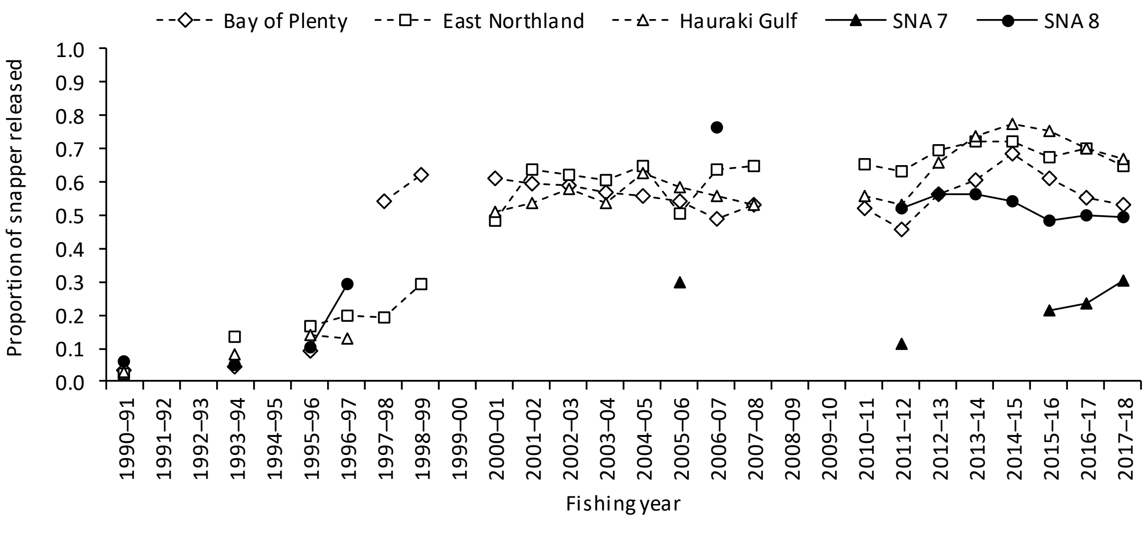

Figure 3: Proportion of the reported recreational snapper catch that was released by fishers interviewed during creel surveys conducted since 1990–91, by fishing year and area (unpublished data, Fisheries New Zealand rec-data database). The three named regions are within SNA 1. Release rates are only shown when at least 100 fish were caught in an area in any given fishing year.

Reported snapper release rates were initially very low during the early 1990s, when the minimum legal size limit for all snapper stocks was 25 cm, and the retention of these fish was essentially unconstrained by the 30 fish daily bag limit in place for all stocks except SNA 7 at that time. Release rates increased in the three regions of SNA 1 following increases in the MLS from 25 cm to 27 cm at the beginning of the 1993–94 fishing year, and the progressive decrease in the daily bag limit for this stock from 30 to 9 fish by October 1995. Snapper release rates then peaked during the 2014–15 fishing year, coinciding with the reduction of the SNA 1 daily bag limit from 9 to 7 fish and the increase of the MLS from 27 cm to 30 cm. Release rates in the three regions of SNA 1 have since declined to the levels recorded during the 2012–13 fishing year. Snapper release rates have been lower, but have followed a similar trend, in SNA 8, and have been generally much lower in SNA 7. Lower release rates in SNA 7 and SNA 8 reflect the lower MLSs for these stocks (25 cm and 27 cm respectively vs. 30 cm) and faster growth rates than in SNA 1.

Recreational fishers use an increasing variety of fishing methods and tackle to catch their fish, which is partially driven by a growing awareness of the need to change their fishing practices to reduce fishing mortality. Over 98% of the snapper catch reported during creel surveys conducted in 2017–18 were caught by fishers using some form of rod and line fishing method, with either baited looks, lures, or soft plastic baits (Table 3). Release mortality rates can vary considerably by fishing method because the damage caused by each type of fishing gear will differ. Recreational advocacy groups such as LegaSea now promote practices designed to avoid catching under-sized fish, minimise release mortality, and maximise utilisation of fish kept (https://legasea.co.nz/2017/02/28/fishcare/) and fishing magazines also often have articles and editorials addressing this issue.

Table 3: Reported numbers of snapper, blue cod, kingfish, and kahawai caught, and percentage released, by fishers interviewed at boat ramps during creel surveys conducted nationally during the 2017–18 fishing year (unpublished data, Fisheries New Zealand rec-data database).

	Snapper		Blue cod		Kingfish		Kahawai	
Fishing method	Caught	% Released	Caught	% Released	Caught	% Released	Caught	% Released
Line & hook (incl lures)	169 822	63%	21 853	55%	3 073	67%	25 964	41%
Soft plastic	9 666	52%	105	50%	126	67%	1 185	38%
Soft plastic & bait	14 152	66%	256	58%	150	67%	1 557	39%
Longline	2 029	19%	329	54%	23	78%	189	20%
Trolling	594	68%	38	92%	294	63%	1 665	26%
Live baiting	384	78%	50	70%	51	69%	158	8%
Diving/spearfishing	252	33%	–	–	239	7%	–	–
Dredging	31	87%	30	33%	–	–	3	33%
Potting	–	–	5	0%	1	0%	–	–
Shore (rod & reel)	53	98%	–	–	–	–	3	0%
Set netting	20	30%	–	–	–	–	21	29%
Drag netting	12	0%	–	–	–	–	7	0%

There are therefore several reasons why levels of snapper release mortality will have changed dynamically over time, regardless of any changes in the length composition and abundance of snapper that are available to recreational fishers. Although some sources of recreational snapper release mortality have been investigated in New Zealand, this work has been undertaken in a piecemeal fashion, and is now out of date.

Far more research has been conducted on recreational release mortality in Australia and, though the scale and nature of the Australian snapper fisheries is very different from those in New Zealand, some lessons can be drawn from these studies. The following sections provide a review of past New Zealand and Australian research into recreational snapper release mortality, and the potential extent of this source of mortality.

3.2 Review of New Zealand recreational snapper release studies

Estimates of snapper release mortality from recreational capture

A pilot study of the survival rate of recreationally caught and released snapper was conducted in the Hauraki Gulf during 1995 by the National Institute of Water & Atmospheric Research (NIWA) (McKenzie & Holdsworth 1997). A total of 216 snapper with lengths ranging from 17 cm to 33 cm were caught by two groups of amateur anglers with various levels of fishing experience; one group was told how to handle their catch to minimise release mortality, whereas the other group received no instruction at all. All snapper were caught by the anglers using 4/0 wasabi brand J-hooks, in depths ranging from 14 m to 20 m. All volunteer anglers were asked to cut the lines of fish that were deep/gill hooked, rather than trying to remove the hook from the fish. Anglers removed their catch from their gear and then handed it to a scientific observer, who tagged the fish with a PIT (Passive Integrated Transponder) tag before it was released into a 600-litre aerated holding tank. The time that each fish was held in the holding tank before it was released into a 4000-m^2 (20 m × 20 m wide by 10 m deep) holding net was recorded. The tagged snapper were held in the holding net for 15 days, which was monitored by divers twice a day so that any dead fish could be removed (McKenzie & Holdsworth 1997). No record was made of when any dead fish retrieved from the holding net, so their survival period is unknown.

Only three snapper out of a control sample of 150 "minimally handled" commercial bottom longline-caught fish died over the 15-day holding period. It was therefore assumed that any recreationally caught fish that succumbed had died because of release mortality, and not holding mortality. Only 18 of the 157 lip-hooked fish, but 36 of the 41 deep/gill hooked (hooked in the gills or gut), died over the following 15 days. Deep/gill hooking was more prevalent for larger fish. Furthermore, the mortality rate of these gut-hooked fish was higher than for the lip-hooked fish across all size classes (Figure 4).

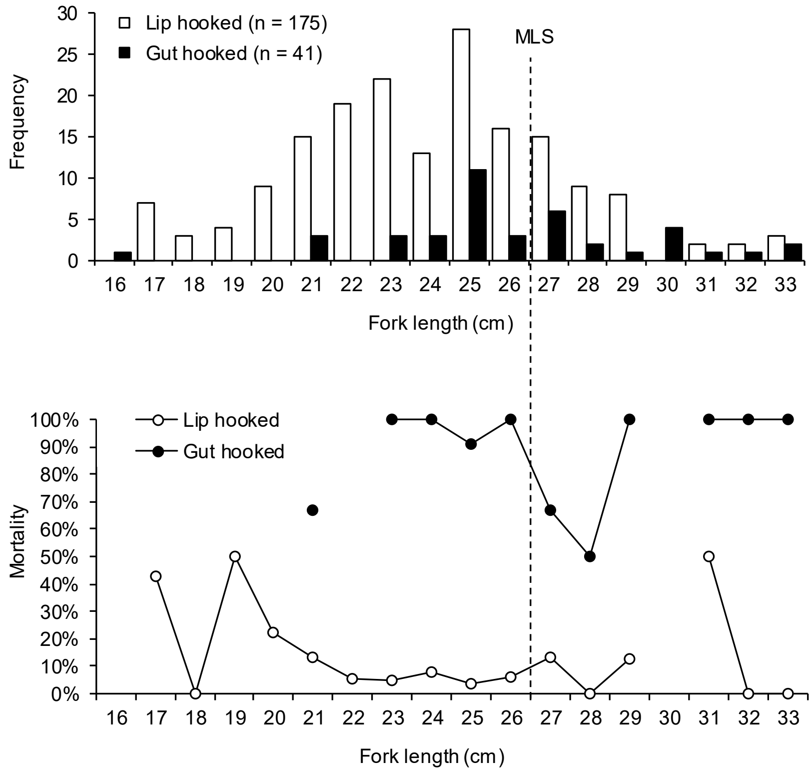

Figure 4: Length frequencies (upper panel) and mortality rates by size (lower panel) of lip-hooked and gut-hooked snapper caught by recreational fishers during a holding net mortality experiment in late 1995.

An *a posteriori* analysis of these data suggested that fish length and fisher experience were not significant predictors of release mortality, but the length of time that each fish was held in a holding tank on the fishing boat before it was released into the holding net was significant. A two-parameter mixed model was used to derive mortality probabilities for gut- and lip-hooked fish relative to holding time (Table 4).

Table 4: Mortality probability of snapper caught by recreational line relative to vessel holding time and hook location.

Holding time (min,)	Deep-hooked	Lip-hooked
0–19	0.736	0.035
20–39	0.825	0.059
40–64	0.889	0.096
65 and over	0.940	0.170

The assumption was made that no additional mortality was induced by the holding net or tagging. After removing the effect of holding time, the mortality of "lip-hooked" fish with the hook removed was in the order of 5–10% and 75–90% for gut-hooked snapper where the hook was not removed (McKenzie & Holdsworth 1997). There was no apparent difference between the release mortality rates of snapper released by the fishers who were given instructions on how to handle fish, and those who weren't, given the relative rate of gut-hooking observed in the catches from the two groups.

The number, size, and condition of snapper released by recreational fishers in SNA 1

Both the 2011–12 and 2017–18 National Panel Surveys have shown that the SNA 1 stock supports New Zealand's largest recreational fishery, based on the numbers of participants and numbers of fish harvested (Wynne-Jones et al. 2014, 2019). Around 90% of this catch is taken from boats.

In the mid-2000s, the Ministry of Fisheries commissioned a pilot survey and two annual surveys in SNA 1 to collect data on released snapper caught by recreational fishers on boats. This included recording data at sea on the number of snapper released or kept and indicators of the condition of released fish (Holdsworth and Boyd 2008a, 2008b). Snapper were measured and assessed by observers on recreational charter vessels and private recreational fishers were recruited as they left boat ramps to measure and record their own catch on data sheets with printed instructions and a ruler.

Over 28 000 recreationally caught snapper were measured at sea in the three regions of SNA 1 during 2004–05 and 2006–07. Recreational fishers were generally cooperative and measured their catch at sea. The length compositions of snapper recorded by private fishers were very similar to those recorded by the independent observers who measured snapper caught during charter boat trips in the same region. The minimum legal size was 27 cm at the time of the survey. Large numbers of 25 cm and 26 cm fish were caught and released and almost all fish over 33 cm were kept. Released snapper comprised 58% of the total snapper catch sampled.

Data were also collected on fish condition, hook type, hook size, where the fish was hooked, and water depth for 15 000 released fish. The charter boat observers provided the most detailed condition factor data, for 8600 released fish. There was some variation in the incidence of fish condition factors by year, but over 95% of the snapper caught were classified as "swimming away" with the remaining 5% classified as either floating away or dying (Table 5). Some of the fish that swam away had visible injuries. About 20% of these fish exhibited signs of damage caused by barotrauma. About 6% of the released catch was classified as deep/gill hooked or externally hooked.

Table 5: Proportion of snapper with combinations of condition factors in SNA 1 in 2005–06 and 2006–07 (Holdsworth & Boyd 2008a, 2008b).

	2005–06	2006–07
Lip-hooked, no barotrauma, swam away	0.69	0.76
Lip-hooked, barotrauma, swam away	0.16	0.11
Lip-hooked, bleeding, swam away	0.04	0.05
Hooked externally, barotrauma, swam away	0.04	0.03
Gut-hooked, or damaged or floating	0.07	0.04

This information was combined with the mortality rate estimates from the 1995 release mortality study (McKenzie & Holdsworth 1997), and estimates of the SNA 1 recreational harvest derived from an aerial access survey in 2004–05 (Hartill et al. 2006), to estimate the number and weight of fish that may have died following release in 2004–05. It was estimated that between 273 000 and 560 000 released snapper may have died at that time, depending on the assumed mortality rate associated with each combination of the release mortality factors given in Table 5. The estimated weight of snapper that would have died as a result of release mortality in 2004–05, based on the incidence of release mortality factors in 2005–06 and 2006–07 was 87–182 t, relative to an estimated landed harvest weight of 2419 t. This equates to an additional 3.6% to 7.5% mortality by weight (Holdsworth & Boyd 2008a, 2008b). The mortality rate estimates used for these calculations intentionally covered a broad range of possible outcomes because they were based on a number of untested assumptions.

Most of the recreational catch taken from New Zealand's largest recreational fishery (SNA 1) is caught in depths less than 30 m (Figure 5a). Although the percentage of the recreational catch that is released is broadly similar across all depths (Figure 5b), two Australian studies reviewed in a later section suggest that the mortality rate of snapper caught in 30+ m can be much higher than in shallower water (Stewart 2008, St John et al. 2009). It is possible, however, that the higher mortality rates observed during these studies may have also been partially due to experimental artefacts, such as excessive holding times on decks and cage effects.

Total snapper release mortality rates will have changed considerably since the mid-1990s, given the subsequent increase in the recreational harvest from SNA 1, the use of new fishing methods, and the 1 April 2014 increase in the minimum legal size from 27 cm to 30 cm and decrease in the daily bag limit, from nine to seven snapper per day.

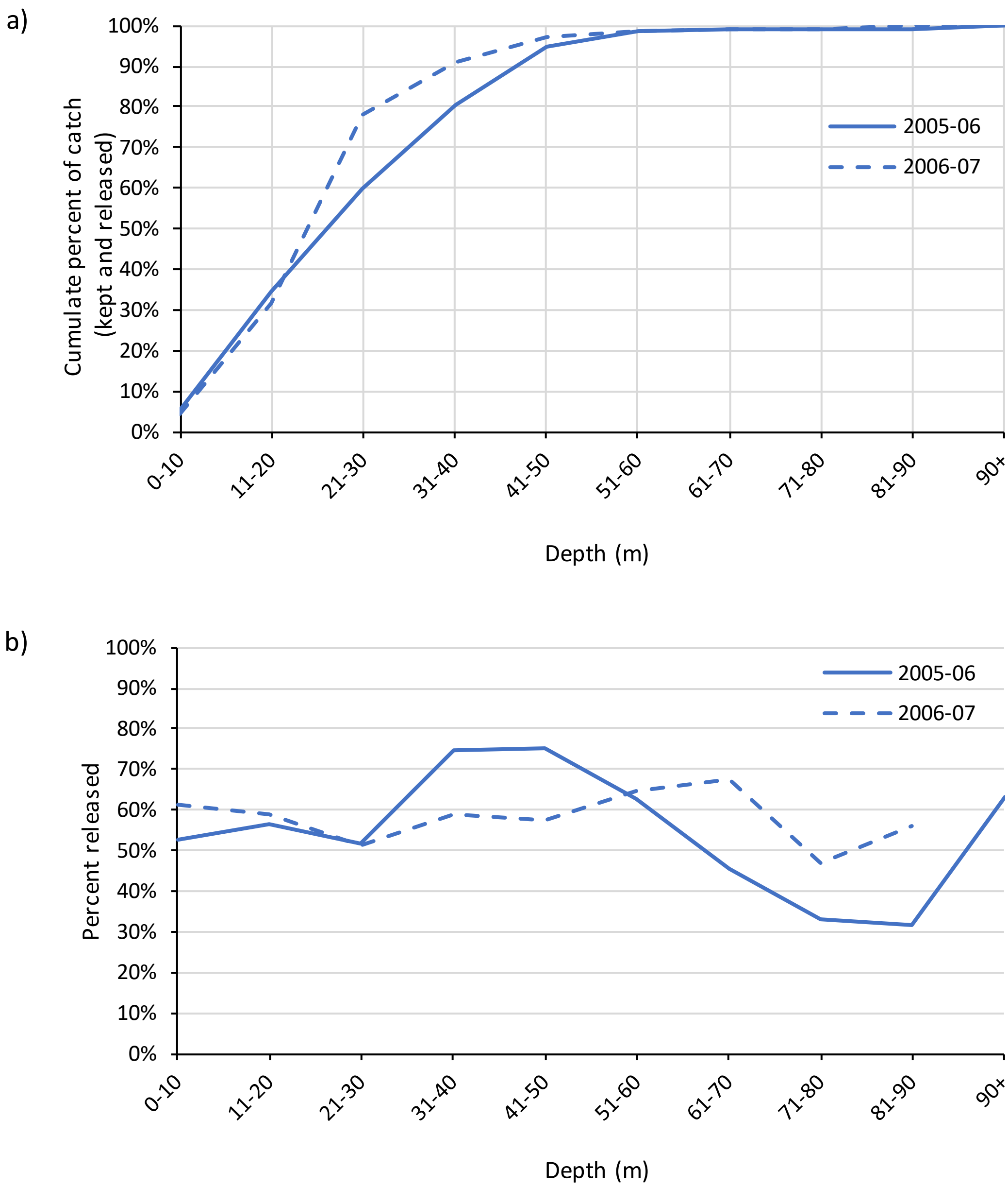

Figure 5: Cumulative depth distribution of the combined released and kept catch reported by fishers participating in the 2005–06 and 2006–07 (based on data from Holdsworth &Boyd 2008a, 2008b) snapper catch and release surveys (upper panel) and the percent of that catch that was released by 10 m depth bin (lower panel).

Mortality, stress, and reflex impairment in sub-legal snapper subjected to simulated angling

The only other New Zealand recreational snapper mortality study that the authors are aware of is a laboratory study by McArley & Herbert (2014). Visually assessed reflex impairment and blood chemistry criteria were used to assess the potential long-term impact of simulated angling (manual chasing) and air exposure durations on snapper survival following release. The authors concluded that

> *"The findings of this study add to the growing body of evidence suggesting that P. auratus, like other sparids, are resilient to angling stress when caught in shallow water and hooked in the mouth or jaw. Although physiologically demanding, strenuous exercise and air exposure associated with typical angling of sub-legal (< 27 cm) P. auratus are not likely to be a direct cause of mortality."*

Although this study has shown that exhaustion and any angling associated reflex impairment is unlikely to directly result in the mortality of a released snapper, some fish may be more vulnerable to predators soon after they have been released, which will also contribute to levels of recreational release mortality. The method used to simulate angling stress in a laboratory situation was not based on hooked fish fighting against fishing gear, but one advantage with this approach is that it essentially controls for other confounding effects, such as damage caused by fishing gear and barotrauma associated with the retrieval of a fish from depth.

3.3 Review of Australian recreational snapper release studies

Recreational fishers account for at least half of the snapper harvest taken in most of the Australian states (https://www.fish.gov.au/report/230-Snapper-2018), and snapper is one of the top 10 recreationally caught species, in terms of weight (Henry & Lyle 2003). A variety of federal and state funded studies have taken several different approaches to investigate potential causes for snapper release mortality, providing a far wider, yet context specific, understanding of this issue. In many cases the levels of release mortality observed can be attributed to more than one factor, but the most likely causes for release mortality become more evident when rates from studies that are based on different experimental designs are compared. The following sections review information on the most evident causes of release mortality that have been assessed by these Australian studies.

Injuries caused by recreational fishing gear

Several Australian studies have shown that the mortality rate of deep/gill-hooked snapper is far higher than for lip-hooked fish, as seen in the only New Zealand study that has attempted to investigate this issue to date (McKenzie & Holdsworth 1997). Grixti et al. (2010) found that 52% of the gut-hooked snapper held in holding catches for three days had died, but only 3% of lip-hooked fish died over the same period. Release mortality rates observed by St John et al. (2009) were generally higher, with 92% of gut-hooked snapper and 34% of lip-hooked fish dying over four days, but the mortality rate of the deeper hooked fish was still three times that of lip-hooked fish in this study.

Results from other studies also suggest higher mortality rates for deep/gill-hooked fish than lip-hooked fish, but gut-hooked fish only accounted for a small percentage of fish caught during these studies, which limits the degree of statistical inference that can be drawn on the impact of hook location given other confounding factors such as handing time and retrieval depth. For example, 9 of the 14 gut-hooked fish held for up to four days by Broadhurst et al. (2012) died, but only 2 of the 142 lip-hooked fish died over the same period. Gut-hooking rates are usually much lower when lures are used (Bartholomew & Bohnsack 2005) because lures are less likely to be ingested than baited hooks.

When snapper are gut-hooked there is very little difference in the likelihood of these fish dying if the hook is removed or if the trace is cut, both in terms of initial mortality and over the following 72 days (Grixti et al. 2010). Much of the damage associated with deep/gill-hooking probably occurs as the fish is being played back to the boat, because larger fish are more likely to ingest a hook and resist capture for a longer period, leading to greater damage to soft oesophageal tissue and to the gills, which are highly vascularised and can bleed profusely if damaged. Critical organs lying just under the floor of the easily pierced oesophagus are also vulnerable and easily damaged. Post-mortems of deep/gill hooked fish by Grixti et al. (2010) found that 65% of the visible damage was to organs in the pericardial or peritoneal cavity, such as to the heart or liver. Although damage to the liver is probably not at least initially fatal (because this organ functions at a cellular level and can regenerate), piercing of a fish's heart is usually fatal (Diggles & Ernest 1997). A punctured heart will haemorrhage into the pericardial cavity, putting increasing pressure on the heart, resulting in cardiac arrest.

Most of the fish that died during the Australian studies did so within the first three days, which suggests that most hook related mortality that did occur during these studies was due to physical damage rather than infected wounds. When a hook is not removed from a gut-hooked snapper and the fish survives for a few days, it will probably eject or pass the hook soon after. McGrath et al. (2011) held 108 hook-ingested snapper in aquarium tanks for 6 weeks, with 77% of the 81 surviving fish ejecting their hooks over an average period of nine days. This hook egestion rate was much higher than for the other two species assessed in this study (mulloway, *Argyrosomus japonicus* and yellowfin bream, *Acanthopagrus australis*).

External damage caused by foul hooking can also lead to mortality, but the incidence of this type of damage in the Australian studies was very low.

Any field-based assessment of recreational snapper size and condition on release in New Zealand should therefore consider the proportion of fish released by fishing method, and the location and nature of any injury inflicted to released fish.

Barotrauma

The retrieval of a fish from depth can lead to two forms of barotrauma. Fish that use an enclosed swim bladder to maintain their buoyancy, such as snapper, will be injured if their swim bladder hyperextends and bursts as the fish is pulled to the surface. The rapid release of this gas into the peritoneal cavity can result in physical injuries, such as: abdominal distension; the crushing or torsion of organs; stomach eversion into the buccal cavity which may mask the gills; intestinal prolapse; and haemorrhaging or a rupture of the body wall. Fish can also experience loss of buoyancy control at the surface. But any fish can also experience physiological stress during retrieval from depth, when the gases dissolved in their bodily fluids come out of solution and expand as ambient pressure decreases. This can cause embolisms (bubbles and blood clots obstructing arteries) and exophthalmia (bulging distended eyes) and, in extreme cases, raised scales (Hughes & Stewart 2013).

Four Australian field studies have investigated depth-related release mortality. Stewart (2008) used commercial fish traps to catch snapper across a range of depths; the fish were then transferred to a 75-litre tub while the trap was emptied and cleaned, then returned by trap to their capture depth. The traps were retrieved after 1–3 days to see how many fish had died. Although no mortalities were observed in fish caught in less than 21 m depth, and only 2% of fish caught in less than 30 m depth subsequently died, mortality rates increased significantly beyond this depth, with 39% dying at 30–44 m and 55% dying at 45–59 m (Figure 6). Smaller fish were more likely to die. Up to 20 fish were returned to each cage, but there was no apparent relationship between fish density and survival.

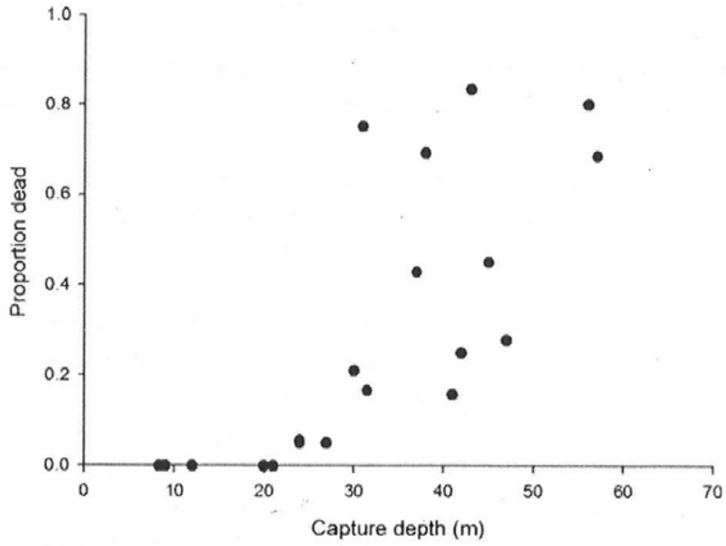

Figure 6: Mortality rates for snapper held in cages at different capture depths (from Stewart 2008).

St John et al. (2009) also used holding cages to assess the survival of released recreational and commercially caught snapper. The authors concluded that depth of capture was by far the most important factor affecting release mortality, which increased from 3.42% in shallow depths (5, 10, and 15 m) to 69% for snapper caught in deeper waters (45 and 65 m). Fish length and the number of fish in each cage were also statistically significant determinants of mortality (Figure 7). Other factors such as whether or not a fish had been vented, the number of days caged, the hook type used, and hook location were not statistically significant. The non-significance of some of these factors, however, may have been due to limited sample sizes given cage effects. For example, the mortality of gut-hooked fish (91.7%) was three times that of lip-hooked fish (33.6%), but less than 2% of the 604 assessed snapper were gut-hooked.

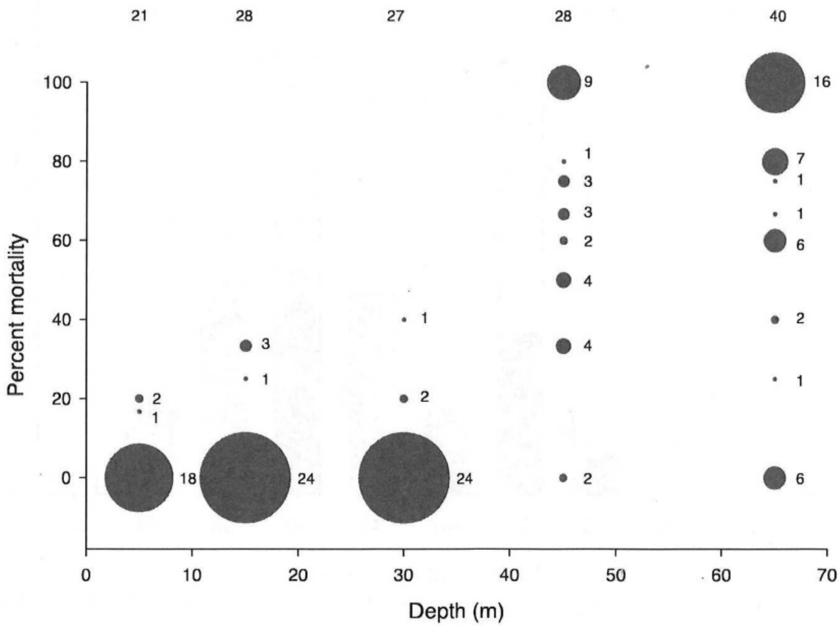

Figure 7: Mortality rates of snapper held in cages at five capture depths (from St John et al. 2009). The recapture depths were 5 m (n = 102 fish), 15 m (n = 102 fish), 30 m (n = 117 fish), 45 m (n = 89 fish), and 65 m (n = 182 fish). Numbers beside bubbles indicate the number of cages.

In the third Australian field study, rod- and line-caught snapper were held in larger 15 m-deep vertical enclosures and monitored over 3 days (McLennan et al. 2014). External signs of barotrauma were evident in 77% of the 267 snapper caught for this experiment. Although the primary purpose of this study was to assess the effectiveness of alternative venting techniques (discussed below), snapper were caught in depths ranging from 37 m to 180 m, but depth and fish size were not statistically significant determinants of survival (Figure 8). The average survival rate across all capture depths was 88%.

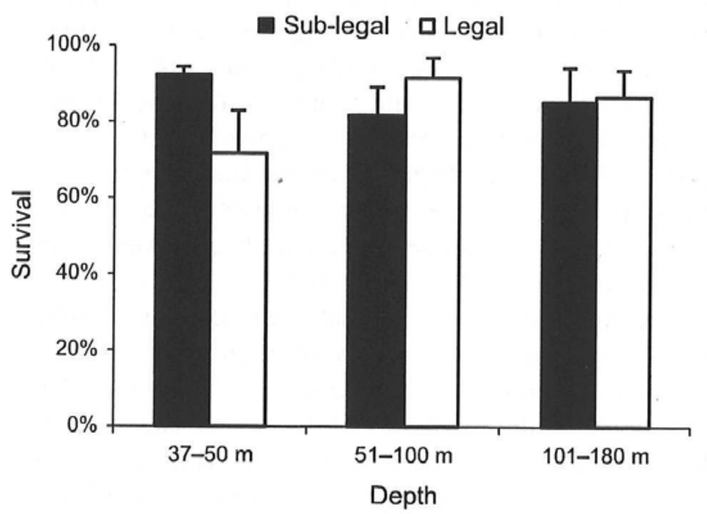

Figure 8: Survival rates of snapper by depth class (from McLennan et al. 2014)

In contrast to the two field studies where snapper were held in relatively small cages or traps, results from a laboratory pressure chamber study suggested that snapper have a potentially high resilience to barotrauma (Hughes & Stewart 2013, Hughes et al. 2019). Laboratory hyperbaric chambers were used to assess the impact of rapid depressurisation on the behaviour and mortality of snapper in a controlled environment, followed by a 220-day monitoring period once the fish had been gradually depressurised to 1 atmosphere. All the 25–31 cm snapper used for these experiments were collected in under 10 m of water, at least 15 months before they were subjected to pressurisation/depressurisation trials. The snapper used for these experiments were first gradually pressurised to their trial start "depth" over 48 hours. This initial pressurisation rate was based on swim bladder secretion rates calculated by Stewart & Hughes (2014), who found that it took 47 hours for a snapper swim bladder to equalise to ambient pressure at 8 atmospheres (70 m) with 27 hours required to gradually depressurise a snapper from 8 to 2 atmospheres (10 m) without causing further barotrauma.

Three trials were conducted to determine survival rates of snapper rapidly raised from a simulated depth, and for two of these trials, the fish were re-pressurised back down to their original simulated capture depth after a brief surface interval (Table 6). Two snapper were subjected to these conditions in the chamber at a time, as experimental replicates. Post-mortems of the fish that died in the third trial found evidence of gas embolisms and haemorrhaging.

Table 6: Survival rates for three simulated catch and release scenarios assessed by Hughes & Stewart (2013).

	Trial 1	Trial 2	Trial 3
Start depth	70 m (8 bar)	30 m (4 bar)	30 m (4 bar)
Re-pressurised	After 2 minutes	After 10 minutes	No
Number of snapper	12	32	32
Number dying	0	0	5 (16%)

The different inferences that can be drawn from the field studies and the laboratory pressure chamber study, about the impact of retrieval depth on the release mortality of snapper, reflect different limitations with each of the approaches used.

With the two cage/trap field studies, the fish were forcibly returned to depth, which the laboratory pressure chamber study would suggest should have resulted in full survival, but this did not happen. One possible explanation for this is the density at which the fish were held in the cages, which was a statistically significant factor for the St John et al. (2009) study (where the density of fish held at deeper depths was on average far higher) but not for the Stewart (2008) study. It is also possible that the snapper constrained in deeper cages by Stewart (2008) may have experienced stronger tidal currents, because this experiment was conducted in and close to Sydney Harbour. It is not clear, therefore, why depth was a significant factor for the two cage/trap studies, but capture depth was not a factor for the large vertical holding net and laboratory studies. Caged fish will be subjected to other forms of stress, but these are not necessarily depth-related. This may explain why survivorship was far higher with the holding net study, which used larger 15 m-tall vertical enclosures to hold line-caught snapper. The highest survival rates were from the laboratory pressure chamber study, which used fish that had not been subjected to any fishing related stress and were already acclimated to the pressure chambers that had been used to increase the ambient pressure over the previous 48 hours. Fish that are caught on a rod and line will undergo capture stress when they are retrieved, whereas fish caught in traps for the Stewart (2008) study may have been stressed by their confinement during capture.

Nonetheless, these studies collectively suggest that appreciable levels of release mortality can occur when snapper are taken from depths greater than 30 m and they are unable to return to those depths. Short-term release mortality rates for snapper caught in less than 30 m may be negligible if the fish are undamaged and can return to their capture depth unaided.

Regardless of any cage or laboratory experiment artefact, the conditions experienced by the snapper in three of the four Australian studies did not fully reflect those of fish caught and released by recreational anglers. Fish which are caught and released can attempt to return to their capture depth, but the fish that were caught for the 15 m-deep holding net were not able to swim down to depths with higher ambient pressures. The fish caught for the two trap/cage studies were caged at unnatural densities which was probably less of an issue for the large vertical holding net study. Further, the size range of the fish used for at least three of these studies were under or close to minimum legal size limits for snapper stocks in New Zealand, but larger fish are often more buoyant and may struggle to get back down to their capture depth, especially if they are exhausted when brought to the surface .

Any field-based assessment of recreational snapper release mortality in New Zealand should therefore consider both the size range of fish commonly released and the depth range from which they were caught.

Swim bladder venting is often mooted as a method that can be used to release gas from a burst swim bladder so a fish can return to depth unaided and has been used in large scale snapper biomass estimation tagging programmes in New Zealand. Post-mortems of snapper subjected to depressurisation trials by Hughes & Stewart (2013) found that a snapper swim bladder will almost certainly rupture if a fish is retrieved from depths greater than 14 m, with the inner layer of the swim bladder usually healing itself within 48 hours. Most snapper with hyper-extended swim bladders are retrieved from depths greater than 14 m, and any venting of snapper may result in needless damage to vital organs in the peritoneal cavity, into which swim bladder gases have escaped. Venting by fishers may improve the survival of released fish that are excessively buoyant, but there are other methods that are less likely to further injure these fish, such as the use of release weights (weights that are attached to a fish to aid its return to depth, which can be detached from the fish by jigging the line it is attached to). St John et al. (2009) vented every second snapper caught and found no significant difference between the survival rates of vented and unvented fish, which supports the conclusion of a review by Wilde (2009), that the practice of venting should be discouraged. Although venting of gases trapped in the peritoneal cavity can lead to unintended damage and infection, the venting of gases from the stomachs of larger snapper that have everted through the mouth is probably still beneficial, because these fish will be too buoyant and exhausted to escape to the surface without the aid of a release weight. McLennan et al. (2014) compared the efficacy of needle vs. buccal (using the fish's own teeth) venting of everted snapper stomachs and found them to be equally effective, with 64% of buccal vented stomachs healing within three days. Some fish may be excessively buoyant, however, even if gas escaping from a burst swim bladder has not resulted in an everted stomach.

Barotrauma related damage to vital organs can also have a sublethal effect on recreationally caught snapper. Peregrin et al. (2015) macroscopically examined 90 female and 90 male snapper (representing five reproductive stages) that were caught by rod and line from 8 m to 70 m. Irrespective of sex, all fish exhibited various clinical signs of barotrauma including: a prolapsed cloaca (60% of fish); gastric herniation (46%); a ruptured swim bladder (73%); organ displacement (48%); and kidney (3%), liver (73%), and coelomic-cavity haemorrhaging (33%). The incidence of all these signs of barotrauma was positively correlated with depth. The authors surmised that liver haemorrhaging was least likely to impact on the welfare of released snapper, but infection of the liver and other tissues could result in septicaemia, with associated mortality. Reproductive stage was also an important barotrauma predictor, with immature and spent fish being less likely to exhibit signs of tissue damage. The reduced incidence of barotrauma damage to vital organs in these fish was attributed to there being more room in the body cavity to accommodate a distended swim bladder, which could put pressure on vital organs when hyper-extended. The implications of macroscopic clinical signs of damage to reproductive organs was limited to haemorrhaged gonads in developing, developed, and ripe or spawning fish, which was mostly observed on the posterior-ventral surfaces of the gonad. The authors concluded that gonad haemorrhaging, and premature egg and milt extrusion, could cumulatively have both short- and long-term impacts on reproductive success.

Excessive handling time and handling related injury

Rough handling and prolonged exposure to the air can cause life-threatening injuries and further tire a snapper to the point where it is unable to swim back to depth, or to avoid predators or scavengers. Although handling practice was one of the main issues that the 1995 New Zealand snapper release mortality set out to investigate (McKenzie & Holdsworth 1997), only two Australian studies have assessed the potential impact of handling related mortality, alongside other factors such as hook location and depth fished (which were found to be better predictors of release mortality).

Broadhurst et al. (2005) monitored the survival of three species caught by tournament anglers given a range of factors including air exposure time and the incidence of scale loss, but a logistic regression of the snapper survival data failed to detect any significant factor that determined whether or not a released snapper survived (including hook location). Broadhurst et al. (2012) found that hook site was a statistically significant determinant of survival, with 9 of the 12 fish that died being gut-hooked. Landing method (knotless net/knotted net/no net), restraint method (wet hand/dry hand/towel/no restraint), and air exposure (under 15/16–30/31–60 seconds) were not significant predictors of mortality, although 9 of the 12 fatalities that occurred during this study were caught by 2 of the 15 anglers, which suggests that angler fishing and handling practice may be highly variable. This result is consistent with the results of the 1995 New Zealand study (McKenzie & Holdsworth 1997) in which the mortality rate of fish caught by a group of fishers, who were trained to handle their fish with care, was not significantly different to that of fish caught by untrained fishers, given hook location.

The handling times of fish caught during the Broadhurst et al. (2005, 2012) studies were brief (mostly less than 60 seconds, but up to 3 minutes), and well within the exposure times that snapper were subjected to during the McArley & Herbert (2014) laboratory air exposure and simulated angling study already described, from which the authors concluded

> *"Despite the limitations of comparing our mortality estimates to real fishing scenarios the findings provide evidence that strenuous exercise and air exposure during angling are not likely to be direct causes of discard mortality in P. auratus."*

Although most snapper released by recreational fishers are likely to be released quickly, and without suffering excessive handling related damage that is not hook site-related, some fish may be handled and exposed to the air for a substantial period of time when an angler has trouble removing the hook from the fish, or when the angler has caught a large fish that is weighed and or photographed before release. The survival of most of these fish may have already been compromised by gut- and gill-hooked injuries, however, as evidenced from the high mortality of deep/gill-hooked fish when the line is cut quickly so that a fish can be released with undue handling time.

The few studies that have attempted to assess the impact of handling practice on fish survival therefore suggest that there are other factors that better explain mortality rates in released snapper (although Broadhurst et al. (2005) found that handing time was a significant issue for trevally – *Pseudocaranx dentex*). Data could still be collected on air exposure times and other fish handing metrics during catch and release experiments, but the likelihood of collecting accurate, quantifiable, and representative statistics on the incidence of these handing metrics from the wider recreational fishery would be low, given the variable and context-specific nature of fisher behaviour.

Predation, scavenging, and disease

Several of the reviewed Australian snapper release mortality studies discuss the potential increased vulnerability of released fish to predation. There was no way of assessing this issue because the fish caught for these studies were held in holding nets or cages that excluded predators. Predation rates on recreational released snapper will be highly context specific, and hence hard to quantify by experimental methods. There is plenty of anecdotal evidence of small snapper being vulnerable to seabirds, mainly shags, as they attempt to return to depth. This component of predation could be observed and recorded by fishers in a characterisation study. Fish that are unable to escape the surface or are deep/gill-hooked with internal damage will be more susceptible to scavenging (generally by gulls), but they are more likely to succumb regardless.

The vulnerability of a released snapper to predation is hard to assess, because this may occur at depth some distance from the boat. Two ways of monitoring the fate of released snapper are to use underwater cameras to observe the fish immediately after they are released, or to use acoustic tags to detect any atypical changes in movement rates and the depths inhabited by released fish. The visual range of a camera underwater is very limited, however, and tagging causes injuries that may also change a fish’s behaviour and survival. The presence of predators and their impact on released snapper will be highly context-dependent and total release predation is therefore not assessable in a generalised and meaningful fashion, but it should be acknowledged regardless.

Summary of likely causes of snapper release mortality

All the evidence presented here suggests that the two primary likely causes for snapper release mortality are hook damage and some form of barotrauma. Past studies have all shown that snapper that become injured when they ingest a hook have a high probability of dying, although the incidence of deep hooking is low relative to lip-hooking rates. The Hughes & Stewart (2013) hyperbaric chamber study showed that, although a snapper’s swim bladder is likely to burst if a fish is retrieved from 10 m or more, there is a high probability of the fish surviving if it can quickly return to depth to recompress the gases released into its peritoneal cavity. But the incidence of release mortality appears to be much higher if a snapper is retrieved from depths greater than 30 m, which is probably the result of some form of decompression sickness. Excessive and rough handling may harm a snapper, but it does not appear to be a primary cause of recreational release mortality, nor predation/scavenging or death, which may still occur, but is not readily apparent.

4. REVIEW OF BLUE COD CATCH DATA AND RELEASE MORTALITY STUDIES

The second species that fisheries managers prioritised for an assessment of recreational release mortality was blue cod (*Parapercis colias*). Blue cod is a prized catch for many recreational fishers and is commonly caught off the lower North Island and around the South Island. The most recent recreational harvest estimate for blue cod is 293 t (Wynne-Jones et al. 2019). This equates to less than 15% of the national blue cod catch in 2017–18 (Table 1), but in four of the eight blue cod QMAs (BCO 1, BCO 2, BCO 3, & BCO 7) the recreational harvest is similar or greater than that landed by the commercial sector. Recreational blue cod release rates are also high, with 55% of the catch reported during creel surveys and 38% of the reported charter boat catch being released in 2017–18 (Table 1). These high release rates reflect changes to the minimum legal size and reductions in daily bag limits for most stocks since 1986, and the 2015 introduction of a seasonal closure on recreational landings of blue cod from the inner Marlborough Sounds (which runs from 1 September to 19 December and replaced slot limit and year-round harvesting bans from the Sounds in previous years) (Table 7).

Table 7: Changes to minimum legal size (MLS in cm), blue cod specific daily bag limit (DL), and combined species daily bag limit (CDL) by Fishstock from 1986 to present. Slot = slot limit (legal size range) and inner sounds closed from 1 September to 19 December. * DS = Doubtful Sound, TS = Thompson Sound, BS = Bradshaw Sound. ** C = inner sounds closed. # excluding Challenger East. ^bag limit of 6 inside Te Whaka ā Te Wera Mātaitai Reserve. Table from Fisheries New Zealand (2019).

Fishstock	BCO 1		BCO 2		BCO 3		BCO3		BCO3		BCO 4	
Area	Auckland		Central (East)		South East (Otago)		North Canterbury		Kaikoura Marine Area		South East (Chatham Is.)	
	MLS	CDL	MLS	CDL	MLS	CDL	MLS	DL	MLS	DL	MLS	CDL
1986	30	30	30	30	30	30	30	30	N/A	N/A	30	30
1993	33	20	33	20	30	30	30	30	N/A	N/A	30	30
1994	33	20	33	20	30	30	30	30	N/A	N/A	30	30
2001	33	20	33	20	30	30	30	10	N/A	N/A	30	30
2008	30	20	33	20	30	30	30	10	N/A	N/A	30	30
2014	30	20	33	20	30	30	30	10	33	6	30	30
2017	30	20	33	20	30	30	30	10	33	6	30	30

Fishstock	BCO5		BCO5		BCO 5		BCO5		BCO 7		BCO7	
Area	Southland & Fiordland (External)		Paterson Inlet ^		Fiordland internal (excl. DS, TS, BS*)		DS, TS, BS*		Challenger West & South		Challenger East (incl. Marlborough Sounds)	
	MLS	CDL	MLS	DL	MLS	DL	MLS	DL	MLS	DL	MLS	DL
1986	30	30	30	30	33	20	33	20	30	30	30	12
1993	33	30	33	30	33	20	33	20	33	20	33	10
1994	33	30	33	15	33	20	33	20	33	20	28	6
2001	33	30	33	15	33	20	33	20	33	20	28	6
2003	33	30	33	15	33	20	33	20	33	20	30	3
2005	33	30	33	15	33	20	C*	C*	33	20	30	3
2008	33	30	33	15	33	20	C*	C*	33	20	C**	C**
2011	33	30	33	15	33	20	C*	C*	33	20	#SLOT 30–35	2
2014	33	20	33	15	33	20	C*	C*	33	20	#SLOT 30–35	2
2015	33	20	33	15	33	3	33	1	33	20	33	2
2017	33	20	33	15	33	3	33	1	33	20	33	2

Fishstock	BCO8		BCO10	
Area	Central (West)		Kermadec	
	MLS	DL	MLS	CDL
1986	30	30	30	30
1993	33	20	33	20
2014	33	10	33	20
2017	33	10	33	20

Creel surveys in southern New Zealand have been conducted sporadically, with most undertaken over the past decade. The catch and release time series that are available for the main blue cod stocks are therefore patchy, describing a period over which there has been little change in recreational bag and size limits (Figure 9). The only changes to recreational catch regulations over the past decade have been for the inner Marlborough Sounds (eastern BCO 7), where a moratorium on blue cod harvesting was gazetted from 1 October 2008 to 1 April 2011, followed by a 30–35 cm slot limit introduced in 2011 (that has since been replaced by the current 33 cm MLS). A seasonal closure on blue cod harvesting from the inner Marlborough Sounds was established when the year-round harvesting moratorium was lifted. These regulatory changes should have had a significant effect on blue cod release rates in this area, but the available creel survey data suggest that there has been relatively little change in release rates across the BCO 7 stock over this period.

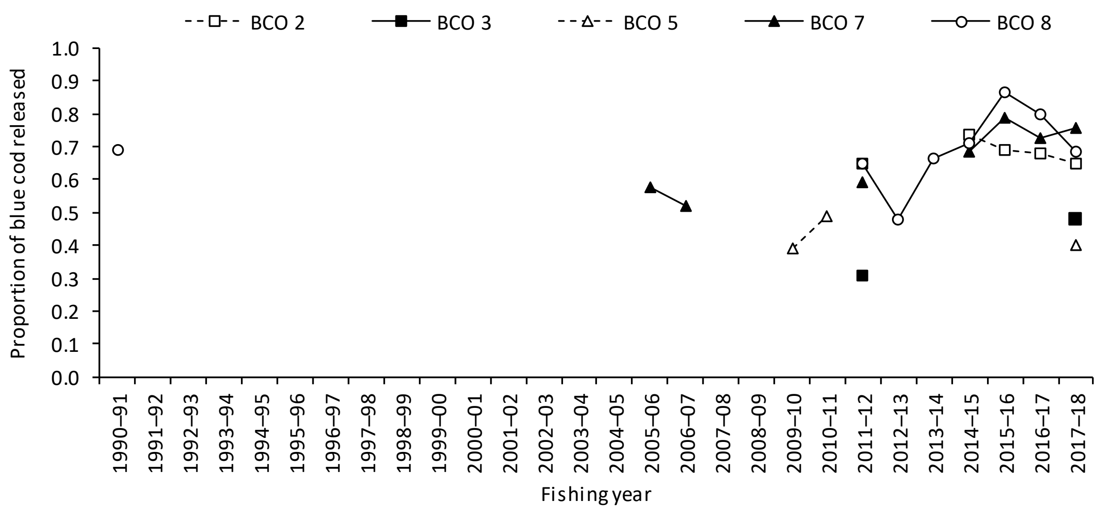

Figure 9: Proportion of the reported recreational blue cod catch that was released by fishers interviewed during creel surveys conducted since 1990–91, by fishing year and area (unpublished data, Fisheries New Zealand rec-data database). Release rates are only shown when at least 100 fish were caught in an area in any given fishing year.

Blue cod are endemic to New Zealand and only three recreational blue cod release-mortality studies have been published. Two of these studies were field based: a three-hour post capture holding tank trial (Davidson 2001); and a two-week holding cage study that assessed mortality rates of cod caught by rod and line fishers using two different hook types (Carbines 1999). The results of the Carbines (1999) study were then used to inform a yield per recruit analysis by Henderson (2009), which highlighted the need to assess sex specific release mortality rates for this protogynous hermaphrodite species, which transitions from being a female to a male as it grows.

Davidson (2001) fished with baited 2/0 hooks to monitor changes in the size, distribution, and behaviour of blue cod caught in and outside the Long Island Kokomohua Marine Reserve, in the Marlborough Sounds over a 7-year period between September 1993 and April 2000. All the fish caught during these surveys were held on board in a recirculated saltwater holding tank for up to three hours, to avoid short-term recaptures. Although the purpose of this study was not to investigate recreational release mortality, Davidson found that a small percentage of the fish died (under 3%), most of which had bled profusely from hook-damaged gills.

Carbines (1999) used baited barbed 1/0 straight shanked and 6/0 kahle hooks to catch sub-legal (under 33 cm) blue cod, which were then held in cod pots at 20 m for two weeks so their survival could be regularly monitored. A control group of fish were also caught in commercial cod pots and held at the same depth for the same period. The sample size for each treatment was 40 fish. The purpose of this study was to assess the possible consequences of a change to the MLS in the Marlborough Sounds. All the control fish and those caught with 6/0 hooks survived, but 25% of the 40 cod caught on 1/0 hooks died (3 of the 5 gut-hooked and 7 of the 8 gill-hooked fish succumbed within 26 hours). None of the fish caught on the larger kahle hooks were gut- or gill-hooked and all survived. Two fish handling treatments were also assessed (with cotton gloves out of direct sunlight vs. with bare hands in direct sunlight), but there was no statistical difference between the mortality rates for these two handling treatments.

Larval blue cod have a functional swim bladder that provides buoyancy during their larval phase (Tom Trnski, Auckland Museum Head of Natural Sciences, pers. comm.), but it is not used to regulate buoyancy during later benthic life stages. Anecdotal experience suggests that blue cod have no difficulty with surface escapement when released and should not therefore experience any prolonged barotrauma associated with a ruptured swim bladder (which may not be functional during later life stages). They are, however, susceptible to predation by shags that have learnt to wait by boats that are fishing.

5. REVIEW OF KINGFISH CATCH DATA AND RELEASE MORTALITY STUDIES

The most recent recreational harvest estimate for yellowtail kingfish (*Seriola lalandi*) is 738 t (Wynne-Jones et al. 2019). This equates to 74% of the estimated harvest of kingfish taken by all sectors in 2017–18. Release rates are high; recreational fishers interviewed at boat ramps during 2017–18 reported that 63% of their kingfish catch was released and charter boat skippers reported 79% release rates (Table 1). Over 94% of the kingfish catch reported by boat-based fishers interviewed during creel surveys in 2017–18 was caught by some form of rod and line fishing with bait or jigs (Table 3). The catch taken by trolling during 2017–18 may have been higher than these data suggest, however, because launch based catches are under-represented in boat ramp data, yet these vessels often tow lures while cruising.

Kingfish catch and release rates have increased substantially since the early 1990s (Figure 10). Although the introduction of a 65 cm MLS in October 1993 appears to have little effect on kingfish release rates, there was a marked increase in release rates following an increase of the MLS to 75 cm in January 2004.

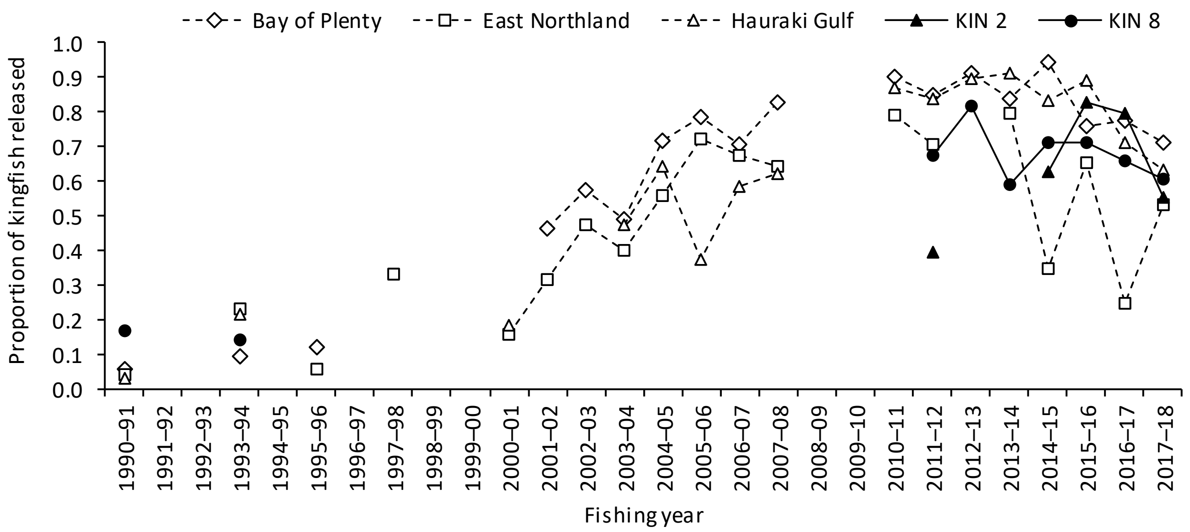

Figure 10: Proportion of the reported recreational kingfish catch that was released by fishers interviewed during creel surveys conducted since 1990–91, by fishing year and area (unpublished data, Fisheries New Zealand rec-data database). The three named regions are within KIN 1. Release rates are only shown when at least 100 fish were caught in an area in any given fishing year.

Volunteer recreational fishers and charter boat operators measured all the kingfish they caught as part of a 2014–15 study to determine the length, sex, and age composition of the recreational catch taken from KIN 1 and some offshore areas. A total of 1183 length measurements were reported for the Northland/Hauraki Gulf region and 1039 from the Bay of Plenty/East Cape region (Holdsworth et al. 2016). Overall, 68% of measured kingfish were released. The method of capture was recorded, and the proportion of legal size fish caught on dead baits or live baits and released was 63%, with the remainder of the released catch being caught on jigs or lures. Deep/gill-hooking occurs mainly for fish caught on baits.

The length distribution of all kingfish measured during the 2014–15 age-and-growth study shows that about half of the fish in the 95–140-cm size range were released (Figure 11). Several of the charter boats in this study had a one kingfish per angler rule.

Yellowtail kingfish (*Seriola* spp.) are also commonly caught by recreational fishers in temperate waters in other parts of the world. However, the authors are aware of only one published study on recreational kingfish release mortality; from Australia, where the recreational catch is also a significant proportion of overall catch (https://www.fish.gov.au/report/218-Yellowtail-Kingfish-2018). This Australian study (Roberts et al. 2011) used two approaches to assess post-release survivorship of kingfish caught by rod and line anglers: a holding cage trial and a biotelemetry study.

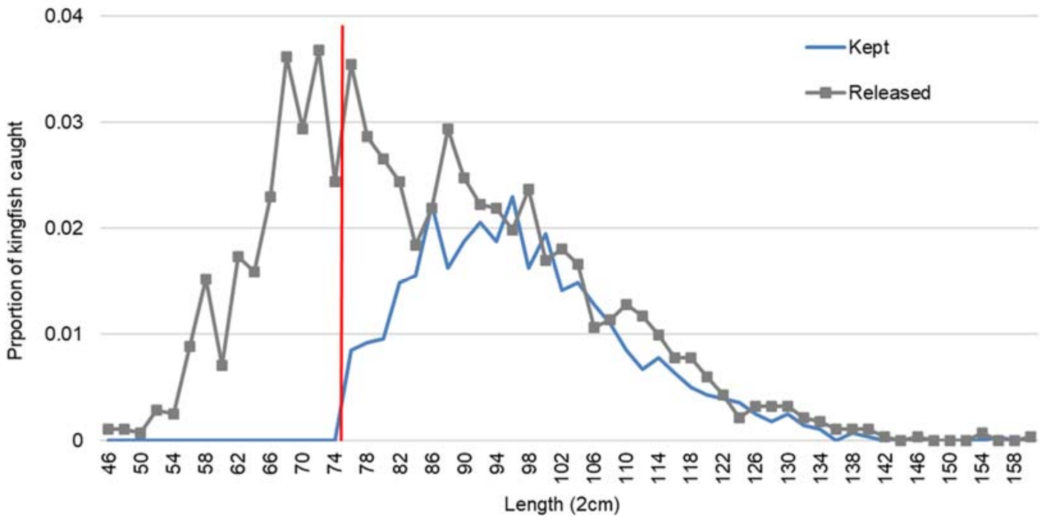

Figure 11: Proportion of kingfish kept or released by 2-cm length bin for all fish measured in the 2014–15 catch-at-age study (Holdsworth et al. 2016). The recreational minimum legal size limit for kingfish is 75 cm (red).

With the holding cage trial, 54 kingfish (60–75 cm) were caught by volunteer anglers who mostly used baited, barbed J-hooks, but a small number of fish were also caught on treble hooks, barbless hooks, or lures. The volunteer anglers were asked to record: the line strength used; hook type; bait type; time of capture; approximate retrieval and air exposure times; type of landing net; how the hook was removed (bare hands, pliers, cloth); if the fish was dropped on the deck; if it bled from the hook wound; and the hooking site. The fish were briefly held on board the volunteer boats in a 110-litre PVC bin, before they were tagged with a T-bar tag and then transferred by a chase boat to 2.3-m diameter by 2.5-m deep holding cages. Most of the 54 fish caught were lip-hooked (74.1%), but eleven were hooked in the gill arches (20.4%) and three were hooked deeper in the gut (5.3%). For all hooking locations, 33.3% of fish showed signs of bleeding, and hook-related tissue damage was evident in 48.1% of the fish. Acclimatised control fish caught in good condition were also held onshore a month beforehand, and subsequently released into the cages alongside the fish caught by the volunteer anglers.

All caged fish were fed sardines and monitored for mortality over the following five days. Eight of the fish caught by volunteer anglers died during the monitoring period (14.8%), and seven of these were gill-hooked (63.6% of all gill-hooked fish). Six of the seven gill-hooked fish that died were bleeding when first caught. All the gill-hooked fish that died did so within 60 minutes of capture. Other fish that died all did so within 4 hours. A GLMM was used to identify which factors best explained the incidence of mortality and the only significant factor was hook location. No other factor was statistically significant when the hook location term was dropped from the model.

Aquarium trials were also used to determine the most appropriate method of attaching biotelemetry (acoustic) tags to kingfish, to monitor their post-release survival. None of these fish died, and a double dart tag attachment method was chosen as the most reliable and least detrimental attachment method for a subsequent tag and release study. Ten gill-hooked and twelve jaw-hooked kingfish were caught by rod and line and tagged with acoustic tags that transmitted ambient depth and acceleration rates, and then released into an area monitored by 28 acoustic receivers. With the gill-hooked fish, the hook was left in place and the line was cut to minimise bleeding and improve the chances of the fish surviving. The hook was removed from all jaw-hooked fish. None of the jaw-hooked fish bled, but all gill-hooked fish showed signs of bleeding. Three of the detection buoys were lost and there was therefore insufficient data available to determine the survivorship for two of the gill-hooked and two of the jaw-hooked fish. Detection rates for the remaining 18 biotelemetry-tagged fish were both variable and sporadic, so interpretations of these data were inconclusive. Nonetheless, depth and acceleration detection data suggest that survival rates for the gill-hooked fish over the next 15 days were reasonably high, with all fish displaying variable depth swimming behaviour similar to that detected from jaw-caught fish. The apparent higher survivorship of these gill-hooked fish in this second experiment could have been because the hooks were not removed from the gills, with the trace being cut off short instead.

This study did not investigate whether kingfish were susceptible to angling-induced barotrauma, but this is considered unlikely. Hughes et al. (2016) found that carangid species, including yellowtail kingfish (*Seriola lalandi*), have specialised anatomical structures that they use to vent their swim bladder rapidly when changing depth. Kingfish have a membranous opening at the roof of their swim bladder that leads to a flattened tube which bifurcates around the vertebral column and exits below the gill plate. Simulated decompression experiments conducted in a hyperbaric chamber have shown that venting through this flattened tube begins when the swim bladder has inflated to approximately double its initial volume and ceases when neutral buoyancy is achieved. A kingfish should therefore be able to return to a comfortable depth soon after it is released, without rupturing its swim bladder or suffering tissue damage caused by a prolonged embolism (bubbles forming in tissues as gases that are in solution in the blood expand as ambient pressure decreases).

6. REVIEW OF KAHAWAI CATCH DATA AND RELEASE MORTALITY STUDIES

Kahawai (*Arripis trutta*) is the second most commonly-caught fish by recreational fishers in New Zealand, with a recreational harvest estimate of 1702 t in 2017–18 (Wynne-Jones et al. 2019). Substantial catches of this species are also taken around the southern half of Australia, where the same species is one of three known as Australian salmon (https://www.fish.gov.au/report/160-AUSTRALIAN-SALMONS-2018). A lower proportion of the recreational catch of this species is released in New Zealand by recreational fishers than for the other three species considered in this report. This is thought to be: because there is no minimum legal size limit for kahawai; because it is part of a 20-fish combined species bag limit, which is rarely exceeded; and because there has been an increase in utilisation as a table fish, or it is used for bait. Despite having lower release rates than for other species, kahawai recreational release rates have increased in all stocks over time (Figure 12). There have been no changes in fishing regulations, but stock abundance has increased in the three regions in KAH 1 and fisher attitudes toward catch and release have changed. Fishers interviewed during boat ramp interview surveys in 2017–18 released 39% of their reported catch, and charter boat skippers reported 18% release rates (Table 1).

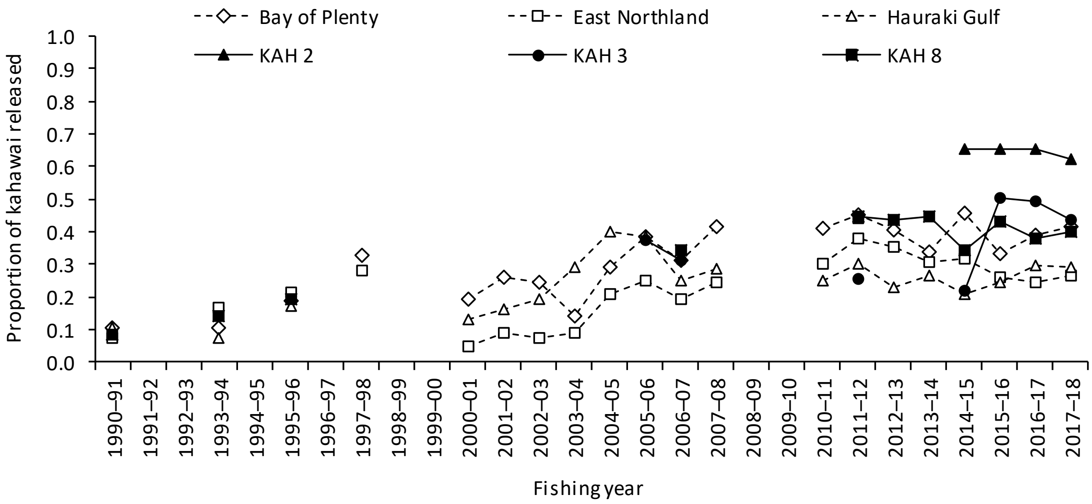

Figure 12: Proportion of the reported recreational kahawai catch that was released by fishers interviewed during creel surveys conducted since 1990–91, by fishing year and area (unpublished data, Fisheries New Zealand rec-data database). The three named regions are within KAH 1. Release rates are only shown when at least 100 fish were caught in an area in any given fishing year.

Kahawai are probably not susceptible to angling-induced barotrauma because this pelagic species has probably developed a swim bladder venting mechanism similar to that seen in kingfish (Julian Hughes, New South Wales Department of Primary Industries Fisheries Scientist, pers. comm.). Kahawai are also often targeted and caught from surface schools. This species may be more susceptible to handling damage and infection, however, because it has softer flesh than kingfish, and larger scales that are more easily dislodged (which would expose the skin to infection). Kahawai tagged with dart tags in the late 1980s and early 1990s were often recaptured with ulcerated tag wounds caused by weed-fouled tags flogging around and aggravating the surrounding flesh. There was less fouling and faster healing for other species tagged with this type of tag around that time (authors pers. obs.). Carefully handled kahawai and released kahawai may still be reasonably robust. Hughes et al. (2014) successfully kept about 100 rod and line caught kahawai in a 35-m^3 recirculated saltwater tank for over year, for gastric evacuation experiments, without losing any fish to injury or disease.

Most of the recreational kahawai catch is taken from FMA 1, where commercial catch limits for the KAH 1 management area were introduced in the early 1990s. A further catch reduction in the mid-2000s has led to a substantial rebuilding of the kahawai fish stock (Hartill & Bian 2016). The resulting increase in abundance and recreational catch will probably have resulted in increased recreational release mortality, but the impact of this source of incidental fishing mortality is probably low relative to the size of the stock. Kahawai stocks are considered to be above management target levels and the utility of quantifying recreational release mortality would probably be higher for other species, such as snapper and blue cod. However, generic advice can still be provided to recreational fishers on the correct handling of kahawai to maximise fish welfare and reduce recreational release mortality.

7. POTENTIAL EXPERIMENTAL APPROACHES AND THEIR LIMITATIONS

The design of any catch and release study should consider experimental artefacts that might affect the accuracy and applicability of any results obtained. Ideally, any experimental study would be based on an initial characterisation of the catch and condition of a species taken by commonly used recreational fishing gears, to identify key factors to be considered when assessing potential sources of release mortality. This initial characterisation should collect data on: the proportion of the catch taken by each fishing gear type; gear metrics; hook location; damage caused by each gear type (which may vary by fish size); depths fished (where barotrauma is an issue) and, where exhaustion from a prolonged retrieval period is of concern, the observed incidence of any predation/scavenging on released fish; and the size composition of fish kept or released, given these factors. The factors identified from the characterisation study and knowledge of the biology of the species of interest can then be used to identify the most appropriate experimental approach and its configuration. The characterisation is also needed to scale results of the release experiment by the incidence of the critical factors in the fishery as a whole, to estimate total release mortality.

Experimental approaches commonly used to estimate recreational catch and release mortality rates fall into three groups: tag mark recapture studies; biotelemetry studies; and containment studies. These are considered in turn.

Mark recapture release mortality estimation

With the tag mark recapture approach, capture method metrics and conditional states are recorded for fish which are tagged and released, so that release mortality rates can be inferred from tag return rates associated with each gear type and conditional state. Tag return rates from mark recapture programmes are usually in the order of 1–3%, so thousands of fish must be tagged to get an adequate measure of differential tag return rates. Absolute release mortality rates can be estimated from a single release event if a large number of control fish are also tagged and released; but obtaining enough control fish that have either been bred in captivity or have recovered from their initial capture by a less harmful method and are likely to experience natural mortality rates similar to fish left in the wild is problematic. However, aside from other issues such as the need to estimate tag shedding, tag-related mortality and reporting rates, a large-scale mark recapture recreational release study would not be cost-effective given the number of variables and uncertainties involved. This approach is not recommended in the New Zealand context.

Biotelemetry monitoring of released fish

Biotelemetry tagging offers a more feasible approach that could be used to estimate recreational release mortality rates for larger and more mobile species such as kingfish. Biotelemetry tags can be used to monitor and assess post-release behaviour and mortality rates over several weeks or months. This approach may be the best option for larger pelagic species that are too mobile for a holding cage. Larger species are also less likely to be affected by the application and drag from an external tag that could be quickly attached, without requiring any invasive implantation surgery.

Two biotelemetry tag technologies can be used to monitor the behaviour and survivorship of fish released by recreational fishers are: those which archive and transmit stored data to satellites at the end of the deployment; and acoustic tags which transmit data to moored receivers when they are in range. Each technology has its advantages and disadvantages.

The two main configurations of satellite transponder tags that could be used to determine release mortality rates are survivorship pop-off tags and archival pop-off tags (which are also referred to as pop-up tags). Both types of tags are designed to break their link to the tag anchor if the detected depth has not changed for a programmed period or after a programmed deployment period, so the tag can float to the surface and transmit positional and other archived data. Survivorship pop-off tags are less expensive than archival pop-off tags, because they are pre-programmed and the satellite data retrieval costs are prepaid. A simple Survivorship Pop-up Archival Tag (sPAT) made by Wildlife Computers weighs 60 g in air and is programmed to release after 30, 45, or 60 days after deployment or when certain conditions indicating the tag is no longer on a swimming fish are met (conditional release). After release the location is estimated using Argos satellites and some data are transmitted including detail temperature, depth, and light level profile for the last five days of the deployment. If the tag is recovered, the full archive of data can be retrieved. These cost about US $2000 (June 2020) including satellite time: https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/spat/.

The latest pop-up archival tags from Microwave Telemetry Inc are much smaller than other archival pop-off tags (46 g, 12.2 x 3.3 mm) and store and transmit detailed temperature, depth, and light level information during a deployment of up to 12 months. These data can be used to infer habitat preferences and to track broad scale movement. Light level geolocation is estimated from time at noon and day length, so the ~30+ km^2 resolution of the resulting position estimates would be of limited use for coastal species. The cost of the X-Tag is around US $4500 (June 2020) each plus the cost of satellite time: (https://www.microwavetelemetry.com/uploads/Specifications/MTI_X-Tag_SR_Specifications.pdf). A simulation study by Goodyear (2002) suggests that, under ideal conditions (no tag failure, tag loss, or tag induced mortality), at least 100 fish would need to be tagged to estimate the release mortality rate associated with a single catch/handling treatment, so the cost of a mortality tag based study may be high.

The alternative biotelemetry approach is to use surgically implanted acoustic tags, which currently cost approximately NZ$1600 (for Vemco V13 depth-sensing tags). Although these tags are cheaper than satellite tags, the additional cost of deploying and regularly downloading data from an array of acoustic receiver buoys should also be considered. A large number of acoustic receiver buoys with overlapping reception ranges is also required, because the signal transmitted by an acoustic tag is rapidly attenuated in sea water, with smaller ~10 mm tags having an effective range of 150 to 200 m, and larger 100 mm tags having a range of about 1000 m. The life of a tag is determined by the power and frequency of the signal it transmits, but the effective monitoring period may also be limited by the time that tagged fish remain within detection range. The temporal and spatial extent of a study based on this monitoring technology is therefore far more limited than if satellite tags are used, but the smaller size of the acoustic tags makes them more suitable when monitoring larger numbers of smaller species.

Both types of electronic tags can be used to regularly collect depth and location data, from which release behaviour and mortality rates can be inferred. Hightower et al. (2001) suggested that it is necessary to establish *a priori* a set of rules to help determine the viability of a fish, given movement rates and depths or areas inhabited and the temporal coverage provided by tag transmissions, which may be patchy at times.

Containment trials

Most catch and release mortality estimation studies are based on some form of containment study, where either holding nets, subsurface cages, or holding tanks are used to monitor the fate of fish caught and released by recreational fishers. This approach is far more cost effective for smaller and non-pelagic species, because the increased cost associated with each additional fish is low relative to the initial establishment costs.

The duration of any field study is usually limited to 10 days or less for logistical reasons, but much of the release mortality that has been observed during published containment studies has occurred soon after capture, before the fish has been transferred to a holding enclosure so its survival can be monitored over several days. Some of this initial, and possible subsequent mortality, would have been potentially caused by the need to temporarily hold fish on or beside a fishing vessel in a small tank, cage, or net before a transfer is possible. The length of time fish are held at the surface will have a greater effect on species that can be subject to swim bladder related barotrauma, such as snapper. The initial capture of fish usually occurs at least a few hundred metres away from the monitoring holding enclosure, so that fishing can take place from multiple boats fishing in a range of depths. The “release” of fish onto a small and shallow interim holding enclosure subjects the fish to additional stress that it would not encounter if it was released back to the wild under non-experimental conditions. Fish suffering from barotrauma will also suffer additional stress, because the shallow depth of any interim holding enclosure will prevent a “released” fish from decompressing and re-acclimating to its capture depth. Some studies have attempted to address this issue by immediately releasing fish into small cages that are immediately lowered to the assumed capture depth, but this approach introduces other effects associated with small cages, such as mesh abrasion and constriction, as well as forcing the fish down to a depth which it might not have been able or inclined to return to unaided. The survival of fish held in cages that constrict free movement may also be affected by other factors that would not usually affect a released fish, such as crowding, strong tidal currents, and turbidity. The methods used to temporarily hold "released" fish before they can be transferred to a larger holding enclosure may be as important as the approach used to subsequently hold the fish for monitoring purposes over several days.

All the containment studies reviewed for the four New Zealand species of interest suggest that any observed subsequent mortality usually occurs within three days, regardless of the duration of the monitoring period. Containment studies rarely last for more than 10 days, but longer-term release mortality could still occur if any capture related tissue damage becomes infected. Release mortality rates can also be underestimated by a containment study, because predators/scavengers are excluded, and this may be particularly relevant if fish are in a weakened or damaged state following release.

The best option for the design of a holding enclosure used to monitor the survival of released fish over multiple days is likely to be species-specific. Pelagic species such as kahawai are less likely to suffer containment related stress and mortality if they are held in large holding nets that provide enough room for unconstricted schooling behaviour. Demersal species that use swim bladders to control their buoyancy, such as snapper, may require a deeper holding enclosure to allow them to mitigate the effects of barotrauma. Smaller sub-surface cages may be more appropriate for benthic species, such as blue cod, which appear to have high survival rates when caught and held in pots.

Pollock & Pine (2007) also recommend that control fish (which preferably have not experienced any angling-related effects) should always be included as an experimental treatment, against which recreational gear-related mortality rates can be measured. The number of fish for a control sample should be similar to the number of fish that are caught and released with the most commonly observed release condition (e.g., lip-hooking for snapper). In reality, all control fish will experience some handling before they are released into a holding enclosure, but this should be minimised to the greatest extent possible. For snapper this could mean catching control fish by longline in shallow water and using only lip-hooked fish that appear to be in apparently perfect condition in holding enclosure(s) alongside fish caught by recreational fishers. Potting methods could be used to catch a control sample of blue cod, to avoid any hook-related damage. Control fish should be held alongside other experimental fish in the same enclosure(s).

Multiple holding enclosures should be used for a containment study. Pollock & Pine (2007) suggest that the experimental unit for a containment study should be at the containment enclosure level rather than the fish level, to take cage effects into account. The precision of a release mortality estimate will be overestimated if the fish is assumed to be the experimental unit. Although the deployment of multiple enclosures is logistically feasible if small cages are used, this would not be possible if large holding enclosures are needed for a particular species or location. Fish should still be released into multiple holding nets if at all possible, so that a randomised block design can be used to test for possible cage effects, to gauge whether the precision of a release mortality estimate has been overestimated if the sampling unit is assumed to be at the individual fish level.

Rogers et al. (2014) used simulations to explore trade-offs between the number of cage replicates and the number of fish held in each cage, as well as the effect of control fish survival and among-cage survival variability on the precision of mortality estimates. The results of these simulations suggest that, increasing the number of fish per cage had a greater impact on estimated precision than increasing the number of cages, but, for the scenarios examined, at least six replicate cages should be used, regardless of the expected mortality rate for a specific factor. The scripts developed by the authors are provided as supplementary data to Rogers et al. (2014) and can be used to explore survey design trade-offs for other expected mortality rates; although the range of values explored by this publication probably encompass those that would be expected for the four species considered here.

8. TRIAL OF A CITIZEN SCIENCE APP TO COLLECT CATCH AND RELEASE DATA

To date, the only data available on factors that may determine recreational catch and release mortality rates were collected during the two characterisation surveys of the recreational SNA 1 boat-based fishery (Holdsworth & Boyd 2008a, 2008b). Figures 3, 9, 10, and 11, however, show that release rates can vary considerably between species, fish stocks, and over time. Up-to-date and context-specific data are therefore required to determine the factors that should be assessed by any recreational release mortality experiment, and the extent to which the effect of these factors will manifest themselves over time. Although a scientifically structured and directed survey of a recreational fishery can be used to collect a representative and accurate characterisation of catch and release factors from a fishery, the cost of this approach is substantial, and it is unlikely to be conducted in a continuous fashion. A prototype citizen science catch and release app has therefore been developed as part of this study, to explore the feasibility of collecting catch and release factor data from several key fisheries simultaneously, in a continuous fashion (Figures 13 & 14). A copy of the instructions given to app users is given in Appendix 1.

Results from field testing of this app were not available at the time that this report was written, because of the Covid-19 level-4 lockdown, which prevented recruited volunteer app users from going fishing.

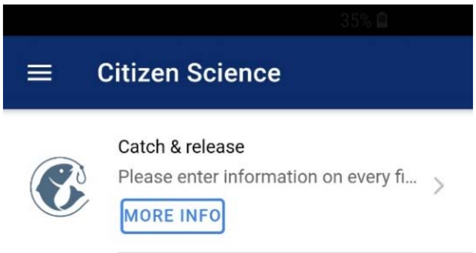

Figure 13: Selection tab for the NIWA Citizen Science catch and release app.

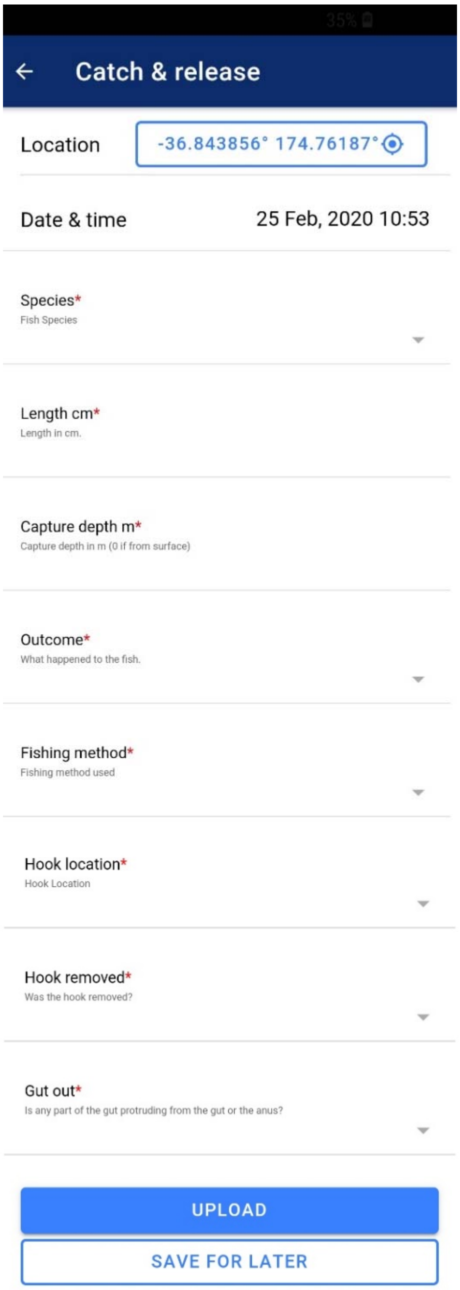

Figure 14: NIWA Citizen Science catch and release app question fields.

9. SNAPPER RELEASE MORTALITY EXPERIMENTAL DESIGN

The design of a release mortality experiment should ideally be informed by an up to date characterisation of a recreational fishery targeting the species of interest, but enough information on snapper exists from the studies reviewed above to formulate an experimental design. New estimates of snapper release mortality will provide data on the impact of current and future size and bag limits that apply to amateur fishers, to support management decisions and reduce waste.

The most cost-effective and logistically feasible design for a release mortality experiment is a replicated holding net design. Snapper released at the surface into a holding net that allows them to swim down are more likely to experience typical catch and release conditions than if they are held in a cage, because they are not forcibly recompressed when a cage is lowered to the sea floor, and lower stocking densities are possible when a sufficiently large holding net is used. However, the advantages of a large holding net should be weighed against the need to hold fish in replicate nets, because it is the net/cage which is the experimental unit, and not the fish (Pollock & Pine 2007).

Snapper released into a holding net should be free to attempt to swim down to depths where the ambient pressure is at least one atmosphere higher than on the surface. Previous studies have shown that barotrauma is one possible cause of release mortality, and any undue restriction on a snapper's ability to recompress is likely to lead to an overestimate of release mortality. A net design based on that described by Brown et al. (2010) is therefore recommended (Figure 15), because several of these lantern nets could be built at reasonable cost and deployed simultaneously.

Two changes to this net design that would be required in this context would be to change the size of mesh used and to add a mortality sock to aid the retrieval of dead snapper. The 101-mm mesh used by Brown et al. (2010) should be replaced with a 50-mm knotless mesh, to prevent escapement and the likelihood of fish becoming enmeshed in the holding net. A mortality sock is a shallow conical cone made of fine mesh that sits in the conical base of a lantern net that can be pulled up at regular intervals (avoiding any need to dive in the net). A splash camera could be lowered into each holding net at regular intervals to see if there are any dead snapper that need to be retrieved. Mortality socks are commonly used by the salmon aquaculture industry in Canada. All holding nets should be heavily weighted at the bottom, to minimise any distortion due to high current flow.

The maximum rate at which each net or enclosure can be stocked with control and release treatment fish is determined by the metabolic demands of the fish being held, and stocking densities are therefore usually expressed in terms of kg per m^3. Salmon farms commonly use stocking densities as high as 25 kg per m^3, but a lower stocking density should be adopted for a release mortality experiment because it will take time for the fish to become acclimatised to the net, and to minimise the chances of containment mortality (which can still be estimated from the mortality rate of control fish). If it is assumed that the snapper held in a 15-m tall holding net only occupied the bottom third of the net, then a 2-m diameter net containing 60 fish would have a stocking density of 3.75 kg per m^3. More fish could be held in larger diameter nets but transporting and emptying these larger nets would be difficult at sea.

The number of replicates required would be determined by the factors (e.g., depth) that would have to be controlled for and the minimum number of replicates per factor treatment (15 m, 25 m, etc.), or combinations of treatments. Simulations undertaken by Rogers et al. (2014) suggest that at least six net replicates would be required per treatment. As described in earlier sections of this report, past snapper release mortality studies in New Zealand and Australia have found that capture depth and hook location are, *a priori*, likely to be the factors that best explain recreational release mortality rates, assuming handling time is relatively short.

The increased rate in mortality rate of fish caught in waters deeper than 30 m, seen by the Stewart (2008) and St John et al. (2009) caging studies (Figures 6 and 7 respectively), suggests that at least one depth factor treatment should be for fish caught in depths over 30 m, and three capture depth treatment bins are therefore proposed (for snapper caught in around 15 m, 25 m, and 35 m). Snapper caught in these depth ranges probably account for around 70% of the recreational catch from SNA 1 (Figure 5a). If six replicate nets are each stocked with fish caught in each of these depth treatments, then a total of 18 replicate nets are recommended for the experiment. There would be some logistical problems stocking and monitoring 18 nets at once. Six nets deployed over three experimental periods are recommended.

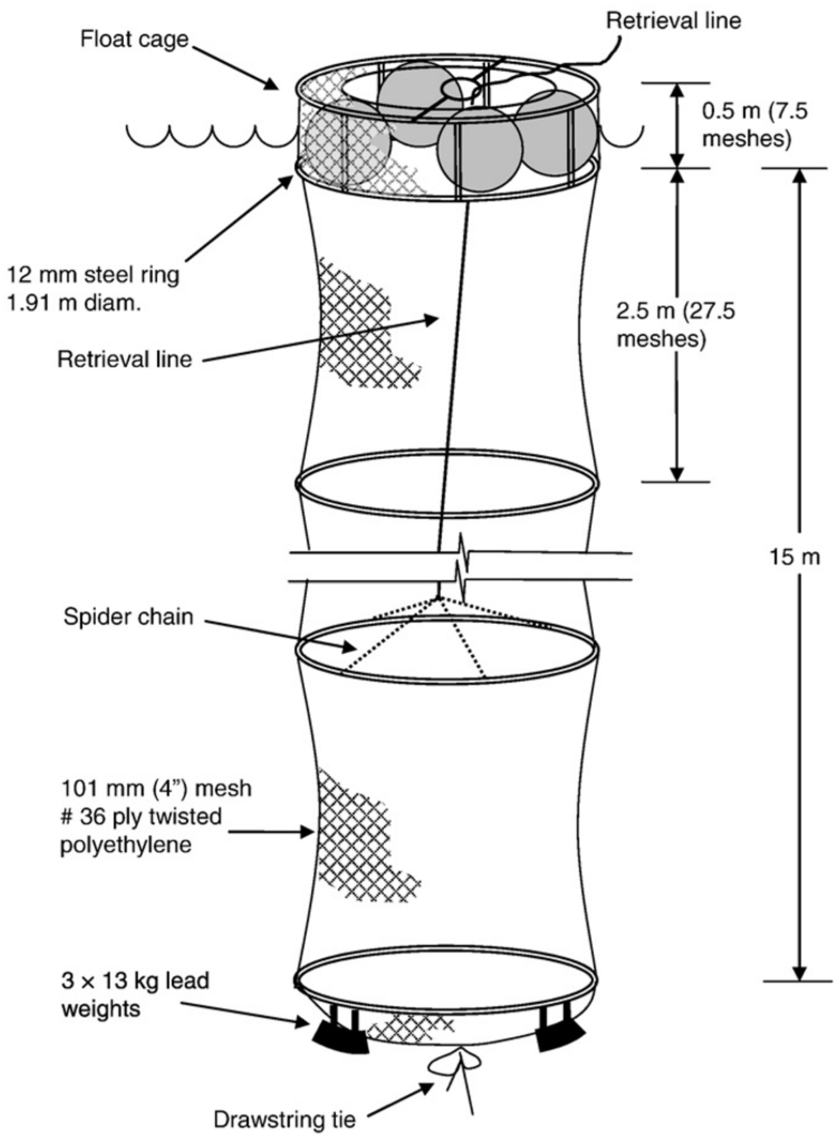

Figure 15: Fish holding net design proposed and designed by Brown et al. (2010).

The other *a priori* factor, to consider is hook location, which could be a factor nested within fishing depth treatments. A balanced sample size for each hook location type in each replicate net would be hard to achieve, because at least 80% of the fish caught by volunteer fishers using normal fishing practices are likely to be lip-hooked, and prolonged fishing would be required to catch additional gut- and externally-hooked snapper to achieve a balanced design.

Control fish could be caught by longline in shallow waters, with only lip-hooked fish in apparently good condition being released into each replicate net. Control fish should be released into each net at least five days before the recreational release treatment fish are released into the same net, so they have time to acclimatise to holding conditions, and so that any control fish that did die soon after release could be removed. Pollock & Pine (2007) recommend that the number of control fish should equal the number of the most common release treatment type (lip-hooked fish), but this should be weighed against the number of fish that can be held in each replicate net and the need to fish long enough to catch fish that are gut- or externally-hooked, to adequately estimate associated mortality rates. We recommend that each net be stocked with 20 control fish and 40 treatment fish, resulting in a total of 60 fish per net. If 18 holding nets were deployed according to the replicated design described above, this would result in a target sample size of 360 control fish and 720 release mortality treatment fish.

Both control and treatment fish could be tagged with a Passive Integrated Transponder (PIT) tags, so that the fate of each fish can be associated with factors that describe its initial capture and release condition. T-bar and dart tags are not considered suitable, because they could potentially be bitten off by other fish and may also cause harmful injuries that may affect behavior and lead to tag-induced mortality. The PIT tag should be injected into dorsal tissue, because this is likely to be less harmful than injecting the tag into the gut cavity.

Volunteer anglers fishing from a charter boat tied up alongside the holding net could be used to stock three nets a day, with one net moored in each of the three depth bins, and the stocking order of these nets determined at random in advance. Six charter boat fishing days would therefore be required in total, but these days could be split into three 2-day tagging episodes (requiring the construction of six nets). Sequential day stocking of three nets per day is more cost effective than constructing and monitoring just three nets at a time, because a commercial longline could provide control fish for more than three nets in a single day, and a larger number of nets could be monitored throughout the holding period if more nets are stocked concurrently.

Fish should be released into the holding net as soon as possible, and not held on board in a holding tank, because this would subject fish to experimental artefacts that they would not usually experience under normal fishing conditions. Fisher-independent observers could be used to tag and record data for each fish that is released into a net, so that all fish are treated in a similar manner, while allowing the volunteer fishers to focus on their normal fishing practice. Fishers will be asked to catch fish with hook and bait methods only, but they will be free to use their preferred hook and bait, with a range of bait types provided for that purpose. Fishers will not be told whether or not to remove the hook or to cut the line for any gut-hooked fish, but their choice of fishing gear and release method will be recorded for any fish released into a holding net. Fishers will be asked not to vent any of the fish they catch, because venting is relatively uncommon and considered to be an atypical practice.

It is recommended that all experimental treatment fish should be held for 4 days and monitored by the research team twice a day using a splash camera. Any dead fish should be retrieved from the mortality sock as soon as observed. This would mean that control fish caught five days before the recreationally caught fish would have been held in captivity for at least nine days. The majority of snapper that have died during past release mortality experiments have died within the first hour, with virtually no mortality being observed after the first day. Dead fish should be removed and identified twice a day, so that Kaplan-Meier (Kaplan & Meier 1958) survival curves can be estimated for each release treatment factor, to estimate any further mortality that would have occurred if the monitoring period had been extended indefinitely.

The PIT tags of all fish that have survived at the end of the four-day monitoring period should be read so that the fate of all retrieved fish is known given the conditions they experienced during their capture; some fish may escape during the holding period and the data for the these unaccounted for fish should be removed from the data set before any subsequent analyses are undertaken. The external state of all retrieved fish should be macroscopically examined and classified, but there is probably little merit in conducting detailed post-mortems on these fish given the detailed summary post-mortems of snapper retrieved from a broad range of depths reported by Peregrin et al. (2015); similar outcomes would be expected for snapper caught in New Zealand waters.

Although the proposed experimental approach has been designed to estimate release mortality rates associated with the two *a priori* causal factors identified by previous snapper release mortality studies, *a posteriori* tests could still be used to estimate the impact of other co-occurring factors recorded at the time of capture. These could include: fish length; hook size; tissue damage; behavioural state following release; handling time; and any other factors that can be quantified consistently.

A pilot study is recommended at the start of a snapper release mortality project to build and test a net and the logistics involved with stocking it, monitoring the fish, removing dead fish, and retrieving the net at the end of the experiment.

10. BLUE COD RELEASE MORTALITY EXPERIMENTAL DESIGN

Blue cod are endemic to New Zealand, but only limited quantitative information is available on factors that may determine release mortality rates for this species. The authors therefore recommend that an initial characterisation of recreational blue cod catch, including releases, should be undertaken to identify potential risk factors and inform an appropriate experimental release mortality design.

The following general experimental approach is proposed. Blue cod are commonly caught in pots and they can be held live in a pot for several weeks. All the control and kahle hook-caught blue cod that Carbines (1999) held in 0.414 m^3, 0.45-m high truncated conical pots survived a 2-week monitoring period. Similar pots could be used for a recreational blue cod mortality study. Control fish could be caught in commercial cod pots and transferred into pots based on the same design as those used by Carbines and lowered back to the sea floor for the fish to acclimatise for a few days. Anglers fishing from private fishing boats at the same location could then release recreationally caught cod into identical pots carried by each vessel for that purpose. The collapsible mesh design used by Carbines would be more suitable for this type of experiment than commercial cod pots, which are too large and heavy for most recreational fishing vessels. It would be preferable for recreationally released and control fish to be held alongside each other in the same pots, but there is no way of doing this without acclimatising control fish beforehand, so they could overcome possible barotrauma effects.

A number of pots could be easily stocked and deployed from multiple recreational vessels, providing a large number of replicates for each experimental treatment. It is possible that holding fish in a pot alongside a boat until several fish have been caught, for holding purposes, may itself lead to fish dying, but this is not likely to be an issue. Only 3% of the blue cod held onboard in recirculated holding tanks by Davidson (2001) died, and these deaths were assumed to be because the fish were gut-hooked and bleeding, whereas all lip-hooked cod were alive at the time of release.

If cod are caught and released into holding pots from private fishing vessels, then an independent observer should be present, initially, to show the volunteer fishers how to PIT tag and release their cod into pots and to record relevant data. It may not be necessary for an independent observer to be present for further catch and release events, because the number of fish caught daily by each boat may be low and the ongoing presence of an observer could be prohibitively expensive.

Carbines (1999) stocked each pot with 10 blue cod (one cod per 0.17 m^2 or per 0.042 m^3), without any control or kahle hooked fish dying, but this might be an upper stocking density limit because all these fish were smaller than the 33 cm total length MLS in place at that time. The area available to each fish may be more important than volume. One way of testing for a suitable stocking density across a broader size range could be to use commercial cod pots in pilot experiments using different stocking densities to determine the likely upper limit at which mortalities may occur. To avoid synergistic effects, experimental studies should use stocking densities well below densities observed to cause mortality in pilot surveys.

All pots should be monitored twice a day by divers, to both retrieve any dead fish, and to feed the cod, because cannibalism could be an issue for this species. The recovery of some PIT tags might not be possible if dead fish are not retrieved before they are cannibalised. There may be little to gain from monitoring the experimental pots for more than 4 days, as all the cod that died during the two-week monitoring period in 1999 did so within the first 26 hours.

Two release mortality risk factors yet to be assessed for blue cod are air exposure time and avian predation. The incidence of avian predation could be determined from an initial catch and release characterisation survey such as that done for snapper by Holdsworth & Boyd (2008a).

11. KINGFISH RELEASE MORTALITY EXPERIMENTAL DESIGN

New Zealand has a high-profile recreational fishery for yellowtail kingfish widely promoted by the fishing media and tackle retailers. Catch and release is also encouraged and 77% of fishers who caught and kept kingfish in the National Panel Survey landed only one kingfish (Wynne-Jones et al. 2019). Yellowtail kingfish are reasonably robust and have been recaptured following capture and tagging from commercial longline and trawl vessels and a variety of recreational methods. The New Zealand Gamefish Tagging Programme has recorded over 23 000 kingfish released with 1600 tagged fish recaptured (Holdsworth & Saul 2019).

Roberts et al. (2011) conducted a well-designed containment experiment, including controls, on 54 recreationally caught kingfish (between 60 cm and 75 cm fork length), with very high survival of lip-hooked kingfish. However, 7 of the 11 fish hooked in the gills died within 1 hour. Of the three fish hooked in the throat or stomach, all survived the 5-day monitoring period.

There would seem to be no need to repeat a containment study on undersize lip-hooked kingfish. The unanswered question is around the fate of deep/gill-hooked kingfish. In the New Zealand recreational fishery, kingfish can become wary of jigs and many large kingfish are targeted and caught on baits, with a proportion of these gut-hooked. They are often released with the hook still in the fish. An electronic tagging study of the survival rate of deep/gill-hooked kingfish is recommended as having the most management utility. Having a single treatment, with controls, would reduce the sample size and cost of the project. The main purpose would be to provide data to support better fishing practice by amateur fishers with advice on which fish to keep and which fish would survive release. The high rate of mortality for kingfish bleeding from the gills has been established, even from a small sample size, in the Australian containment study (Roberts et al. 2011). A long-term monitoring approach may be required, to determine the long-term effects of deep/gill hooking on feeding and survival for this highly mobile species. Electronic tags that release from the fish if they die offer the most viable means of monitoring the survival of legal size fish (over 75 cm) over the long term. Kingfish is the only species considered in this report that is large enough to carry any of the current versions of pop-up tags.

The recommended approach would be to release kingfish with Survivorship Pop-up Archival Tags (sPAT) made by Wildlife Computers. Fish caught on live baits that are deep/gill-hooked would have the trace cut and the hook left in the fish. Tags would be attached with a nylon tag head and tether in the dorsal musculature. Control fish would be caught on lures, which cannot easily be swallowed, using heavy tackle and the hook would be removed and the condition of the fish assessed before measuring and tagging. Ideally, controls would be representative of the same population/location and size as the treatment fish. Several locations may need to be fished to achieve an adequate sample size. The tags could be programmed to remain on the fish for 45 days.

A pilot study is recommended to test tag performance and the attachment method. This could involve 6 to 10 kingfish of various sizes over 75 cm. The recommended sPAT tags report the status of the release pin when it detaches from the tether. Floating tags or tags with broken pins may indicate that the tags are being pulled off by other kingfish in the school. If the results of this pilot study indicate high levels of tag retention and performance, then a larger study could be conducted to assess release mortality rates for deep/gill-hooked fish. An experimental sample size of at least 60 fish is recommended for such a study, with up to half of these being control fish, depending on tag retention and performance.

12. USE OF RELEASE MORTALITY ESTIMATES TO INFORM FISHERIES MANAGEMENT

There are at least four ways that estimates of recreational release mortality could be used to inform and improve the management of fish stocks that are most commonly fished by recreational fishers. These are:

- To fully understand and account for release mortality when setting amateur size and bag limits, so that any changes to these regulations are more likely to achieve their intended aim.
- To increase the awareness of recreational fishers to the consequences of their fishing practice, and ensure people know how to catch and handle a fish to maximise its chance of survival on release and reduce waste.
- To better inform stock assessment models so that all forms of fishing induced mortality are accounted for.
- When the Minister sets the Total Allowable Catch, an allowance is made for other sources of fishing related mortality, including recreational release mortality. The setting of this fishing related mortality allowance would be better informed if quantitative estimates of release mortality were available. Currently such estimates are not available for recreational fisheries (and for most other types of non-recreational fishing).

The recreational harvest taken from some of New Zealand's inshore fish stocks is now approaching or has exceeded that taken by the commercial sector in some areas. When changes to bag and size limits are made by fisheries managers, the focus is on the projected effect on landed catch, without taking into account incidental mortality, which is largely unknown. Although the incidental mortality caused by most forms of commercial fishing is also largely unknown (and is potentially substantial), there is arguably a greater need to understand the full consequences of recreational release mortality given the larger minimum legal size limits that recreational fishers are subject to, and their requirement to fish within a daily bag limit; both will influence the number and size of fish released.

Most of the information that is available on recreational release mortality is for the SNA 1 fishery. The data from these studies suggests that the additional mortality associated with released catches is low relative to the landed catch (in terms of tonnage); however, these data are now out-of-date given changes to recreational regulations in 2014, and changes in the abundance and size of fish that are now targeted by recreational fishers. This highlights the need to regularly characterise the size composition of recreationally retained and released fish and the incidence of factors that may cause release mortality. Experiments designed to understand the consequences of factors influencing mortality after release, given the size of fish, need not be regularly repeated.

Fisheries New Zealand has found broad support for collecting better recreational fishing information when developing its National Blue Cod Strategy, which may involve changing bag limits based on a traffic light system and providing information about responsible blue cod fishing. Some of this work has started and more data on quantifying the size and number of blue cod released and the condition of those fish would be a useful component of ongoing monitoring under the National Blue Cod Strategy. Anecdotal information suggests that, in some management areas, blue cod release mortality could be significant.

The benefits of understanding release mortality go beyond informing the decisions of fisheries managers. There is increasing public interest in ensuring released fish survive, and the results of any release mortality experiment or characterisation should be publicised to encourage recreational fishers to maximise fish welfare and release survival. Changes to fishing methods and handling practices that maximise fish welfare and the survival of released snapper could be developed and promoted.

The development of stock assessments that account for release mortality is more problematic. Almost all recreational fisheries are only one component of a multi-sector fishery that is also harvested by commercial fishers. Estimates of commercial release mortality and that associated with in-water gear escapement are also required if all sources of incidental mortality are to be included. This is unlikely to be achievable for many fish stocks. Reconstructions of past incidental mortality tonnage estimates will also be hard to estimate with any reasonable level of certainty. The cumulative past impact of release mortality by methods used by each fishing sector is arguably inherent in the size and age composition distributions and abundance indices that current stock assessments are fitted to, but any estimates of incidental fishing mortality by any sector could be used to better inform model projections used to inform changes to catch limits and fishing regulations.

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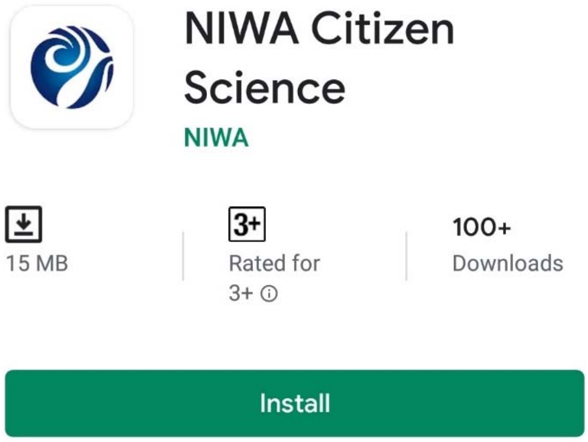
APPENDIX 1: NIWA CITIZEN SCIENCE CATCH & RELEASE APP INSTRUCTIONS

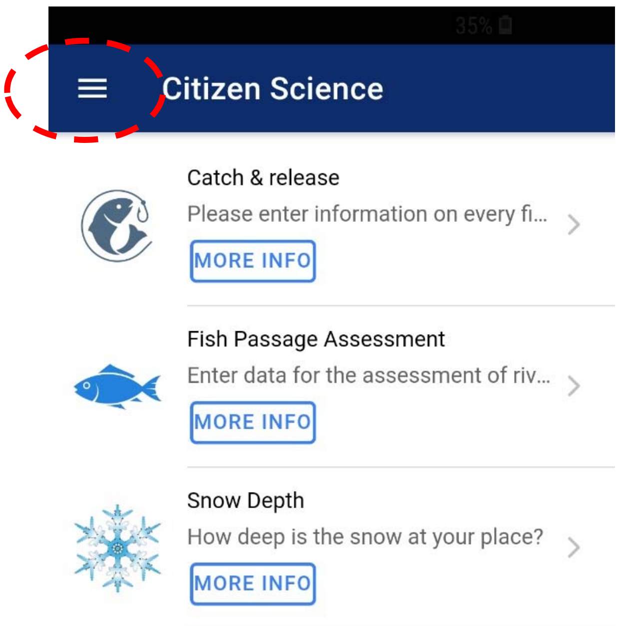
Fisheries New Zealand have commissioned NIWA and Blue Water Marine Research to collect information on the size and condition of fish released by marine recreational fishers. This beta version citizen science App has been developed to see if this is a viable way of collecting data that we can use to understand the rate at which fish are released, and ultimately, their fate.

The current focus is on blue cod, kahawai, kingfish and snapper, which form a large proportion of the national recreational catch and overall have large numbers of fish released. It is very important that you record the catch of both the fish that you keep, and those that you release. All of the information you provide will remain confidential and only be presented in summary form across all fishers.

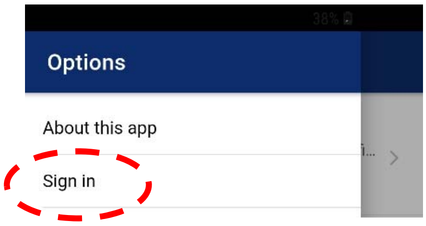
If you haven't done so already, you can download the free **NIWA Citizen Science** App from your App Store.



The **NIWA Citizen Science App** has been designed to quickly build apps to support NIWA citizen science, so you will see several sub apps when you open the app. But before you start you have to click on the sign in menu icon in the top left corner.

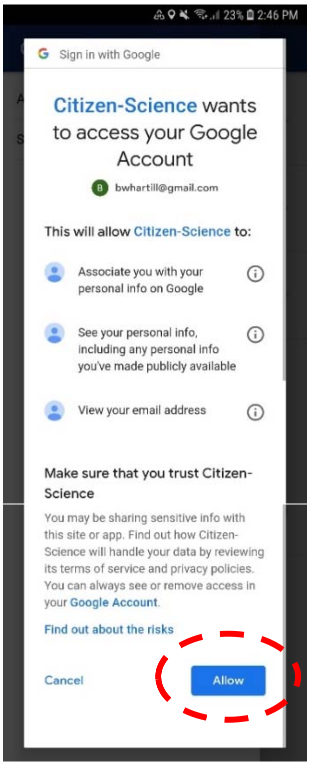


The first time you sign in

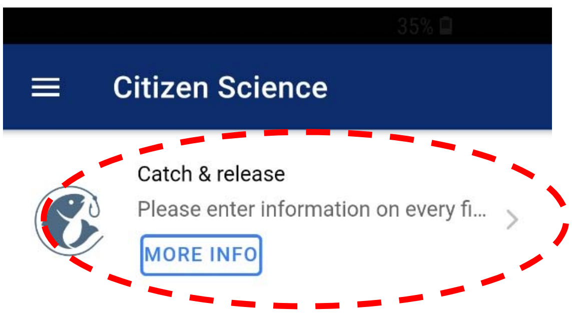


you will be asked for a gmail account, which you will have to create first if you don't already have one. Just Google "gmail" if you need to create a gmail account. Your gmail account tells us which fish is caught by who, so we can identify fish caught during the same trip by the same fish. All of the data you provide is confidential.

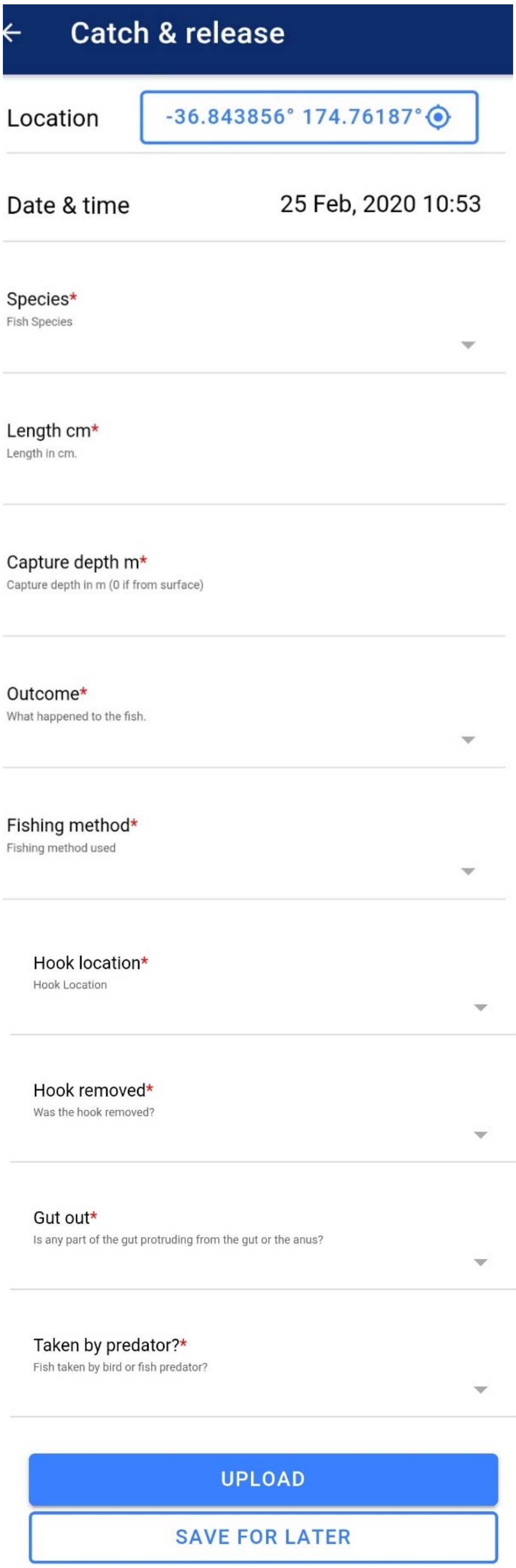
Once you have done this, you will be asked to approve your signing in, and should see the following



You will probably have to do this stage twice before you can select the Catch & Release App and start recording data.



Tap on the **Catch and release** icon to enter data for each fish as follows.



The date and location are entered automatically.

Select a species from the dropdown list – or pick the "Test example" option if you are not actually fishing.

Tap below the **Length** label to enter a measured fish length in centimetres from the nose to centre of the tail. Entering a value will open the next field.

Tap below **Capture depth** label to add the water depth where the fish was hooked. Tap the next field to continue.

Tap **Outcome** and select one of the options from the dropdown list.

Tap **Fishing Method** and select one of the options from the dropdown list.

Tap **Hook location** an option from the list. Lip-hooked includes fish hooked in the mouth, Gills and Gut means fish where the hook is in the throat or deeper, and External is where the fish is foul hooked on the body.

Tap **Hook removed** and select yes or no.

Tap **Gut out** and select an option. For species like snapper the air in the swim bladder expands as the fish is brought to the surface. This can force the stomach into the fish's mouth (select Mouth) or push some intestines out the anus (select Anus). Some fish do not have this problem or the air escapes before the fish reaches the surface (select None).

Tap **Taken by predator** and select yes or no.

Tap **Upload** to send the record of capture to the database, or if you are out of cell phone range you can **Save for later**.

If you select the **Save for later** option, you will have to reopen this entry when you are within cell phone coverage range again, and then tap upload to submit the data for this record. When you have finished an entry for a fish the App returns you to the Citizen Science home page. Tap on **Catch and release** to enter data for the next fish you catch, regardless of whether you keep or release it.