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Aerial-access recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2017–18

New Zealand Fisheries Assessment Report 2019/23

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EXECUTIVE SUMMARY

Hartill, B.; Bian, R.; Rush, N.; Armiger, H. (2019). Aerial-access recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2017–18.

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This report provides estimates of the recreational harvest of snapper, kahawai, red gurnard, tarakihi and trevally taken from FMA 1 during the 2017–18 fishing year. These estimates were primarily derived from a maximum-count aerial-access survey that combined data collected concurrently from two sources: a creel survey of recreational fishers returning to key boat ramps throughout the day; and aerial counts of vessels observed to be fishing at the approximate time of peak fishing effort on the same day. The methods used for this survey were closely based on those used in previous aerial-access surveys of the FMA 1 recreational fishery, in 2004–05 and 2011–12.

Interviewers were present at 20 boat ramps located throughout FMA 1 on 47 days randomly preselected according to a random stratified survey design. Survey flights were also scheduled on the same 47 survey days, but all flights were cancelled on 7 of these days and flights were partially curtailed on another 13 days due to low cloud or problems with aircraft serviceability. Aerial survey counts for unflown days were predicted from the relationship between aerial and creel survey-based counts of boats on fully surveyed days. This imputation of aerial counts for weather affected days was necessary because harvest estimates calculated solely from data collected on fully surveyed days would have been positively biased, as fishing effort is likely to be higher when weather conditions are also favourable for flying. Aerial counts predicted from these area specific regressions suggest that only 10.6% of the effort that took place on the 47 survey days occurred on days when flights were cancelled, and any bias due to reliance on regression-based estimates of effort is unlikely to have a major effect on the overall estimates.

The recreational harvest estimates generated from the aerial-access survey for the 2017–18 year were: 3052 t for SNA 1; 866 t for KAH 1; 26 t for the east coast of GUR 1; 44 t for the east coast of TAR 1; and 116 t for TRE 1. These estimates do not encompass all forms of recreational harvesting however, as some forms of fishing effort are not readily assessable from the air, such as longlining, trolling, diving, netting, and shore-based fishing.

Additional harvests of each species taken by unassessed boat-based methods were estimated from data on the relative catch landed by each boat-based method, collected during creel survey interviews. Including additional landings of fish caught by longlining, trolling, diving, and netting by boat-based fishers increased the harvest estimates to: 3118 t for SNA 1; 919 t for KAH 1; 28 t for the east coast of GUR 1; 45 t for the east coast of TAR 1; and 123 t for TRE 1.

These harvest estimates do not include any allowance for shore-based harvesting, and relative harvest by fishing method data provided by a concurrent off-site national panel survey was used to account for the additional harvest taken from the shore. Including shore-based harvesting increased our recreational harvest estimates to: 3467 t for SNA 1; 1219 t for KAH 1; 31 t for eastern GUR 1; 46 t for eastern TAR 1; and 145 t for TRE 1.

These harvest estimates for the 2017–18 fishing year are compared with those provided by similar aerial-access surveys conducted in 2004–05 and 2011–12. As in 2011–12, a national panel survey has been conducted concurrently alongside the aerial-access survey described in this report, and preliminary harvest estimates provided by this independent study are once again of a broadly similar magnitude. This suggests that the harvest estimates given here are reasonably accurate and can be used to inform the management of the recreational fisheries in FMA 1.

1. INTRODUCTION

Fisheries managers require reliable and up to date information on all sources of mortality if they are to ensure the sustainable management of New Zealand's fish stocks. Recreational fishers account for a significant proportion of the harvest taken from many inshore fish stocks, and scientific survey methods are required to quantify these harvests as there is no requirement for the recreational sector to report their catch, as reporting is not considered feasible.

The development of survey methods capable of providing reliable recreational harvest estimates is an ongoing and iterative process, but considerable progress has been made over the last 15 to 20 years (Hartill et al. 2010). The most frequently used survey method to date in New Zealand has been the aerial-access survey method (Hartill et al. 2011), which is ideally suited to estimating the harvest taken from boats as they are readily enumerated from the air. A comparison of estimates provided by an aerial-access survey of the FMA 1 recreational fishery in 2011–12 with concurrent estimates provided by a fundamentally different national panel survey approach suggests that either method can be used to provide reasonably reliable estimates of recreational harvest (Hartill & Edwards 2015).

This report documents a further aerial-access survey of the recreational fishery in FMA 1, during the 2017–18 fishing year. This survey was undertaken concurrently with a national panel survey that also followed a survey design similar to that used in 2011–12 (Wynne-Jones et al. 2014). The intention was to further corroborate these two alternative survey approaches, and to provide up to date harvest estimates for key FMA 1 fisheries to inform their management. The overall objective of this research was to continue the implementation of an integrated recreational harvest estimation system by providing estimates of absolute total amateur harvest on a stock basis to inform fisheries management.

The specific objectives of Ministry for Primary Industries research project MAF2016-02 were to estimate the recreational harvest of snapper in SNA 1, kahawai in KAH 1, tarakihi in TAR 1 and gurnard in GUR 1 from 1 October 2017 to 30 September 2018 using the aerial access method, and to collaborate with a concurrent national panel survey project to provide robust comparisons of harvest estimates for specified areas.

Although recreational harvest estimates for TRE 1 are not a specified objective for this programme, they are provided in this report as trevally is a species commonly landed by recreational fishers in FMA 1.

2. METHODS

Overview of the aerial-access method

The aerial-access survey methods used in this programme were closely based on those used in previous surveys of some of New Zealand's largest recreational fisheries (Davey et al. 2008; Hartill et al. 2007a, 2007b, 2008, 2013, 2017). The maximum count aerial-access approach used in 2017–18 combines data from two independent on-site surveys: an aerial survey of the fishery; and a creel survey census of fishers returning to selected high-traffic access points throughout each survey day. The aerial survey provides a count of the number of vessels fishing at a point in time, preferably at the time of maximum fishing effort. This aerial count is used to scale up a census estimate of the catch landed at the sampled access points, given the number of censused parties who claimed to have been fishing at the time of the overflight. Both the aerial survey and the creel survey take place on the same randomly pre-selected days, and the data collected from these two surveys are combined to estimate the total harvest of a given species on each survey day. Daily harvest estimates, collected according to a random stratified design, are averaged within each temporal stratum and multiplied by the inverse of the sampling intensity for that stratum, to provide stratum specific harvest estimates.

The method is most suited to estimating the harvest taken by rod and line fishers who are fishing from stationary vessels. Ancillary data are also collected during creel survey interviews to account for other less common forms of boat-based fishing which are not readily enumerated from the air, such as trolling, netting, and longlining. A comprehensive outline of the analytical methods is given in Appendix 1, which is taken from Hartill et al. (2011).

Aerial survey methods

Mid-day counts of recreational fishing vessels were made by observers from fixed wing aircraft flying at an altitude of between 500 (the minimum altitude permissible under civil aviation regulations) and 1000 ft (150 and 300 m respectively). Four simultaneous flights were required to cover coastal waters of FMA 1 during the late morning /early afternoon, when fishing effort usually peaks. Flights lasted up to four and a half hours including transit times to and from the start and end positions of each flight route. Each plane followed a roughly consistent flight route on each survey day, to cover the survey area as efficiently as possible. Examples of each of the four flight routes are given in Figure 1.

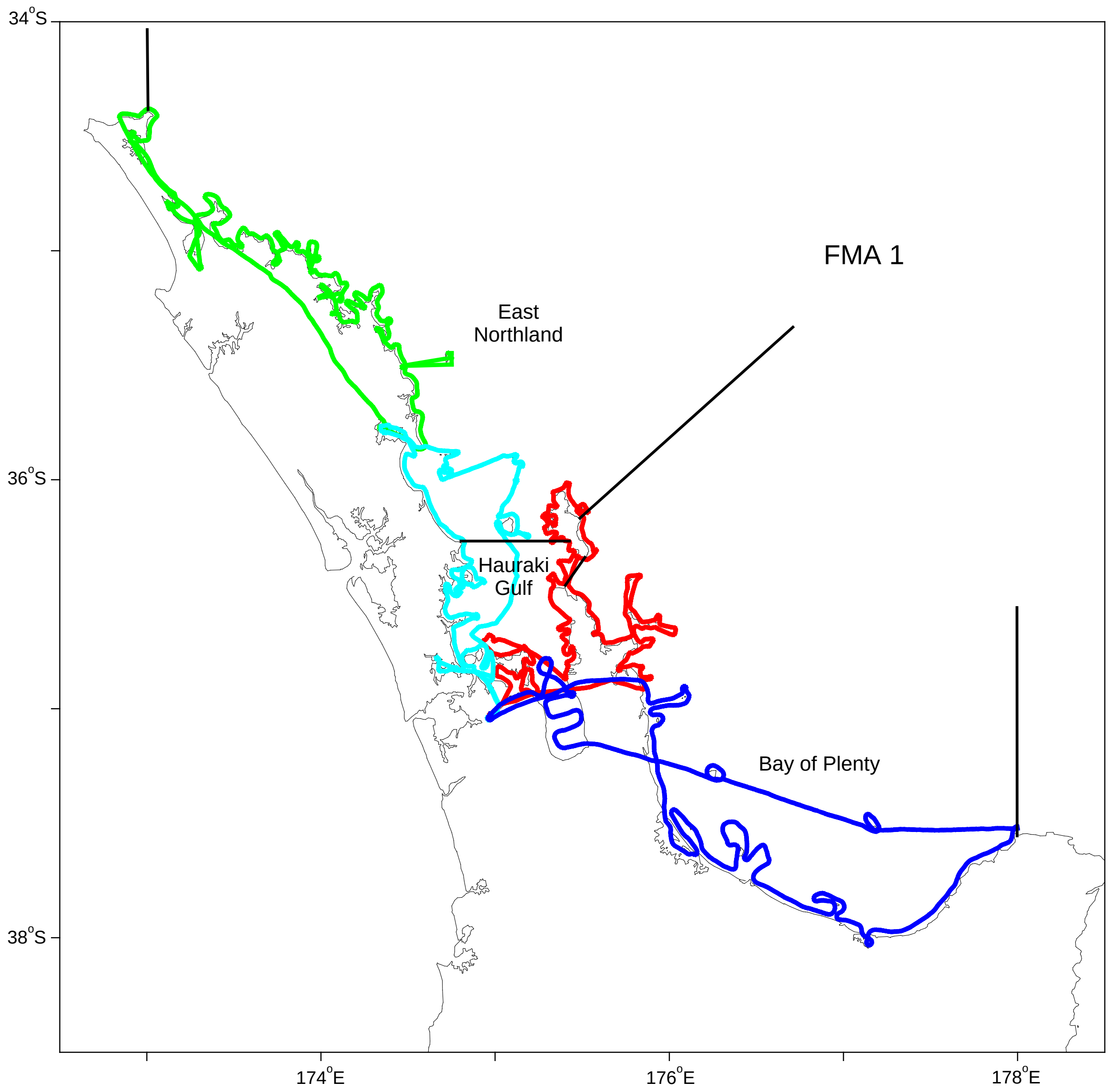


Figure 1: Examples of each of the four flight routes used to count boats actively fishing at midday throughout coastal waters of FMA 1. Single engine Cessna 172 aircraft were used on the three northern routes and a twin engine Piper Seneca was used to survey the more extensive Bay of Plenty route.

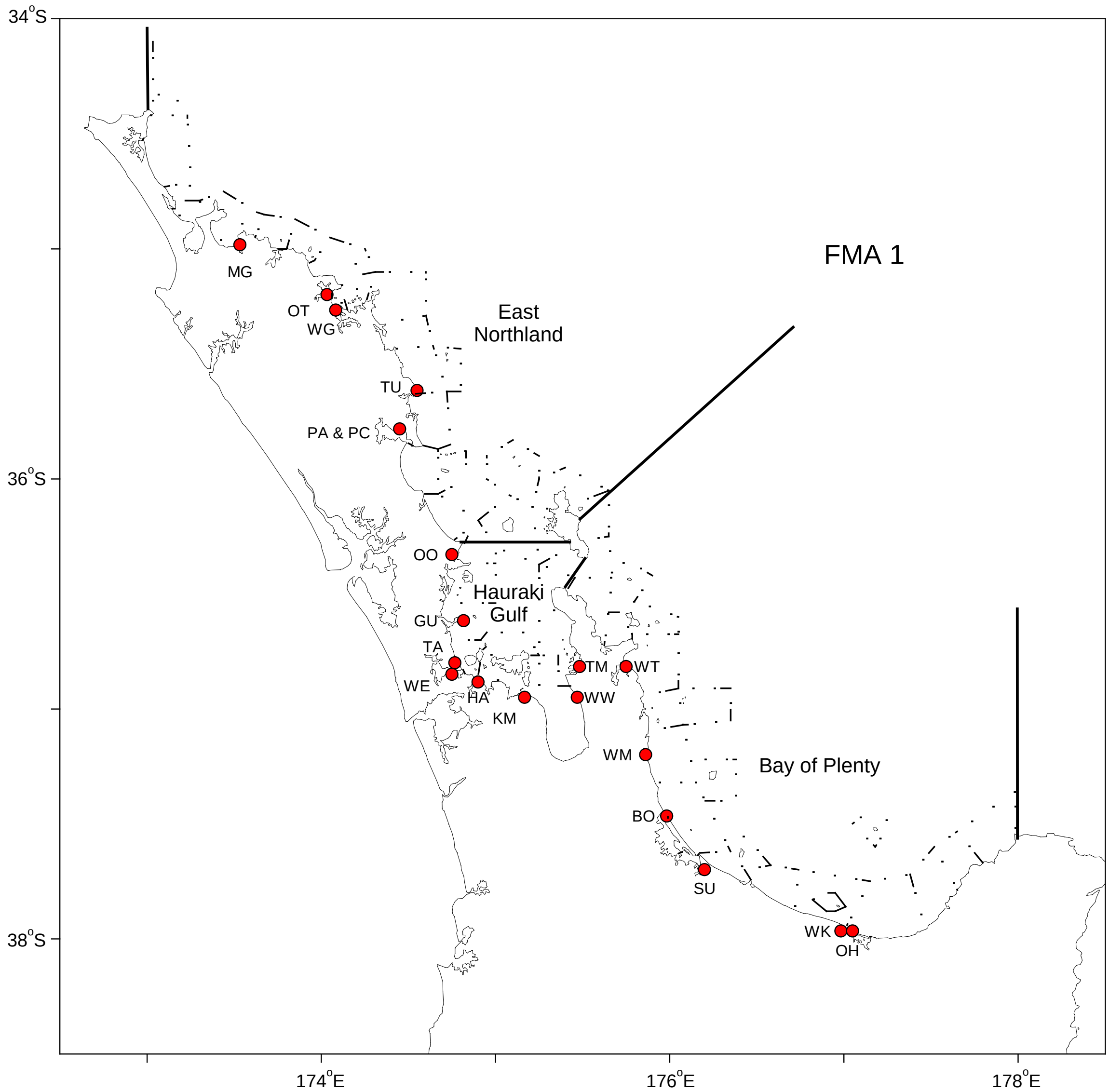
Pilots acted as secondary observers, counting all boats on their side of the plane. This necessitated clear communication between the two parties, as to who was counting which boats in which areas, with overall responsibility resting with the primary observer. Navigation was left to the pilot, although intervention by the observer was sometimes necessary when they felt that the area was not being covered to their satisfaction, or when the pilot was not affording the observer the best possible view of most of the boats. A pool of ten observers was used to ensure that at least four trained staff were available on any given day, with observers randomly allocated to areas on the day flown to minimise any consistent observer bias.

Boats were classified as one of the following: trailer boats (usually with outboards and of trailerable size); launches; yachts; charter boats (based on the number of visible fishers and the general appearance of the boat); kayaks; or jet skis. Boats which were under way were ignored, as were stationary boats obviously not involved in fishing activity, which were evidently occupied with other activities such as swimming or picnicking ashore nearby. Observers and pilots were instructed to classify boats as fishing when there was any doubt.

The time stamped location of each boat was recorded on a purpose built ArcPad 10 GIS application installed on a tablet laptop linked to a GPS receiver. The position of the plane was plotted in real time against a digitised marine chart background, with waypoints plotted every six seconds so the observer could readily determine which areas had already been flown. The plotting of flight routes was most beneficial when featureless areas of water were surveyed away from the shoreline. The electronic recording of aerial survey data facilitated rapid uploading, enumeration, and scrutiny of the data collected by aerial observers.

Although instantaneous counts provide unbiased estimates of fishing effort (Pierce & Bindman 1994), the time taken to census entire regions of FMA 1, such as East Northland, requires a progressive count methodology which has inherent biases that are difficult to overcome reliably (Hoenig et al. 1993). FMA 1 was therefore divided into 69 fine survey strata which were identical to those used in the access point (creel) survey (Figure 2). Counts of vessels fishing within these survey strata were treated as instantaneous counts, as the time taken for an aircraft to traverse each area was many times less than that of the vessels being counted, whose rate of movement was comparatively negligible. Although between 1 and 17 neighbouring survey strata were ultimately amalgamated into 9 analytical areas (Figure 3), the time taken to traverse these amalgamated areas usually ranged from 10 to 55 minutes and these counts are also regarded as instantaneous counts.

The aerial survey provided counts of all types of fishing vessels, including larger vessels such as launches, which would not normally return to boat ramps where interviews can be conducted cost effectively. Although approximately 84% of vessels observed from the air were classified as trailer boats, most of the remainder (launches – 12%, and to a much lesser extent, kayaks, jet skis, yachts and charter boats) would have returned to marinas, moorings or beaches which are difficult to survey. Counts of vessels other than trailer boats were therefore rescaled on the basis of relative occupancy rates, so that all aerial counts could be expressed in terms of trailer boat counts. The boat type occupancy data used to rescale the launch, yacht, charter boat, and other vessel counts was collected during a series of on-the-water surveys undertaken in the Hauraki Gulf during the summer of 2003–04 (Hartill et al. 2007b). The derived occupancy rate scalars were: trailer boats, 2.5 fishers; launches, 2.9 fishers; yachts, 2.6 fishers; charter boats, 10.4 fishers; kayaks and jet skis, 1.6 fishers. All launch counts, for example, were therefore multiplied by a factor of 2.9/2.5, to account for the higher occupancy of this vessel type relative to the trailer boats encountered at boat ramps. The use of scalars assumes that trailer boat fisher catch rates and fishing durations are broadly similar to those of fishing from other types of vessel observed in the same area. The degree of any bias caused by vessel type specific differences in catch rates and fishing durations and catch would be small, because trailer boat fishing usually accounts for about 85% of the boat based fishing seen during aerial surveys in FMA 1.



East Northland

MG Mangonui
OT Opito Bay, Kerikeri
PA Parua Bay (public ramp)
PC Parua Bay (club ramp)
TU Tutukaka
WG Waitangi

Hauraki Gulf

GU Gulf Harbour
HA Half Moon Bay
KM Kawakawa (public ramp)
OO Omaha
TA Takapuna
TM Te Kouma
WE Westhaven
WW Waikawau

Bay of Plenty

BO Bowentown
OH Ohope
SU Sulphur Point, Tauranga
WK Whakatane
WT Whitianga
WM Whangamata

Figure 2: Location of boat ramps and definitions of spatial strata used in both the aerial and access point surveys.

Flights were sometimes cancelled because of low cloud, rain or problems with aircraft serviceability, but estimates of the number of boats fishing at around mid-day are still required for each survey day. Rescheduling to an alternative unscheduled day would lead to positively biased harvest estimates as this would tend to favour days with weather more conducive to fishing. Weather conditions associated with low cloud usually suppress levels of fishing effort, so a harvest estimate for an unflown day would be negatively biased if the flight count was assumed to be zero, and positively biased if the flight count was based on the average count from the other days which were flown (when weather conditions were on average potentially far more conducive for fishing).

To avoid these potential biases, aerial survey counts for unflown days are therefore required, and these were predicted from the relationship between aerial and creel survey based counts of boating parties who reported fishing effort at the time that the aerial survey took place in their fishing area, on other days, when data were available from both of these companion surveys. Separate predictive relationships were generated for each spatial stratum, which were used to estimate the number of boats that would have been seen from the air given the level of effort observed at surveyed access points on the same day (see Figure 5). Both the slope and intercept were estimated for each regression, with the constraint that the intercept was zero positive (as negative levels of predicted fishing effort cannot occur in reality).

The uncertainty associated with area specific regression based aerial count predictions was estimated by bootstrapping and applying absolute residuals sampled from those days where the ramp count was less than or equal to the busiest unflown day, to each predicted aerial count. An alternative method of estimating the uncertainty associated with regression based predictions of aerial counts on flight cancelled days was also investigated, where each data set was bootstrapped and regressed 1000 times, which produced very similar variance estimates to the method already described.

Access point survey methods

Most of the access points surveyed during this study were also surveyed during the 2004–05 and 2011–12 aerial-access surveys (Hartill et al. 2007a, 2013), with some revision to ensure a wide geographical spread of sites within each region and to maximise the potential number of interviews achieved (Figure 2).

Interviewers were present at these ramps throughout daylight hours (starting at 0730 or 0800 and ending about half an hour after official dusk) on each survey day, regardless of prevailing weather conditions. Interviews were conducted in morning and afternoon shifts at each ramp with a period of overlap in the middle of the day. At least one interviewer was therefore present throughout the day, with pairs of interviewers present at Half Moon Bay and Sulphur Point throughout the day when heavy traffic levels were expected at these ramps. Web camera data suggests that very few, if any, fishers would have returned to boat ramps in the early morning, before the first interviewer started their shift. Boats would sometimes have returned to surveyed ramps after the interviewer had finished for the day, however, especially when returning from distant fishing locations. Interviewers were therefore asked to record the number of empty trailers remaining at the ramp at the end of each survey day so that data imputed from other boats that had been interviewed in the evening could be used to account for any harvest that may have been landed by late returning boats that would have otherwise been missed.

Interviewers were instructed to focus primarily on detecting and recording the time at which each boat returned to their ramp and to classify these boats as one of the following: interviewed; interviewed but not fishing; refused but fishing; refused (activity unknown); or not interviewed. From these data it is possible to establish how many boats approached the ramp over any period, and to estimate how many had been fishing, given the proportion of those interviewed that claimed to have been fishing. At busy ramps, or at busy times of day, the interviewer may have been unable to interview all fishing parties approaching the ramp. In such instances, the interviewer was instructed to select boats at random. Information for un-interviewed boats was imputed given a chronological sequencing of these data, by assigning a copy of the data collected by the next interviewed boat, regardless of whether or not that boat had fished. This chronological imputation minimises any bias that may arise from diurnal changes in levels of fishing effort and catch rates.

Interviews followed a standardised format used in all previous boat ramp surveys conducted by MAF Fisheries in the early 1990s and by NIWA since, ensuring that data were collected in a consistent and rigorously tested manner. Data collected as part of these interviews was used to determine where fishing took place, at what time, which methods were used, and which fish were caught by each fisher, for any given combination of method, area, and time. Usually the interviewer was able to measure the catch, but when this was not possible, a count or estimate of the number of fish of each species was made and the nature of that count recorded. From these data it is possible to estimate average catch rates (or harvest rates when fish were landed) in terms of the number of fish and the weight of fish caught (via length weight relationships).

Temporal stratification used in both the aerial and access point surveys

Aerial and boat ramp surveys were conducted on 47 days selected according to a stratified random design closely based on that used in 2003–04 (for the Hauraki Gulf - Hartill et al. 2007b), in 2004–05 (for FMA 1 - Hartill et al. 2007a), and again in 2011–12 (Hartill et al. 2013), to ensure that the aerial-access harvest estimates obtained were as comparable as possible over time.

This level of sampling effort was also considered necessary to provide harvest estimates that were reasonably precise, so that meaningful comparisons could be made with those provided by a concurrent national panel survey undertaken by the National Research Bureau (NRB) during the 2017–18 year, following the methods described in Wynne-Jones et al. (2014). The analytical methods used for this comparison will broadly follow those described in Hartill & Edwards (2015).

Levels of recreational fishing effort can be highly variable given time of year and day of week, typically peaking during summer months when catch rates are usually higher and the day length is longer. Fishing effort is also usually higher on weekends and public holidays and lower during the working week. Sampling effort was therefore stratified by season (summer – 1 October 2017 to 30 April 2018 versus winter – 1 May 2018 to 30 September 2018) and day-type (weekends and public holidays versus midweek days) to improve estimate precision. The allocation of the 47 survey days across combinations of seasonal and day type strata is given in Table 1. These allocations were broadly based on relative levels of sampling effort used in previous aerial surveys conducted in FMA 1, with an additional survey day added to each of the two winter strata.

Table 1: Temporal allocation of aerial-access survey days across combinations of seasonal and day-type strata for the 2017–18 fishing year.

Season	Day-type	No. of days in stratum	Days surveyed	Sampling intensity
Summer	Midweek days	135	11	0.08
	Weekends/holidays	78	20	0.26
Winter	Midweek days	108	8 (9)*	0.06
	Weekends/holidays	45	8	0.16

*a creel survey day scheduled for Saturday 28 July 2018 was worked on Friday 27 July due to miscoordination.

Most of the sampling effort was assigned to the two summer strata, when higher levels of fishing effort were expected. The allocation of sampling effort across the two busier summer strata was based on the results of a previous quantitative optimisation of sampling effort (see Hartill et al. 2007a).

Calculating harvest estimates

A detailed description of the analytical methods used to calculate aerial-access harvest estimates and associated estimates of precision is given in Appendix 1, but a brief description is given here.

Aerial count and fisher interview data were combined for each survey day to estimate the harvest of a given species on that day. The interview data provides a census of all boats returning to selected access points throughout the day, both in terms of fishing effort and landed catch. Interviewers note the time at which each boat returned to the ramp, and if they are unable to interview a party because they are busy interviewing another group of fishers, the catch and effort of the un-interviewed boat is assumed to be the same as the next boat interviewed. This cumulative time series of observed and imputed interview data can be used to estimate the number of parties who claimed to have been fishing at the time that they would have been counted from the air, and the total catch landed at each ramp on each day. The aerial count can therefore be used to scale up the combined catch of fishers crossing a subsample of all access points, given the number of fishing parties (boats) who claimed to have fished at the time of the aerial count on that day.

Daily harvest estimates, collected according to a random stratified design, were averaged within each temporal stratum and multiplied by the inverse of the sampling intensity for that stratum to provide harvest estimates for entire temporal strata. Stratum specific estimates of uncertainty were generated by a nonparametric bootstrapping procedure (resampling with replacement, including non-parametric finite correction following the methods described by Chao & Lo (1985) to account for the relatively large proportion of days sampled in some temporal strata) implemented in R that had been tested and used to calculate harvest estimates and associated estimates of uncertainty for previous aerial-access surveys undertaken by NIWA.

Harvest estimates were calculated for 9 analytical strata (Figure 3) which were amalgamations of the 69 fine scale survey strata used in both the aerial and access point surveys (see Figure 2).

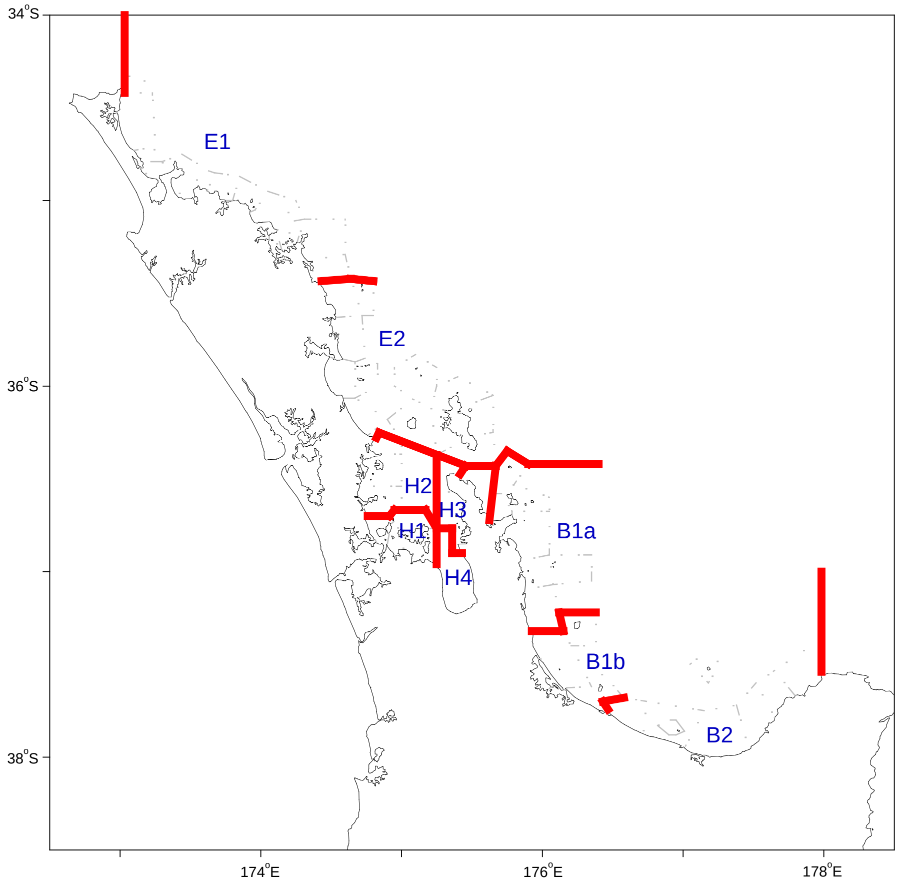


Figure 3: Spatial definitions of analytical strata for which harvest estimates were calculated. Stratum estimates can be combined to provide regional estimates for East Northland (E1 + E2), the Hauraki Gulf (H1 to H4), and for the Bay of Plenty (B1a to B2).

The aerial-access method does not account for the harvest taken by some forms of boat-based fishing which are not readily enumerated from the air (longlining, set netting, diving and trolling) and the additional tonnage taken by these methods was estimated relative to the aerial-access harvest estimate for each fishery. Region specific boat ramp data on the number of snapper, kahawai, red gurnard, tarakihi and trevally landed by interviewed fishers were used to estimate the proportion of the catch that was taken by these unassessed methods in each season. These proportional estimates were then used to scale up the aerial-access harvest estimates for each combination of species, area and season as follows,

$$\hat{H}_b = \frac{1}{1 - r_{\bar{a}}} \hat{H}_a$$

where $\widehat{H_b}$ is the harvest taken by all boat-based fishers, $\widehat{H_a}$ is the harvest estimated by the aerial-access survey, and $r_{\bar{a}}$ is the proportion of the catch harvested by boat-based fishers which was not enumerated from the air.

These estimates were then scaled up to account for the additional harvest taken by shore-based fishers. The data used to estimate the proportion of the total recreational harvest taken by shore-based fishers was that provided by the concurrent national panel survey conducted by the National Research Bureau. These proportional estimates were then used to scale up boat-based harvest estimates for each combination of species, area and season as follows,

$$\hat{H} = \frac{1}{1 - r_{\bar{b}}} \hat{H}_b$$

where $\hat{H}$ is the harvest taken by all boat-based fishers, and $r_{\bar{b}}$ is the proportion of the catch harvested by shore-based fishers.

Variances associated with both the indirectly assessed boat-based, and shore-based fishers were estimated by bootstrapping the underlying data sources 1000 times, and then applying these bootstrap scalars sequentially to the 1000 bootstrap estimates generated from the aerial-access survey (Appendix 3).

3. RESULTS

Aerial survey counts of fishing vessels

The spatial and temporal distribution of fishing effort observed from the air in 2017–18 was broadly similar to that seen in previous aerial surveys of the FMA 1 fishery. Fishing effort was generally highest in the summer months, and, within a season, higher on weekends and public holidays (Figure 4). There was a noticeable increase in effort at holiday locations such as the north-eastern Coromandel and the Bay of Islands on long weekends. Levels of fishing effort within any temporal stratum appear to be highly influenced by prevailing surface wind speeds.

Most of the boats observed were found close to large population centres, especially Auckland, and, to a lesser extent, Tauranga, Coromandel and Whangarei. Aggregations of boats were also seen amongst mussel farms, especially the extensive site in Wilsons Bay, at the top of the Firth of Thames where over 100 trailer boats were often seen fishing during the weekend. On most days, over half of the vessels observed were in the Hauraki Gulf. Overall levels of fishing effort in East Northland were similar to those in the Bay of Plenty, despite the potential differences in weather conditions across this spatial scale.

Vessels classified as trailer boats (potentially trailer borne with an outboard) accounted for the majority of the vessels observed in all areas (80.3% in East Northland; 84.3% in the Hauraki Gulf; 86.5% in the Bay of Plenty) with the remainder mostly comprised of launches (15.5%, 11.1% and 10.7% respectively) and kayaks (2.1%, 2.5% and 1.3% respectively). The relative mix of vessel types in each area remained relatively constant regardless of day type and season and was very similar to that seen in 2004–05 (Hartill et al. 2007a) and 2011–12 (Hartill et al. 2013).

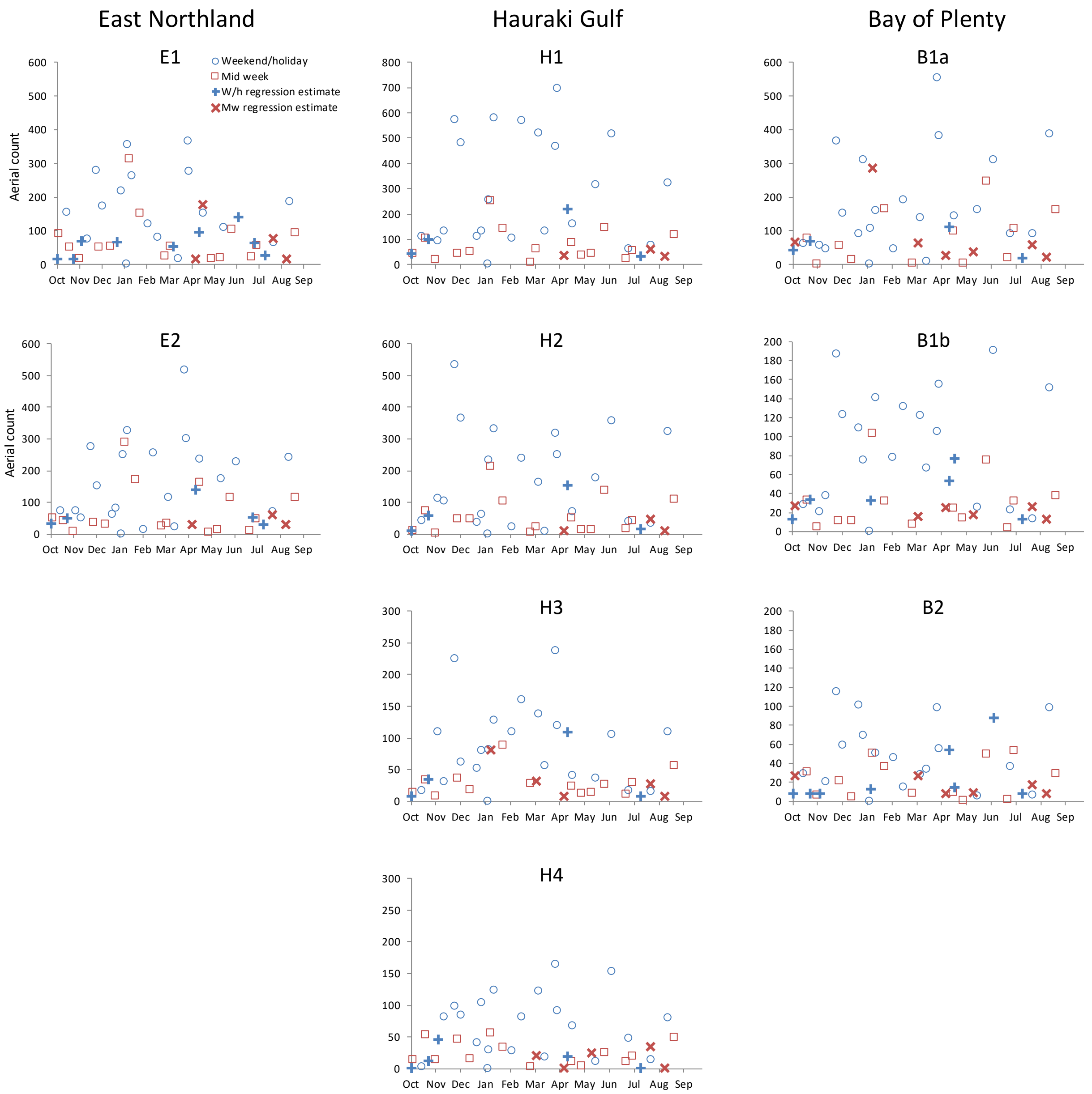


Figure 4: Daily counts of vessels fishing by analytical area, by day type. Observed counts on weekends and public holidays are denoted by open circles and mid-week counts are denoted by open squares. Flights were cancelled on some days due to low cloud, and the level of fishing effort on these days has been estimated via the regressions given in Figure 5. Regression based estimates for weekend/public holiday days are denoted as + and mid-week day estimates are denoted as ×. For a description of the spatial strata refer to Figure 3.

The incidence of flight cancelations during 2017–18 was higher than that experienced during previous aerial-access surveys for a variety of reasons. The summer of 2017–18 was the warmest on record, coinciding with more frequent warm northerly and north easterly winds than normal, consistent with La Niña conditions (Brandolino & Woolley 2018). All flying was cancelled on 7 of 47 scheduled survey days because of extreme weather, which was a slightly higher level of flight cancellation than that experienced during the 2011–12 aerial access survey (when La Niña conditions also prevailed). Some flights were also cancelled or curtailed on 13 other days. Rainfall across the upper North Island was above or well above normal in 2017–18, with low cloud in the far north and eastern Bay of Plenty resulting in a higher incidence of curtailed or cancelled flights in these areas than in previous years. Several flights were also cancelled due to problems with aircraft availability due to unrelated electrical faults and pilots being unwell. Fisher interview data collected by the concurrent boat ramp survey on days when flights were cancelled or curtailed suggest that fishing effort was usually relatively low at these times, but not always (Figure 4).

Flight counts for un-flown days were estimated from the relationship between aerial counts and the number of fishing parties (boats) interviewed during access point surveys who claimed that they had been fishing at the time of the flight on the same survey day. These regressions were used to predict the aerial boat count that would have been made when a flight was cancelled, given the interview data that was collected at surveyed boat ramps, regardless of the prevailing weather (Figure 5).

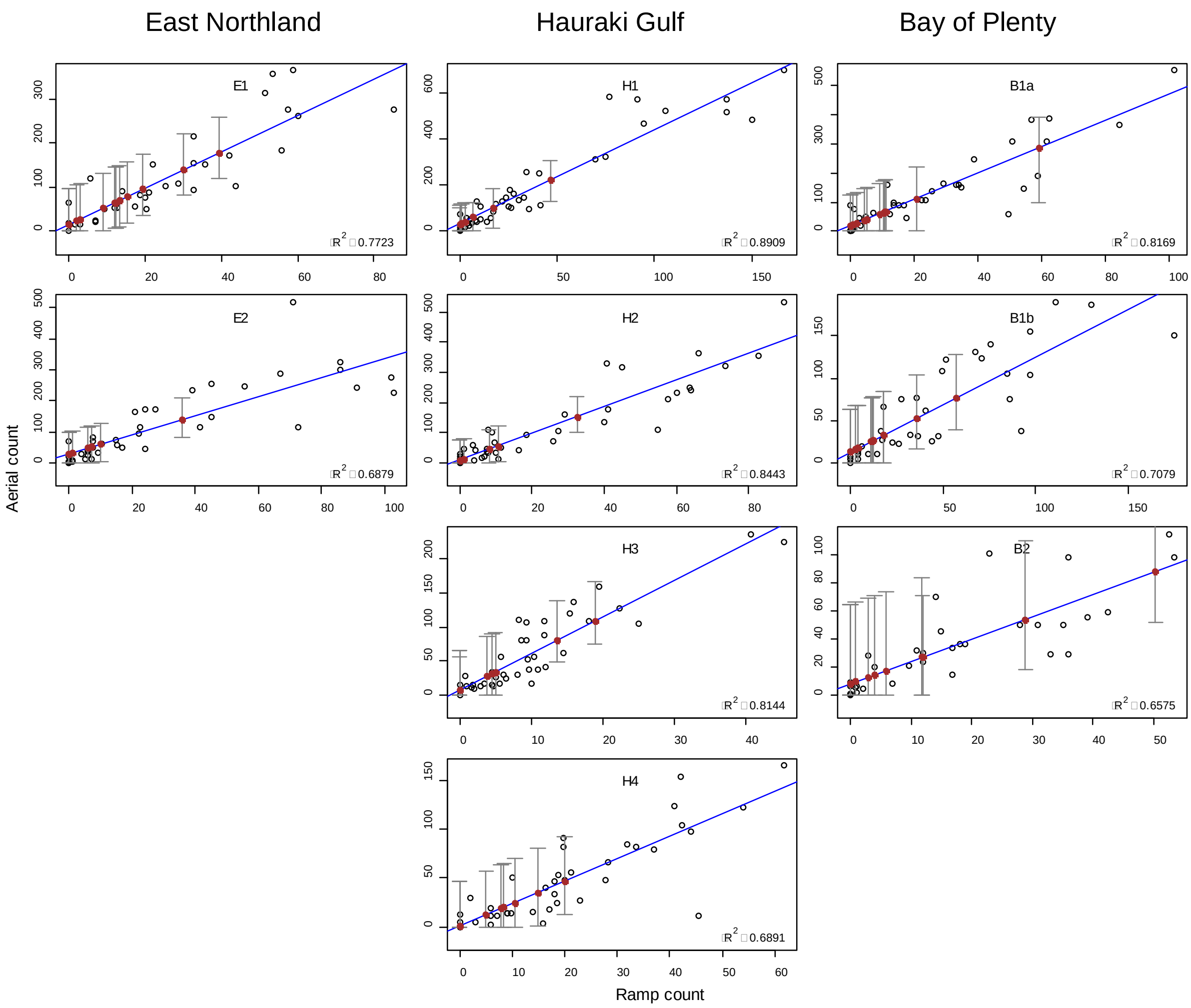


Figure 5: Regressions of aerial counts against counts of interviewed fishing parties (boats) that claimed to have been fishing at the time of the aerial survey, by analytical area. These regressions are used to estimate the number of boats that would have been seen from the air on those days when flights were cancelled and data were only available from concurrent access point surveys. Open circles denote observations on days when both the aerial and access point surveys took place and solid dots with 95% confidence intervals denote predictions of aerial counts for un-flown days. Confidence intervals for each prediction were based on bootstrapped resampling of the absolute residuals calculated for those days when both data sources were available and the number of interviewed fishers claiming to have fished at that time was less than or equal to that occurring on the busiest un-flown day.

These predictive relationships, between the data collected concurrently by the aerial and creel surveys on most scheduled survey days, were also used to predict the aerial counts for Friday the 27th of July 2018. By mistake, the creel survey occurred on this date although it had originally been scheduled for the following day, and, consequently, no concurrent aerial survey count was available. The sensitivity of the harvest estimates to the inclusion or exclusion of this additional unscheduled survey day was examined and had little influence on either the magnitude or the precision of the estimates obtained. The creel survey data collected on this additional day was ultimately used when producing the final harvest estimates, to better account for daily variability in fishing effort and harvest.

Although the confidence intervals associated with most of the regression-based estimates of fishing effort appear broad, the error associated with these predicted flight counts only contributed a very small fraction to the overall variance associated with harvest estimates. This is because the predicted level of effort for most un-flown days was low relative to the variability and level of effort observed on the more numerous fully surveyed days. These regressions suggest that only 10.6 % of the effort that took place on the 47 survey days occurred at times when aerial surveying was not possible.

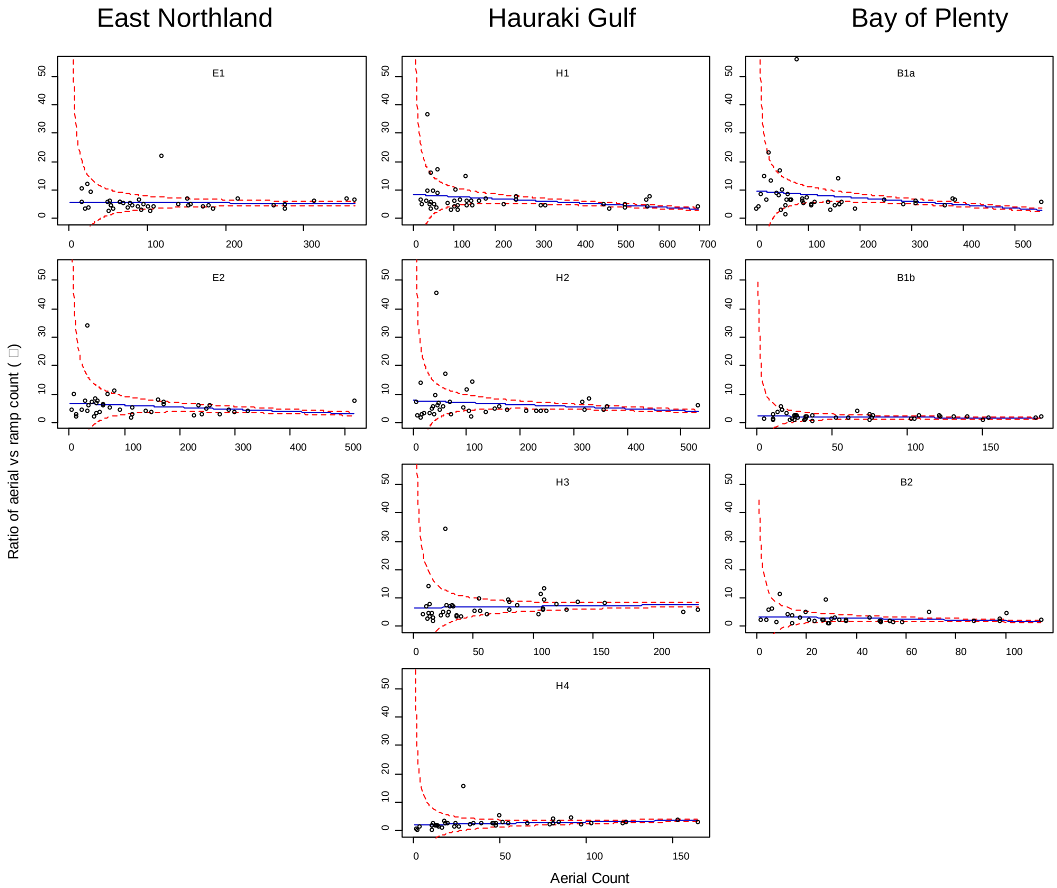


Figure 6: Estimates of the proportion of boats that returned to surveyed ramps on each survey day (ρ) by analytical area. These estimates are ratios of aerial counts relative to counts of fishing parties (boats) that claimed to have been fishing at the time of the aerial survey during access point interviews, which are regressed against each other in Figure 5. Dashed lines denote confidence intervals calculated by the delta method and assuming that the aerial count is measured without error. For a description of the spatial strata refer to Figure 3.

The ratio of aerial counts relative to counts of interviewed fishing parties (boats) that claimed to have been fishing at the time of the aerial survey (as plotted in Figure 5) provides an estimate of the proportion of boats fishing on each survey day that returned to surveyed ramps (Figure 6). In most areas approximately one boat in six returned to surveyed ramps, but a far higher proportion of fishers returned to surveyed ramps in the Firth of Thames (H4), and in the eastern Bay of Plenty (B1b and B2). Most of the effort in area H4 was observed in the extensive Wilson Bay mussel farm area, which will have originated from a large and adjacent boat ramp at Waikawau Bay. The proportion of boats using surveyed access points was often far more variable on days when low levels of effort were observed from the air.

<u>Access point survey</u>

The temporal survey design (see Table 1) for the creel survey was almost fully implemented with only a small number of interview sessions missed (Table 2). Interviewers were absent on a small number of occasions for a variety of reasons which were not related to levels of recreational fishing effort occurring at that time, such as illness. Interview sessions were intentionally cancelled on three days at Ohope because staff were transferred to the much busier Whakatane ramp nearby, when another staff member resigned at short notice. The small number of missed sessions had very little impact on the outcome of the survey as data were still available from other nearby ramps on the small number of affected days.

Table 2: Summary statistics for access point survey of recreational fishers returning to key ramps in East Northland, the Hauraki Gulf and the Bay of Plenty during the 2017–18 fishing year.

Region	Ramp	Hours worked	Days worked	Fishing boats interviewed	Non-fishing boats interviewed	Boat activity unknown	Fishers interviewed	SNA landed	KAH landed	GUR landed	TAR landed	TRE landed
East	Mangonui	573	47	674	347	113	1 542	1 886	552	56	133	56
Northland	Opito Bay	566	47	593	112	68	1 423	1 564	448	17	57	60
	Waitangi	554	46	870	333	198	2 126	2 210	702	24	56	186
	Tutukaka	574	47	598	203	147	1 441	739	293	5	62	113
	Parua (public)	572	47	473	161	170	1 175	1 257	257	34	8	77
	Parua (club)	578	47	511	156	160	1 160	2 035	346	83	107	143
	Total	3 417	47	3 719	1 312	856	8 867	9 691	2 598	219	423	635
Hauraki	Omaha	560	46	765	655	702	1 945	3 230	340	204	17	143
Gulf	Gulf Harbour	567	47	609	299	645	1 345	3 113	500	39	2	43
	Takapuna	547	46	617	463	293	1 517	3 241	665	64	1	52
	Westhaven	561	46	486	511	153	1 221	2 447	424	30	–	23
	Half Moon Bay	827	46	730	517	746	1 993	6 042	1 003	40	2	165
	Kawakawa (public)	537	45	503	135	166	1 261	3 162	774	63	–	28
	Waikawau	584	47	1 041	6	1 371	2 808	11 210	1 447	170	–	19
	Te Kouma	575	47	616	28	215	1 815	4 111	420	17	–	93
	Total	4 758	47	5 367	2 614	4 291	13 905	36 556	5 573	627	22	566
Bay of	Whitianga	573	47	594	418	526	1 431	1 675	621	49	59	176
Plenty	Whangamata	549	45	828	323	647	2 070	2 257	632	254	393	218
	Bowentown	569	47	780	106	62	1 996	2 756	764	99	244	337
	Sulphur Point	1 031	47	1 827	581	878	4 373	6 131	2 136	362	865	647
	Whakatane	574	47	676	229	582	1 670	4 293	1 228	603	795	98
	Ohope	520	44	320	182	102	784	1 456	507	206	156	184
	Total	3 815	47	5 025	1 839	2 797	12 324	18 568	5 888	1 573	2 512	1 660
FMA 1		11 990	47	14 111	5 765	7 944	35 096	64 815	14 059	2 419	2 957	2 861

Traffic rates at boat ramps in the Hauraki Gulf and western Bay of Plenty were generally higher than elsewhere (Table 2). Fewer boats returned to the normally high traffic boat ramp at Half Moon Bay in 2018 because a storm on the 5th of January caused extensive damage to all of the pontoon jetties, which were subsequently removed for the following 10 months, making this a less attractive access point for fishers to launch from.

Snapper was by far the most commonly landed species at all ramps, especially in the Hauraki Gulf, where the average number of snapper landed per boat was two to three times higher than in East Northland and the Bay of Plenty. The highest catch rates of kahawai, gurnard, tarakihi and trevally occurred in the Bay of Plenty.

Thousands of snapper and kahawai were measured, providing good descriptions of the length composition of landings of these species from all three regions of FMA 1 (Appendix 2). Large numbers of red gurnard, tarakihi and trevally were also measured in the Bay of Plenty, although these species were far less common in catches from East Northland and the Hauraki Gulf. There were regional differences in length compositions of all five species.

Harvest estimates

The estimated stationary boat-based harvest of snapper from SNA 1 during the 2017–18 fishing year was 3062 t (Table 3). Over 62% of this harvest was caught in the Hauraki Gulf, with 20% landed from East Northland and 18% taken from the Bay of Plenty. The harvest of snapper taken over the 7-month summer season accounted for about 70% of the harvest in all three regions.

The additional harvest taken by boat-based methods not directly assessed by the aerial-access method, such as longlining and trolling, was relatively modest as only a very small percentage of the catch landed at surveyed ramps was taken by these methods (1.0 to 6.1%). This additional source of harvesting increased the SNA 1 estimate of boat-based harvesting to 3118 t. The boat-based harvest estimates were reasonably precise, with CVs ranging from 0.05 to 0.23, depending on the scale of temporal and spatial resolution (Table 3).

The addition of regional estimates of the relative shore-based harvest derived from a concurrent national panel survey increases the 2017–18 aerial-access harvest estimate for SNA 1 by 11% to 3467 t (Table 3).

Table 3: Estimates of the recreational harvest of snapper taken from three regions of SNA 1 during the 2017–18 fishing year, during summer (1 October 2017 to 30 April 2018), winter (1 May 2018 to 30 September 2018) and for the full fishing year. Regional harvest estimates are also given by day type. Coefficients of variation associated with each estimate are given in brackets. Aerial-access method estimates are further adjusted to include the harvest taken by some forms of fishing which are not readily enumerated from the air (longlining, trolling and diving). Regional estimates of the relative percentage of the harvest taken by fishers using shore-based methods (whose harvest is not estimated by the aerial-access survey method) and adjustments for this harvest source are given in the last two columns of this table. These estimates of relative shore-based catch are derived from a concurrent national panel survey conducted by the National Research Bureau, which was not part of this study.

Region	Day type	Summer	Winter	2017–18	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	460 (0.12)	142 (0.14)	602 (0.10)	2.0%	615 (0.10)	14.6%	720 (0.10)
	Weekends/ Pubic holidays	245 (0.14)	66 (0.23)	311 (0.12)		318 (0.12)		
	Midweek days	215 (0.20)	76 (0.17)	291 (0.15)		297 (0.15)		
Hauraki Gulf	All days	1355 (0.08)	550 (0.13)	1905 (0.07)	1.0%	1923 (0.07)	7.0%	2068 (0.07)
	Weekends/ Pubic holidays	799 (0.08)	292 (0.18)	1091 (0.07)		1102 (0.08)		
	Midweek days	556 (0.15)	258 (0.18)	813 (0.12)		821 (0.12)		
Bay of Plenty	All days	326 (0.12)	219 (0.16)	545 (0.10)	6.1%	580 (0.10)	14.7%	680 (0.10)
	Weekends/ Pubic holidays	201 (0.14)	118 (0.23)	320 (0.12)		340 (0.12)		
	Midweek days	125 (0.23)	101 (0.22)	225 (0.16)		240 (0.16)		
SNA 1	All days	2141 (0.06)	911 (0.09)	3052 (0.05)		3118 (0.05)		3467 (0.05)
	Weekends/ Pubic holidays	1246 (0.06)	476 (0.12)	1722 (0.06)		1760 (0.06)		
	Midweek days	895 (0.11)	434 (0.12)	1330 (0.09)		1358 (0.09)		

The second most commonly caught species in all three regions was kahawai, with an estimated 919 t taken by boat-based fishers from KAH 1 during the 2017–18 fishing year (Table 4). Over half of this estimated catch was taken from the Hauraki Gulf. Most of the kahawai harvest was taken during the summer months. Trolling and, to a far lesser extent longlining, accounted for a further 3.0 to 10.2% of the regional boat-based kahawai catch, which was not directly assessable from the air. All harvests were estimated with reasonable precision.

The addition of regional estimates of the shore-based kahawai harvests derived from a concurrent national panel survey increases the 2017–18 aerial-access harvest estimate for KAH 1 by 33% to 1219 t (Table 4).

Table 4: Estimates of the recreational harvest of kahawai taken from three regions of KAH 1 during the 2017–18 fishing year, during summer (1 October 2017 to 30 April 2018), winter (1 May 2018 to 30 September 2018) and for the full fishing year. Regional harvest estimates are also given by day type. Coefficients of variation associated with each estimate are given in brackets. Aerial-access method estimates are further adjusted to include the harvest taken by some forms of fishing which are not readily enumerated from the air (longlining, trolling and diving). Regional estimates of the relative percentage of the harvest taken by fishers using shore-based methods (whose harvest is not estimated by the aerial-access survey method) and adjustments for this harvest source are given in the last two columns of this table. These estimates of relative shore-based catch are derived from a concurrent national panel survey conducted by the National Research Bureau, which was not part of this study.

Region	Day type	Summer	Winter	2017–18	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	144 (0.13)	32 (0.19)	176 (0.11)	10.2%	195 (0.11)	37.4%	312 (0.13)
	Weekends/ Pubic holidays	91 (0.16)	19 (0.30)	110 (0.14)		122 (0.14)		
	Midweek days	53 (0.23)	13 (0.21)	66 (0.19)		73 (0.19)		
Hauraki Gulf	All days	290 (0.10)	155 (0.15)	445 (0.08)	3.0%	458 (0.08)	11.4%	517 (0.09)
	Weekends/ Pubic holidays	201 (0.12)	96 (0.20)	297 (0.10)		307 (0.10)		
	Midweek days	89 (0.16)	59 (0.24)	147 (0.14)		152 (0.14)		
Bay of Plenty	All days	171 (0.14)	75 (0.17)	246 (0.11)	7.2%	265 (0.11)	31.9%	390 (0.11)
	Weekends/ Pubic holidays	107 (0.16)	37 (0.21)	144 (0.13)		155 (0.13)		
	Midweek days	65 (0.25)	38 (0.26)	102 (0.19)		110 (0.19)		
KAH 1	All days	605 (0.07)	262 (0.10)	866 (0.06)		919 (0.06)		1219 (0.06)
	Weekends/ Pubic holidays	399 (0.08)	152 (0.14)	551 (0.07)		584 (0.07)		
	Midweek days	206 (0.12)	110 (0.15)	315 (0.10)		335 (0.10)		

Harvest estimates for red gurnard relate to the east coast portion of the GUR 1 fish stock only, as no survey effort took place on the west coast of the North Island. The harvest of red gurnard was far lower than any of the other four species considered in this report, with only an estimated 28 tonnes landed throughout eastern GUR 1 during the 2017–18 fishing year by fishers using boat-based methods (Table 5). Almost half of this tonnage was taken from the Bay of Plenty during summer months. Longlining accounted for 2.6 to 8.9% of the boat-based harvest (Table 5). The lower precision associated with these estimates reflect the low incidence of red gurnard in recreational catches in most areas of eastern GUR 1.

The addition of regional estimates of the shore-based harvest derived from a concurrent national panel survey increases the 2017–18 aerial-access harvest estimate for the east coast of GUR 1 by 11% to 31 t.

Table 5: Estimates of the recreational harvest of red gurnard taken from three regions of the east coast of GUR 1 during the 2017–18 fishing year, during summer (1 October 2017 to 30 April 2018), winter (1 May 2018 to 30 September 2018) and for the full fishing year. Regional harvest estimates are also given by day type. Coefficients of variation associated with each estimate are given in brackets. Aerial-access method estimates are further adjusted to include the harvest taken by some forms of fishing which are not readily enumerated from the air (longlining, trolling and diving). Regional estimates of the relative percentage of the harvest taken by fishers using shore-based methods (whose harvest is not estimated by the aerial-access survey method) and adjustments for this harvest source are given in the last two columns of this table. These estimates of relative shore-based catch are derived from a concurrent national panel survey conducted by the National Research Bureau, which was not part of this study.

Region	Day type	Summer	Winter	2017–18	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	2 (0.27)	1 (0.28)	3 (0.21)	6.4%	3 (0.21)	8.8%	4 (0.22)
	Weekends/ Pubic holidays	1 (0.30)	1 (0.38)	1 (0.24)		1 (0.24)		
	Midweek days	1 (0.39)	0 (0.38)	2 (0.32)		2 (0.32)		
Hauraki Gulf	All days	4 (0.16)	5 (0.33)	9 (0.190)	2.4%	9 (0.19)	2.9%	9 (0.19)
	Weekends/ Pubic holidays	2 (0.20)	2 (0.22)	4 (0.15)		4 (0.15)		
	Midweek days	2 (0.26)	3 (0.53)	5 (0.33)		5 (0.33)		
Bay of Plenty	All days	6 (0.18)	8 (0.23)	14 (0.16)	9.8%	15 (0.16)	14.7%	18 (0.16)
	Weekends/ Pubic holidays	3 (0.24)	5 (0.30)	8 (0.21)		9 (0.21)		
	Midweek days	3 (0.30)	3 (0.31)	5 (0.22)		6 (0.22)		
GUR 1 (East) 1	All days	12 (0.12)	14 (0.18)	26 (0.11)		28 (0.11)		31 (0.11)
	Weekends/ Pubic holidays	6 (0.15)	8 (0.21)	14 (0.14)		15 (0.14)		
	Midweek days	6 (0.18)	6 (0.29)	12 (0.17)		13 (0.17)		

Harvest estimates for tarakihi relate to the east coast portion of the TAR 1 fish stock only, as no survey effort took place on the west coast of the North Island. The boat based harvest estimate for eastern TAR 1 for the 2017–18 fishing year was 45 t for boat-based fishing, of which 82% was landed from the Bay of Plenty (Table 6). The summer and winter harvest estimates for the Bay of Plenty region were similar; with higher catch rates during the winter were offset by lower fishing effort during these months. Almost no tarakihi were observed in Hauraki Gulf landings, with the few observed catches coming from deeper waters off the north western Gulf. Adjustments made for tarakihi caught by other boat-based methods which were not assessable from the air increased the harvest estimates by a very small degree for East Northland (0.7%) and the Bay of Plenty (1.8%), and this increase is solely attributable to longlining (Table 6).

The additional inclusion of regional estimates of the shore-based harvest derived from a concurrent national panel survey increases the 2017–18 aerial-access harvest estimate for the east coast of TAR 1 by less than 1 tonne, to a combined total of 46 t (Table 6).

Table 6: Estimates of the recreational harvest of tarakihi taken from three regions of the east coast of TAR 1 during the 2017–18 fishing year, during summer (1 October 2017 to 30 April 2018), winter (1 May 2018 to 30 September 2018) and for the full fishing year. Regional harvest estimates are also given by day type. Coefficients of variation associated with each estimate are given in brackets. Aerial-access method estimates are further adjusted to include the harvest taken by some forms of fishing which are not readily enumerated from the air (longlining, trolling and diving). Regional estimates of the relative percentage of the harvest taken by fishers using shore-based methods (whose harvest is not estimated by the aerial-access survey method) and adjustments for this harvest source are given in the last two columns of this table. These estimates of relative shore-based catch are derived from a concurrent national panel survey conducted by the National Research Bureau, which was not part of this study.

Region	Day type	Summer	Winter	2017–18	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	4 (0.43)	5 (0.41)	8 (0.31)	0.7%	8 (0.31)	0.0%	8 (0.31)
	Weekends/ Public holidays	2 (0.51)	2 (0.76)	4 (0.45)		4 (0.45)		
	Midweek days	2 (0.73)	3 (0.45)	4 (0.40)		4 (0.40)		
Hauraki Gulf	All days	0.1 (0.91)	0.1 (0.87)	0.1 (0.64)	0.0%	0.1 (0.64)	0.0%	0.1 (0.64)
	Weekends/ Public holidays	0.1 (0.91)	0.1 (0.87)	0.1 (0.64)		0.1 (0.64)		
	Midweek days	–	–	–		–		
Bay of Plenty	All days	20 (0.18)	16 (0.24)	36 (0.15)	1.8%	37 (0.15)	2.0%	37 (0.15)
	Weekends/ Public holidays	10 (0.26)	7 (0.32)	17 (0.20)		17 (0.20)		
	Midweek days	10 (0.26)	9 (0.35)	19 (0.22)		19 (0.22)		
TAR 1 (East)	All days	24 (0.17)	21 (0.21)	44 (0.13)		45 (0.13)		46 (0.13)
	Weekends/ Public holidays	12 (0.23)	9 (0.30)	21 (0.19)		21 (0.19)		
	Midweek days	12 (0.25)	11 (0.28)	23 (0.19)		24 (0.19)		

Although recreational harvest estimates for TRE 1 were not a specified requirement for this project, they are provided here as trevally was the third most commonly landed species by recreational fishers in FMA 1. A large proportion of the TRE 1 harvest was taken from the Bay of Plenty (50%), but relatively substantial tonnages were also taken from the Hauraki Gulf (20%) and from East Northland (30%). Almost all of the trevally harvest was taken during the summer. Only a small proportion of the trevally catch in each region was taken by longlining and trolling (3.3% to 10.2%) (Table 7).

The addition of regional estimates of the shore-based harvest derived from a concurrent national panel survey increases the 2017–18 aerial-access harvest estimate for TRE 1 by 18% overall, to 145 t (Table 7).

Table 7: Estimates of the recreational harvest of trevally taken from three regions of TRE 1 during the 2017–18 fishing year, during summer (1 October 2017 to 30 April 2018), winter (1 May 2018 to 30 September 2018) and for the full fishing year. Regional harvest estimates are also given by day type. Coefficients of variation associated with each estimate are given in brackets. Aerial-access method estimates are further adjusted to include the harvest taken by some forms of fishing which are not readily enumerated from the air (longlining, trolling and diving). Regional estimates of the relative percentage of the harvest taken by fishers using shore-based methods (whose harvest is not estimated by the aerial-access survey method) and adjustments for this harvest source are given in the last two columns of this table. These estimates of relative shore-based catch are derived from a concurrent national panel survey conducted by the National Research Bureau, which was not part of this study.

Region	Day type	Summer	Winter	2017–18	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	29 (0.16)	5 (0.18)	34 (0.14)	10.2%	38 (0.14)	20.6%	47 (0.15)
	Weekends/ Pubic holidays	16 (0.17)	3 (0.25)	19 (0.15)		21 (0.15)		
	Midweek days	13 (0.30)	2 (0.28)	15 (0.26)		16 (0.26)		
Hauraki Gulf	All days	16 (0.14)	8 (0.26)	24 (0.13)	4.8%	25 (0.13)	1.9%	25 (0.13)
	Weekends/ Pubic holidays	12 (0.15)	5 (0.35)	17 (0.15)		17 (0.15)		
	Midweek days	4 (0.33)	3 (0.37)	7 (0.25)		7 (0.25)		
Bay of Plenty	All days	43 (0.15)	15 (0.28)	58 (0.14)	3.3%	60 (0.14)	16.7%	72 (0.14)
	Weekends/ Pubic holidays	27 (0.16)	8 (0.31)	35 (0.15)		36 (0.15)		
	Midweek days	16 (0.29)	8 (0.46)	23 (0.25)		24 (0.25)		
TRE 1	All days	88 (0.10)	28 (0.17)	116 (0.09)		123 (0.09)		145 (0.09)
	Weekends/ Pubic holidays	55 (0.10)	16 (0.19)	71 (0.09)		75 (0.09)		
	Midweek days	33 (0.19)	12 (0.30)	45 (0.16)		48 (0.16)		

Comparison of harvest estimates from the 2004–05, 2011–12 and 2017–18 aerial-access surveys.

The methods used to estimate recreational harvests in 2017–18 were closely based on those used to estimate recreational harvests in all three regions of FMA 1 in 2004–05 (Hartill et al. 2007a) and 2011–12 (Hartill et al. 2013). A comparison of estimates of total recreational harvest of snapper, kahawai, red gurnard, tarakihi and trevally provided by these three surveys is given in Table 8.

Table 8: Comparision of estimates of the total recreational harvest of snapper, kahawai, red gurnard, tarakihi and trevally provided by aerial-access surveys in 2004–05 (Hartill et al. 2007a), 2011–12 (Hartill et al. 2013) and 2017–18. Numbers in brackets denote CVs

Species	Fishery	2004–05	2011–12	2017–18
Snapper	East Northland	557 (0.13)	718 (0.14)	720 (0.10)
	Hauraki Gulf	1345 (0.10)	2490 (0.08)	2068 (0.07)
	Bay of Plenty	517 (0.10)	546 (0.12)	680 (0.10)
	SNA 1	2419 (0.06)	3754 (0.06)	3467 (0.05)
Kahawai	East Northland	129 (0.14)	191 (0.16)	312 (0.13)
	Hauraki Gulf	98 (0.18)	483 (0.13)	517 (0.09)
	Bay of Plenty	303 (0.14)	268 (0.12)	390 (0.11)
	KAH 1	530 (0.09)	942 (0.08)	1219 (0.06)
Red gurnard	GUR 1	127 (0.14)	24 (0.09)	31 (0.11)
Tarakihi	TAR 1	90 (0.18)	67 (0.15)	46 (0.13)
Trevally	TRE 1	105 (0.18)	124 (0.12)	145 (0.09)

Almost all of the difference between the SNA 1 harvest estimates for the three survey years stems from the Hauraki Gulf, where the 2011–12 estimate is 85% higher than the previous 2004–05 estimate and 20% higher than the 2017–18 estimate. Kahawai estimates have increased in all areas, although more so in the Hauraki Gulf.

4. DISCUSSION

The incidence of cancelled flights during the 2017–18 aerial-access survey was slightly higher than that experienced during the 2004–05 and 2011–12 surveys for a variety of reasons, including a higher incidence of low cloud in the far north and eastern Bay of Plenty, and a lower rate of aircraft serviceability. The scheduling of both the aerial and the access point surveys on the same sample of days does, however, provide an informed means of estimating what aerial counts would have been on weather affected days. Aerial counts predicted from area specific regressions suggest that only 10.6% of the fishing effort that took place across all 47 scheduled survey days occurred on days when flights were cancelled. Any additional uncertainty associated with these predictions will therefore have little impact on overall variance estimates, given the low level of fishing effort that usually occurred on those occasions when flights were cancelled.

Although all of the stockwide and most of the regional and seasonal harvest tonnages presented here have been estimated with reasonable precision, independent corroboration is required to verify their likely accuracy. The potential accuracy of the aerial-access survey method used in this study was assessed in 2011–12, based on parallel estimates provided by two other independent surveys: a national panel survey (Wynne-Jones et al. 2014); and a smaller scale creel census survey of almost all of the access points in the western Bay of Plenty (Holdsworth 2016). For most of the fisheries for which two or more harvest estimates were available from alternative surveys in 2011–12, pairwise comparisons of both stock wide and seasonal harvest estimates were statistically similar.

Detailed investigative analyses of both spatially and temporally disaggregated harvest estimates were undertaken in an attempt to detect likely causes for any differences between harvest estimates (Edwards & Hartill 2015). These analyses suggested that survey methods that are based on a temporal sampling frame, such as the aerial-access approach used for this survey, can by chance produce positively or negatively biased estimates if the randomised preselection of survey days is non-representative with respect to daily levels of fishing effort. Although the extent of this source of bias was relatively low when seasonal and day-type harvest estimates from the 2011–12 aerial-access survey were combined to produce annual estimates, the representativeness of the days surveyed as part of this survey has yet to be assessed. A similar comparison of harvest estimates provided by the 2017–18 aerial-access survey and those provided by a concurrent national panel survey conducted by the National Research Bureau (MAF2016/01 - national panel survey of marine recreational fishers 2017–18) will be undertaken in the near future as part of another study commissioned by MPI (MAF2018/01 - Analysis and interpretation of national panel survey results). A preliminary comparison of initial harvest estimates produced from the two 2017–18 surveys already suggests, however, that both survey approaches have produced estimates of similar magnitude and are therefore probably sufficiently accurate for fisheries management purposes (unpublished analyses presented to Marine Amateur Fisheries Working Group).

Other sources of potential bias associated with the aerial-access approach were described and discussed by Hartill et al. (2013) but none of these is thought to have been significant in 2017–18.

The survey and analytical methods used to generate harvest estimates for the five species most commonly caught by recreational fishers in FMA 1 in 2017–18 were very similar to those used for the 2004–05 and 2011–12 aerial access surveys, and some inference can therefore be made about changing levels of recreational harvesting over the past thirteen years.

The recreational SNA 1 harvest estimate for 2011–12 (3754 t) was almost 65% higher than that estimated in 2004–05 (2419 t), and higher than the 2600 t combined annual non-commercial catch allowance (recreational and customary) for this stock at that time. The subsequent inclusion of a revised recreational catch history in a 2014 assessment of the SNA 1 stock (Francis & McKenzie 2015a, 2015b) and concerns about the apparent increasing trend in recreational harvesting at that time (as of 1 October 2013) led to: an increase in the minimum legal size limit for recreational fishers from 27 cm to 30 cm; a decrease in the daily bag limit from 9 to 7 fish per fisher; and an increase in non-commercial annual catch allowances to 3000 t for recreational fishers and 50 t for customary fishers. The catch estimate from this survey (3467 t) is approximately 10% less than the 2011–12 estimate, which will be, in some part, due to the 2013 increase in the minimum size limit and decrease in the daily bag limit, although the estimate for 2017–18 is higher than the current 3000 t annual recreational allowance for SNA 1.

The increase in recreational landings from KAH 1 over the past decade, indicated by the aerial-access estimates provided by the 2004–05 (530 t), 2011–12 (942 t) and 2017–18 (1219 t) surveys, is consistent with data provided by an ongoing recreational kahawai catch-at-age sampling programme (Armiger et al. 2014), the most recent stock assessment (Hartill & Bian 2016), and anecdotal reports by fishers. Most of this increase has occurred in the Hauraki Gulf, where recreational kahawai landings between 2001 and 2007 were mostly of small 3 and 4 year old fish, with a subsequent steady increase in the size of fish landed following an influx of much older and larger fish during the summer of 2007–08.

Conversely, the estimated catch of 31 t of red gurnard in 2017–18 was similar to that in 2011–12 following an apparently substantial decline in recreational landings from the east coast of GUR 1 from 127 t in 2004–05. There was a similar decline in eastern GUR 1 standardised commercial trawl catch rates during the early 2000s, which have remained relatively steady since the mid-2000s (Kendrick & Bentley in prep). The decline in the recreational harvest from TAR 1 reported here is also not surprising given the most recent commercial CPUE standardisation analysis (Langley 2017) and the results of the most recent stock assessment, which suggest that there has been a general decline in the spawning biomass since the late 1980s (Langley 2018). The aerial-access estimates for TRE 1 (105 t, 124 t and 145 t) were broadly similar given their associated estimates of uncertainty, although the recreational harvest taken from this stock may be increasing.

Any interpretation of trends from the point estimates, such as those described above should however, be treated with some caution, as recreational harvests can vary considerably from year to year (and consequently during the years between surveys) due to prevailing and varying climatic conditions that influence both the level of recreational fishing effort taking place, and the movements of fish that will determine their availability to recreational fishers predominately fishing in shallower waters. A more nuanced understanding of relative trends in recreational harvesting is available from an ongoing digital camera/creel monitoring programme, which is another component of Fisheries New Zealand's recreational harvest monitoring system.

NIWA has used digital cameras to monitor the number of trailer boats returning to high traffic boat ramps in FMA 1 since 2004–05, and has conducted regular creel surveys of fishers returning to these ramps since 2011–12 (and intermittently before then such as in 2004–05) to estimate the annual proportion of observed boats that have been used for fishing, and to estimate the average weight of commonly caught species landed by these vessel (Hartill et al. 2016). These indices of effort and catch per boat trip can be combined to give an estimate of the weight of fish landed at each ramp each year. The relative difference between the weight of fish landed annually at Takapuna and Half Moon Bay in 2004–05 and in 2011–12 is very similar to the relative difference between the aerial-access estimates for these two years for the entire Hauraki Gulf. This similarity suggests that the continuous annual camera/creel survey monitoring at indicator ramps provides a meaningful measure of relative changes in recreational harvesting that is more continual and informative than that provided by aerial-access and national panel surveys that are currently conducted every 6 to 7 years.

These camera/creel survey-based indices suggest that, for snapper and kahawai at least, the tonnage of fish landed in the Hauraki Gulf during the years between the 2011–12 and 2017–18 aerial-access and national panel survey years was much lower than during survey years. Both the number of boats returning annually to Takapuna and Half Moon Bay and catch rates of commonly caught fish were lower in the Gulf during these intervening years. These two factors may be related, as fishers are less likely to go fishing when anecdotal reports suggest that the fishing is poor. The summer of 2017–18 was the warmest on record (Brandolino & Woolley 2018), resulting in anomalously warm sea surface temperatures in the Tasman Sea, coinciding with increased snapper and kahawai catch rates in the Hauraki Gulf. Approximately half of all the recreational fishing effort in FMA 1 occurs in the shallower embayed waters of the Hauraki Gulf, where the influence of interannual variability in sea surface temperatures is more likely to manifest itself on the localised influx of fish during summer months. It is interesting to note that that both the 2011–12 and 2017–18 survey years coincided with La Niña conditions, which tend to produce more north easterly winds and higher sea surface temperatures. The El Niño 2004–05 survey year, however, coincided with a period of lower sea surface temperatures in the Gulf, which may have suppressed catch rates.

In summary, although the harvest estimates provided by aerial-access surveys, such as that described here and, alternatively, by the national panel survey, give a good indication of the catch landed by recreational fishers at the time that these surveys are conducted, other sources of information are also required for fisheries managers to take the variable nature of recreational landings into account to ensure the sustainable and equitable use of the fishery over the long term. Levels of recreational harvesting for a period of several years or more should not, therefore, be inferred uncritically from harvest estimates provided by a single 12 month survey, such as that described here.

5. CONCLUSIONS

The key conclusions of this research are:

- Recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally are available from an aerial-access survey conducted throughout FMA 1 during the 2017–18 fishing year. An aerial survey and an access point survey were used to estimate harvests taken by the recreational fishery on 47 days randomly preselected according to a stratified temporal design, following methods used for similar surveys of the FMA 1 fishery in 2004–05 and 2011–12.
- The aerial-access approach provides estimates of the harvest taken from stationary boat fishing methods only, which accounts for the majority of the recreational harvest from the fisheries of interest. Harvests taken by unassessed methods that cannot be directly assessed from the air, such as longlining, netting, trolling, diving and shore-based fishing, were estimated indirectly from concurrent creel survey data on the relative catch by these methods.
- The aerial-access survey harvest estimate for SNA 1 for the 2017–18 fishing year is 3015 t, which increased to 3467 t once the harvest taken by other fishing methods was taken into account.
- Two thirds of the estimated recreational harvest for SNA 1 was taken from the Hauraki Gulf (2080 t) where over half of the fishing effort in FMA 1 occurs.
- The harvest estimate for KAH 1 for 2017–18 is 866 t which increases to 1219 t once the harvest from other indirectly assessed boat and shore methods is taken into account.
- Just over half of the estimated recreational harvest from KAH 1 was taken from the Hauraki Gulf (517 t), where catch rates have increased over the past decade following an influx of schools of large kahawai during the mid to late 2000s.
- The GUR 1 QMA falls on both the east and west coasts of the upper North Island and a harvest estimate is only available for eastern GUR 1 from this study as no data were collected from the west coast fishery. The estimated harvest taken by all forms of recreational fishing from eastern GUR 1 was estimated to be 31 t, of which 18 t was taken from the Bay of Plenty.
- The estimated harvest of tarakihi taken by all forms of recreational fishing from the eastern portion of TAR 1 is 46 t, of which an estimated 37 t was taken from the Bay of Plenty. Almost all of the remaining recreational harvest taken from TAR 1was landed from East Northland waters.
- Trevally were landed throughout TRE 1, where an estimated total of 145 t was harvested by recreational fishers.
- The harvest estimates provided by this and similar aerial-access surveys of the FMA 1 recreational fishery in 2004–05 and 2011–12 should only be used as point in time estimates, as ramp specific annual landing indices provided by an ongoing camera/creel survey based monitoring programme suggest that the recreational harvest can vary considerably from year to year. The point in time absolute harvest estimates provided by the aerial-access surveys (and concurrent national panel surveys) should be used in conjunction with the continual but relative ramp specific camera/creel harvest indices, to better understand and manage the recreational fishery in this area.
- As in 2011–12, a national panel survey has been conducted concurrently alongside the aerial-access survey described in this report, and preliminary harvest estimates provided by this independent study are once again of a broadly similar magnitude. This suggests that the harvest estimates given here are both plausible and reasonably accurate given the levels of error associated with all available estimates.
- A more detailed and through comparison of the harvest estimates provided by both of these surveys will be undertaken as part of a separate programme – MAF2018/01 - Analysis and interpretation of national panel survey results.

6. ACKNOWLEDGMENTS

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APPENDIX 1: Analytical methods

The analytical approach used to calculate a harvest estimate for each survey day, and to weight these estimates together to generate an annual harvest estimate, can be broken down into six steps.

1. Generating a diurnal profile of boat fishing effort from census data collected at a subset of access points on each survey day.
2. Using an aerial count of all fishing vessels, and a concurrent value derived from the profile of boat effort generated in step 1, to calculate a ratio that can be used to scale up the catch landed at surveyed access points on each survey day.
3. Generating a diurnal profile of the harvest landed at censused access points on each survey day.
4. Using the ratio calculated in step 2, to scale up a harvest estimate calculated from the profile generated in step 3, to account for that landed by all fishers returning to all access points on each survey day.
5. Generating season/day-type stratum harvest estimates from the daily harvest estimates calculated in step 4.
6. Implementing steps 1 to 5 in a nonparametric bootstrapping procedure, to generate associated variance estimates.

Descriptions of these six steps follow:

1) Diurnal profiling of boat effort

A diurnal profile is constructed by dividing a 24-hour period up into K time bins of equal length (e.g., 96 15-minute time bins) and summing the number of times an event has occurred in each time bin, k.

Profiles of effort are generated for each survey day, from the imputed time series of interviews conducted at each access point. From the outset, effort is considered at two levels; at the level of a group of fishers who fished from a boat (collectively termed boat effort) and at the individual fisher level (termed fisher effort). The number of interviewed boats fishing at any given time of day (a boat effort profile) is generated by combining data from all boats observed by the interviewers.

A value of 1.0 is assigned for boat i, to all time bins, starting at k_s^i, the time bin in which fishing started, and ending in at k_e^i, the last time bin when fishing occurred.

$$b_i(k) = \begin{cases} 0, k < k_s^i \\ 1, k_s^i \le k \le k_e^i \\ 0, k > k_e^i \end{cases} . \qquad (1)$$

If fishing occurred in two or more areas during a trip, or if a fisher switched to another fishing method, then the effort associated with the different areas and methods is considered separately.

Values from individual boats are then combined,

$$b(k) = \sum_{i=1}^{v} b_i(k) , \qquad (2)$$

where v is the number of fishing boats interviewed and $b(k)$ is the number of censused boats that were fishing at time k. These estimates can then be considered in series, to profile changes in levels of boat effort throughout the day.

2) Calculating a ratio to scale up the catch landed at surveyed access points

The number of censused boats fishing, *b(k),* is based on a subsample of all boats fishing on day *d*, as only a subsample of access points was surveyed, yet many fishers would have returned to unsurveyed access points, and their catch and effort must be considered. Aerial counts of fishing vessels provide a means of scaling our subsample up to account for all effort (and catch) taking place on each survey day.

If the aerial count of boats fishing at the time of the flight, k_f, is $c_d(k_f)$, the ratio we use to scale up our subsample to account for all fishing effort and catch on day *d* is ρ_d.

$$\rho_d = \frac{c_d(k_f)}{b(k_f)}. \qquad (3)$$

3) Estimating the harvest landed at surveyed access points

If *J* fishers were on boat *i* and the *j*th fisher's non-fishing time was Δk^{ij} time units and they caught m^{ij} fish with total weight of w^{ij}, then in a similar fashion to the boat effort, we can distribute a fisher's harvest across *K* time units as

$$h_{ij}(k) = \begin{cases} 0, k < k_s^{ij} \\ \dfrac{h_{ij}(k_s^{ij}, k_e^{ij})}{k_e^{ij} - k_s^{ij}}, k_s^{ji} \le k \le k_e^{ij} \\ 0, k > k_e^{ij} \end{cases}. \qquad (4)$$

These quantities of harvest for individual fishers can be combined at the boat level by summing the harvest quantities of co-fishers in each time bin,

$$h_i(k) = \sum_{j=1}^{J} h_{ij}(k), \qquad (5)$$

where $h_{ij}(k_s^{ij}, k_e^{ij})$ is the harvest of the *j*th fisher on the *i*th boat between time units k_s^{ij} and k_e^{ij} which can either be considered as the *j*th fisher's total number of fish caught m^{ij}, or total biomass of fish caught w^{ij}.

The total number or weight of fish landed at surveyed access points can be calculated for each time bin, *k*, by

$$\tilde{h}(k) = \sum_{i=1}^{v} h_i(k), \qquad (6)$$

for a given survey day. Values calculated for each time bin, *k*, can then be considered in series, to profile changes in harvest levels throughout the day.

4) Scaling up the harvest landed at surveyed access points to account for that landed at all access points

Because $\tilde{h}_d$ is derived from interviews conducted at a subsample of access points, it is necessary to scale this estimate to account for all fishers, including those returning to unsurveyed access points. The scalar used is ρ_d (see Equation 3), which is based on an aerial count of boats made on the same day.

$$h_d(k) = \tilde{h}_d(k) \cdot \rho_d = \sum_{i=1}^{m} \left(h_{di}(k) \cdot \rho_d \right) = \sum_{i=1}^{m} \left(h_{di}(k) \cdot \frac{c_d(k_f)}{b_d(k_f)} \right). \quad (7)$$

An estimate of the total number (or weight) of fish harvested on a given survey day is calculated by summing up the estimated harvest derived for each time bin on that day.

$$h_d = \sum_{k=1}^{K} h(k) = \sum_{k=1}^{K} \tilde{h}(k) \cdot \rho_d \ . \quad (8)$$

5) Calculating harvest estimates for temporal strata

As we adopted a random stratified design to reduce variance, separate estimates are required for each temporal stratum. Daily estimates of harvest are therefore averaged within their respective strata, where n_t is the number of days n surveyed within each stratum t.

$$\hat{h}_d = \frac{1}{n_t} \cdot \sum_{d=1}^{n_t} h_d \ . \quad (9)$$

Average daily harvest estimates are then multiplied by the number of days occurring within each temporal stratum, N_t, to produce harvest estimates for each temporal stratum.

$$\hat{H}_t = N_t \cdot \hat{h}_d = \frac{N_t}{n_t} \cdot \sum_{d=1}^{n_t} h_d \ , \quad (10)$$

which can be combined to provide seasonal and annual harvest estimates for a given area.

6) Estimating uncertainty

Stratum specific estimates of uncertainty are generated by a nonparametric bootstrapping procedure (which was implemented in C++). Data collected from each seasonal/day-type/area stratum are bootstrapped according to a two-stage process.

The first stage is a modification of the conventional bootstrap that accounts for the fact that the days that were surveyed were selected from a finite set of potential days in each temporal stratum (see Table 1). This bootstrap method for finite populations was independently suggested by Bickel & Freedman (1984) and Chao & Lo (1985), and is reviewed by Booth et al. (1994).

Let N_t be the number of potential days in stratum t, and $n_{rep,t}$ be the integer part of N_t/n_t, where n_t is the number of days that were surveyed in that stratum. First construct a set of N_t potential days by taking n_{rep} replicates of the n_t days that were surveyed and adding $N_t - n_{rep}n_t$ days selected at random, without replacement, from the n_t days. Next randomly select n_t days from this finite bootstrap set of N_t potential days, without replacement. It is important to note that the set of potential days constructed in this first stage is reconstructed for each subsequent bootstrap.

At the second stage, interview data collected on each of the n_t days selected in the first stage are sampled at random with replacement, where the number of interviews selected is determined by the number of boats actually interviewed on that day. Data from each bootstrap data set are then used to calculate a daily harvest weight given the methods described in steps 1 to 8, and the harvest weights for all days within stratum t are used to generate a harvest estimate for that stratum, as described in steps 9 and 10.

This two-stage process is performed 1000 times, and the mean, median, 5% and 95% percentiles of these bootstraps is calculated for each stratum.

A more parsimonious approach?

The analytical approach described here combines aerial count data with diurnal profiles of boat effort and harvest, to estimate the harvest on a survey day, but it is not strictly necessary to generate either of these profiles.

The boat effort profile is required to estimate the number of censused boats which were fishing at the time of the overflight. A potentially simpler alternative to generating a daily profile of boat effort would be to ask fishing parties if they had fished at the time of the overflight. This is a leading question, however, which could introduce bias. Further, the timing of the overflight will vary daily, to some degree, and any question based on a standardized time may lead to further error.

Alternatively, information collected on the times at which fishing started and finished could be used *a posteriori* to determine which boats were fishing at the time of the overflight. This approach does not necessarily require a profile of fishing effort, but profile generation requires little extra effort given the steps already required. The generation of an effort profile is informative, as it can be used to assess whether the flight count was taken at around the time of peak fishing effort, which is desirable.

Diurnal profiling of the landed catch is also not strictly necessary, as the area under a harvest weight profile is simply the total weight of all fish landed at the censused access points during the period surveyed. Some form of imputation is still required, however, to account those parties that returned to surveyed access points on survey days, who were not intercepted by an interviewer.

Ancillary estimates

The methods described above outline the approach used to generate diurnal profiles of boat effort, and harvest, and from these profiles, the total harvest. These calculations can be easily adapted to provide a diurnal profile of fisher effort, which can then be combined with a corresponding profile of harvest, to provide a diurnal profile of harvest rate.

In a similar manner to Equation 1, a fisher's effort, e, is distributed in K time bins.

$$e_{ij}(k) = \begin{cases} 0, k < k_s^{ij} \\ \dfrac{k_e^{ij} - k_s^{ij} - \Delta k^{ij}}{k_e^{ij} - k_s^{ij}}, k_s^{ij} \le k \le k_e^{ij} \\ 0, k > k_e^{ij} \end{cases} . \qquad (11)$$

Individual fisher effort can be combined at the boat level by summing the effort of co-fishers in each time bin.

$$e_i(k) = \sum_{j=1}^{J} e_{ij}(k). \tag{12}$$

The level of effort expended by all boats can be calculated for each time bin by summing across all boats.

$$\tilde{e}(k) = \sum_{i=1}^{v} e_i(k). \tag{13}$$

The values calculated for each time bin, *k*, can then be considered in series, to produce diurnal profiles of effort, at the boat, or alternatively, fisher level.

An estimate of the total number of hours fished in a given time bin is the product of the number of hours fished in that time bin and the same aerial count based scalar used previously to account for fishers returning to unsurveyed access points (see Equation 3).

$$e_d(k) = \tilde{e}_d(k) \cdot \rho_d = \sum_{i=1}^{m} \left(e_{di}(k) \cdot \rho_d \right) = \sum_{i=1}^{m} \left(e_{di}(k) \cdot \frac{c_d(k_f)}{b_d(k_f)} \right). \tag{14}$$

These estimates of the total number of hours fished in each time bin can then be summed for the day, to produce an estimate of the total number of hours fished on that day,

$$e_d = \sum_{k=1}^{K} e(k) = \sum_{k=1}^{K} \tilde{e}(k) \cdot \rho_d , \tag{15}$$

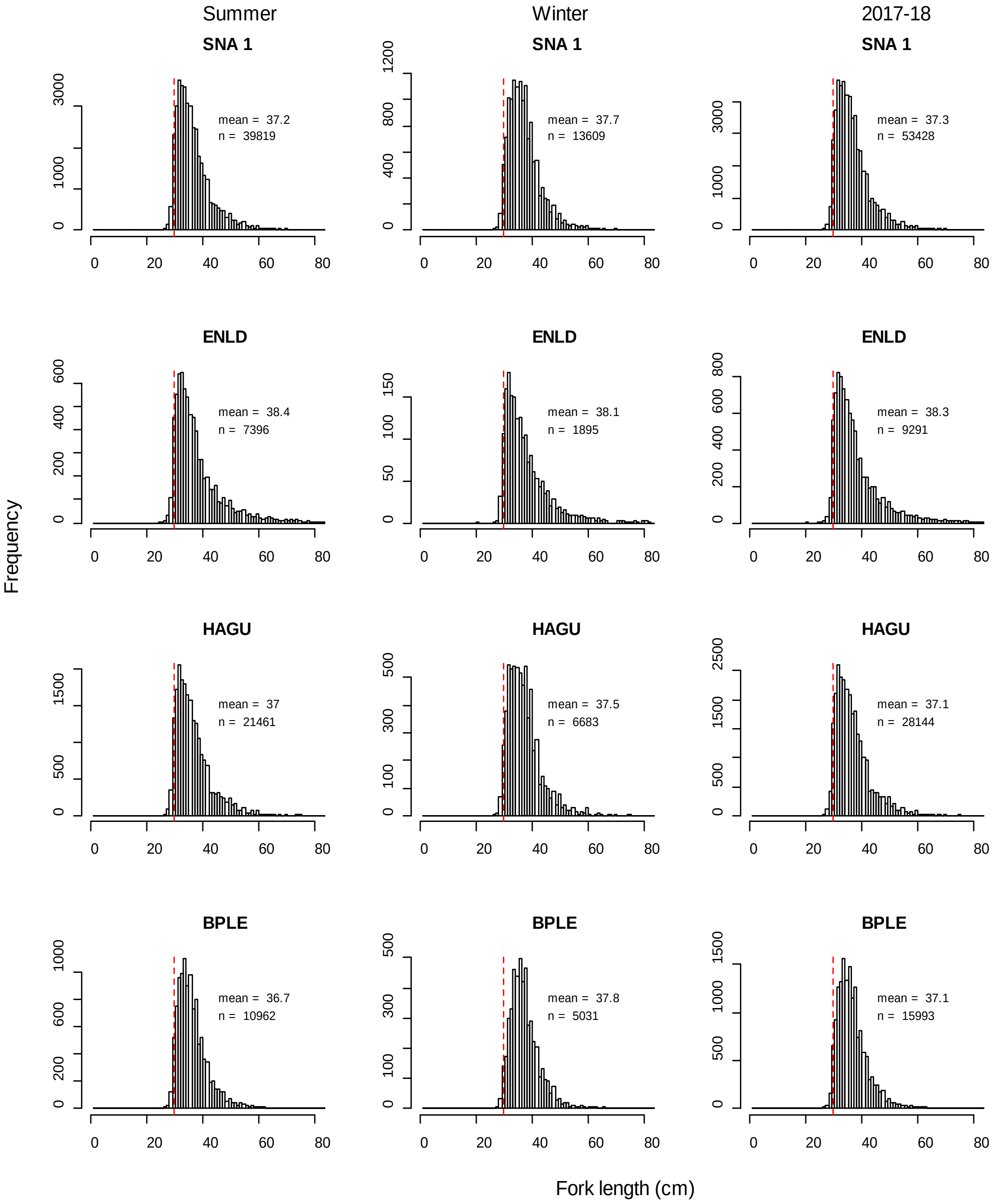
which are averaged to produce an estimate of the average daily level of fishing effort in a given stratum.

$$\hat{e}_d = \frac{1}{n_t} \cdot \sum_{d=1}^{n_t} e_d . \tag{16}$$

To generate a diurnal profile of harvest rates, it is simply a matter of dividing the values from a harvest profile by the values in the corresponding fisher effort profile.

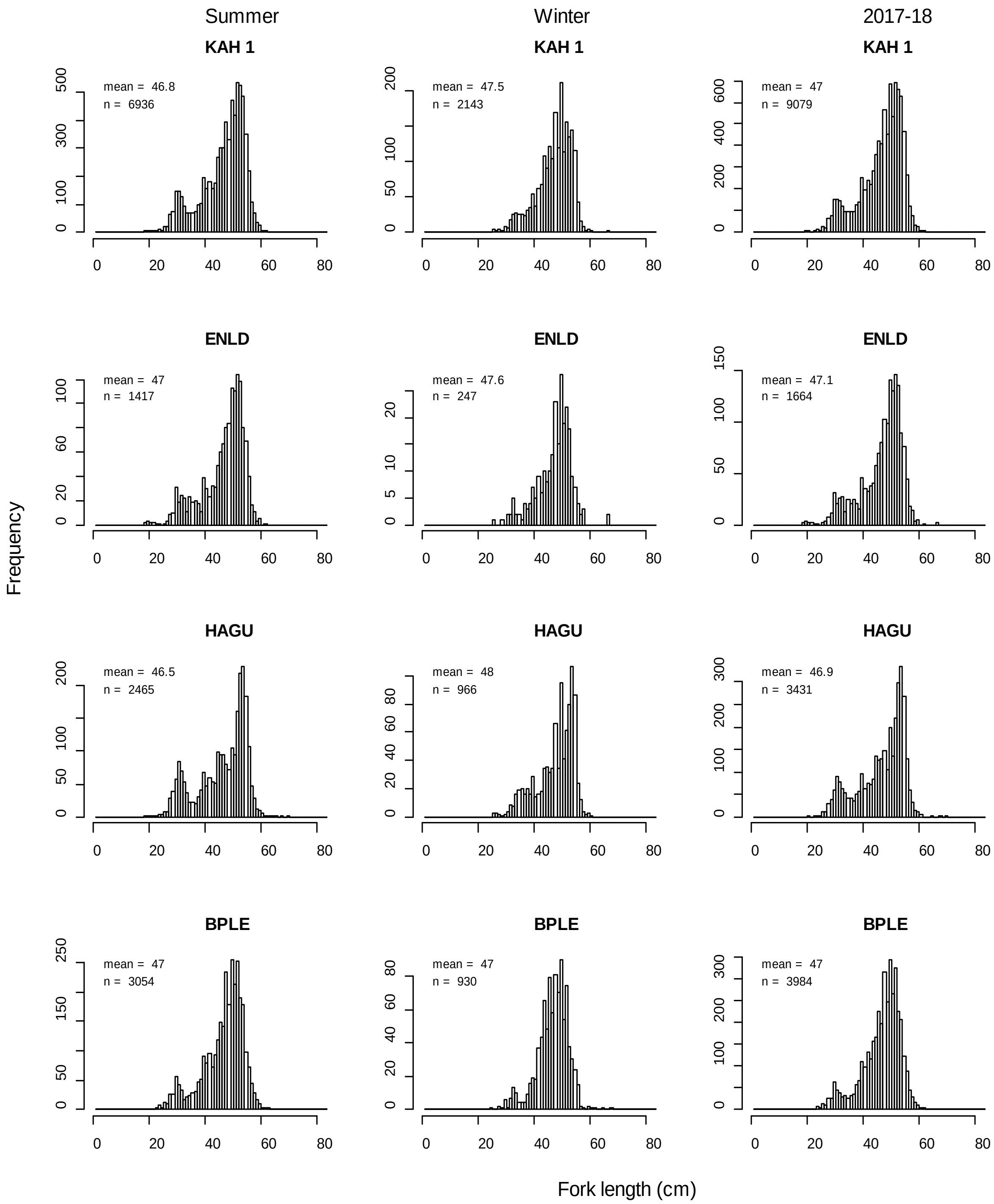
APPENDIX 2: length frequency distributions for species for which harvest estimates are provided by region and season

Snapper length frequencies – the 30 cm MLS is indicated by vertical dashed lines



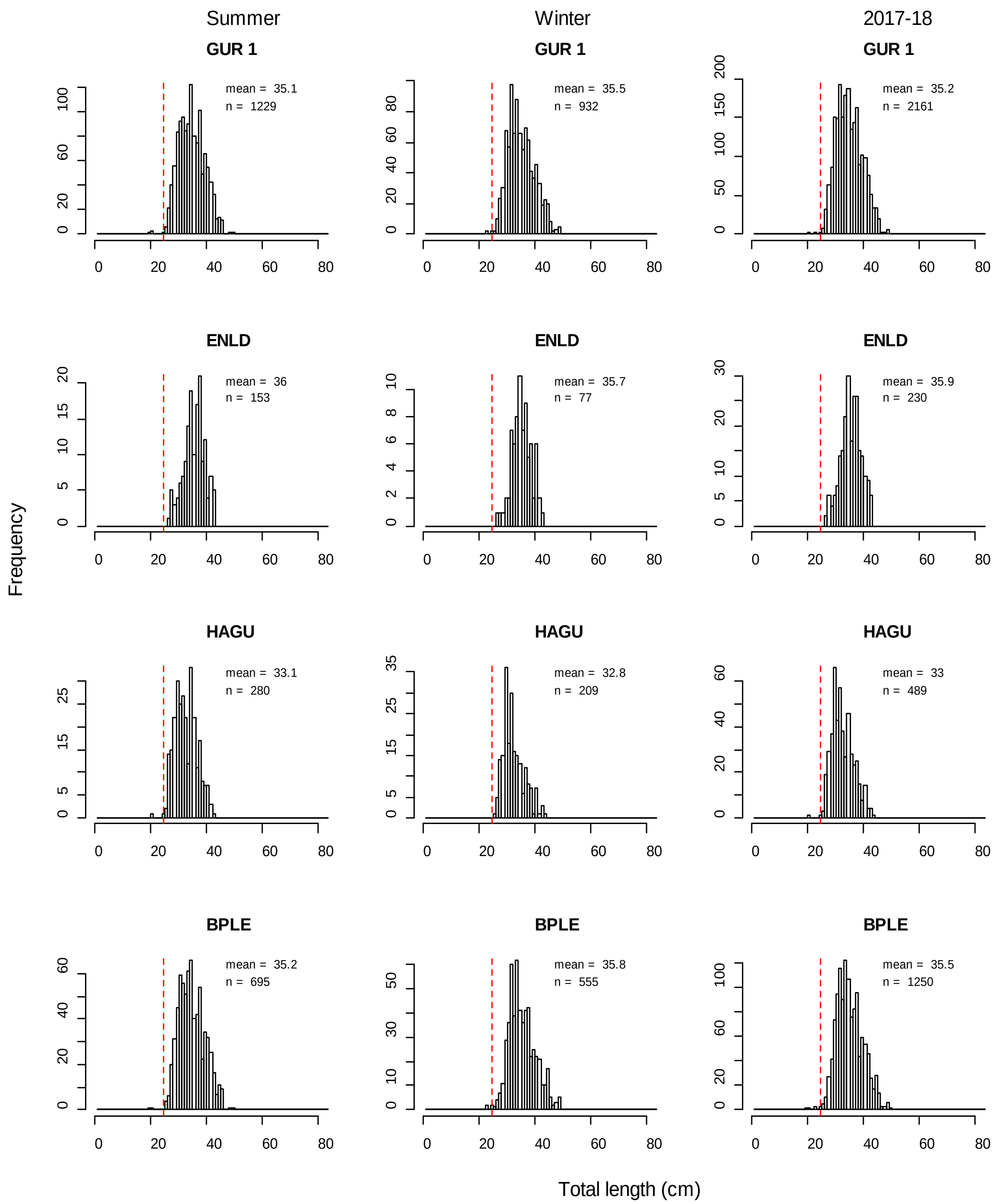
APPENDIX 2: continued

Kahawai length frequencies



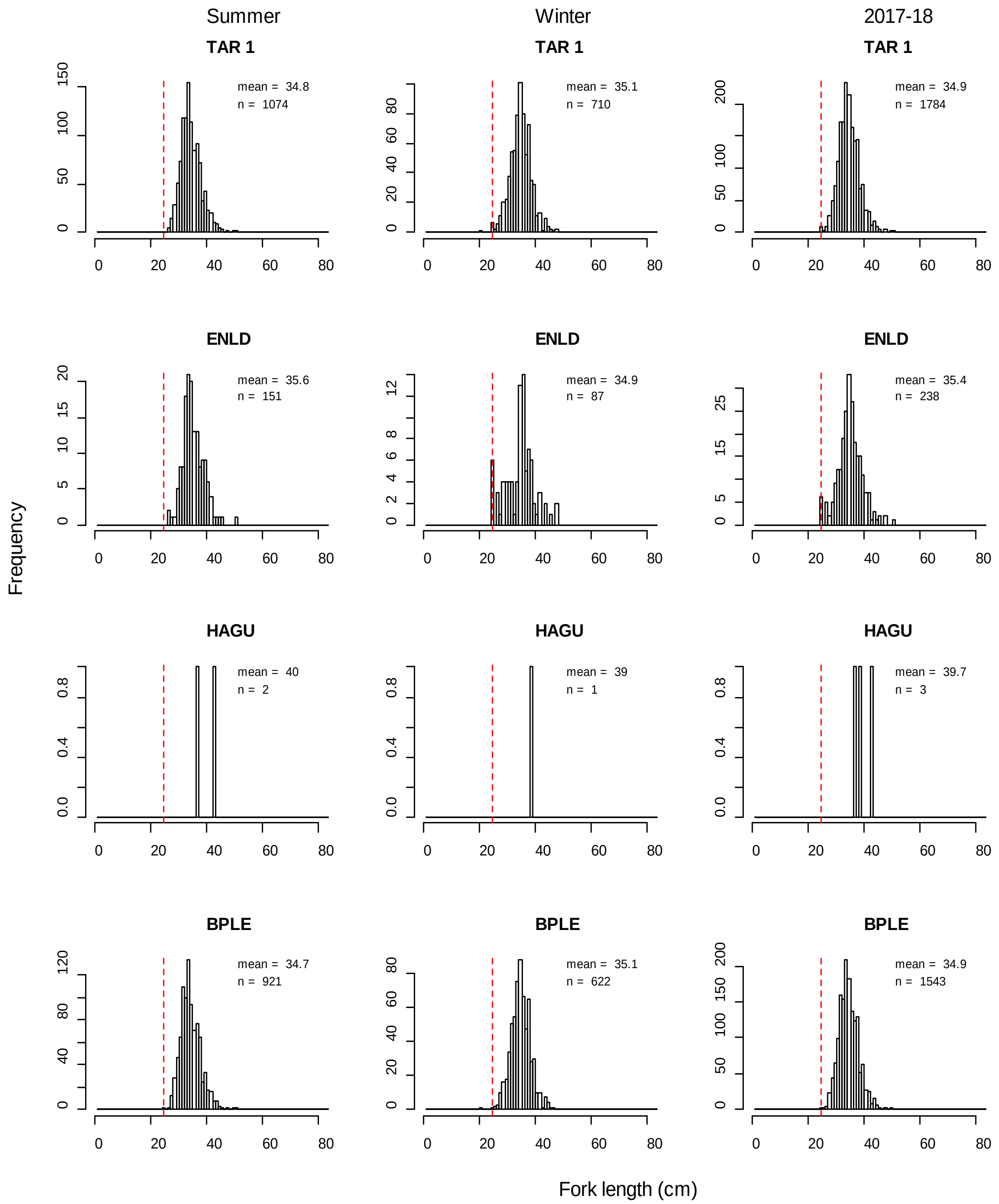
APPENDIX 2: continued

Red gurnard length frequencies – the 25 cm MLS is indicated by vertical dashed lines



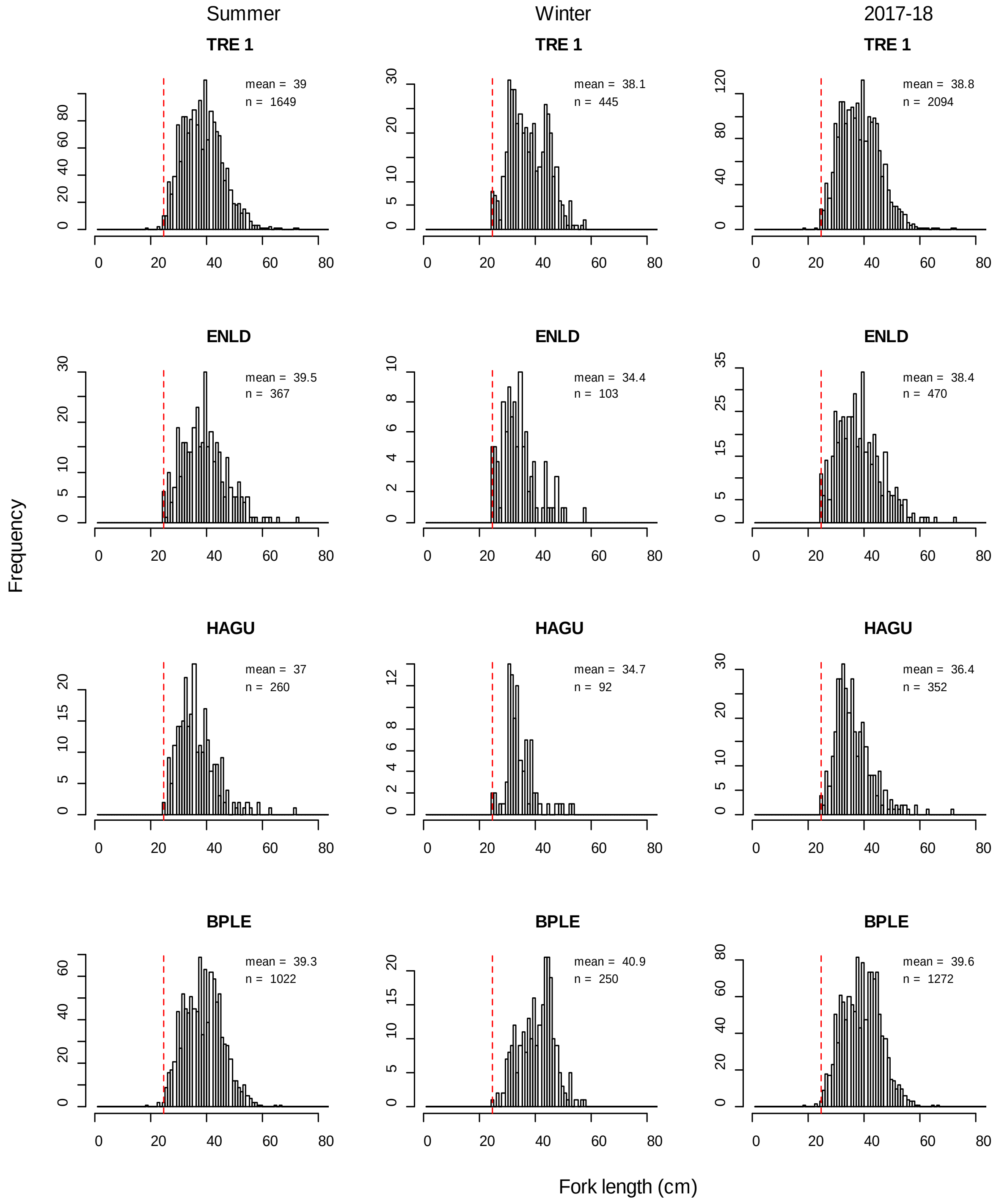
APPENDIX 2: continued

Tarakihi length frequencies – the 25 cm MLS is indicated by vertical dashed lines



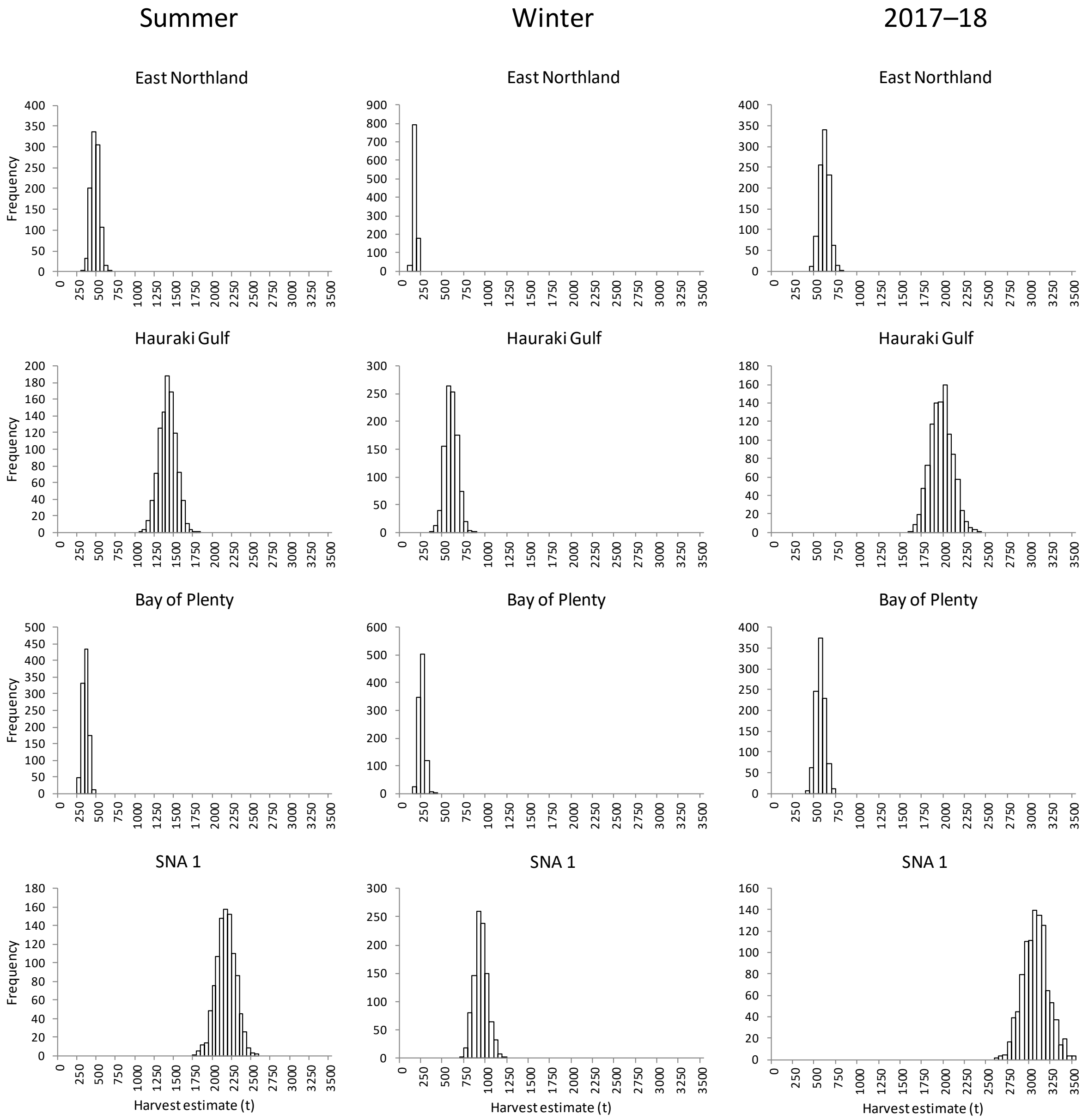
APPENDIX 2: continued

Trevally length frequencies – the 25 cm MLS is indicated by vertical dashed lines



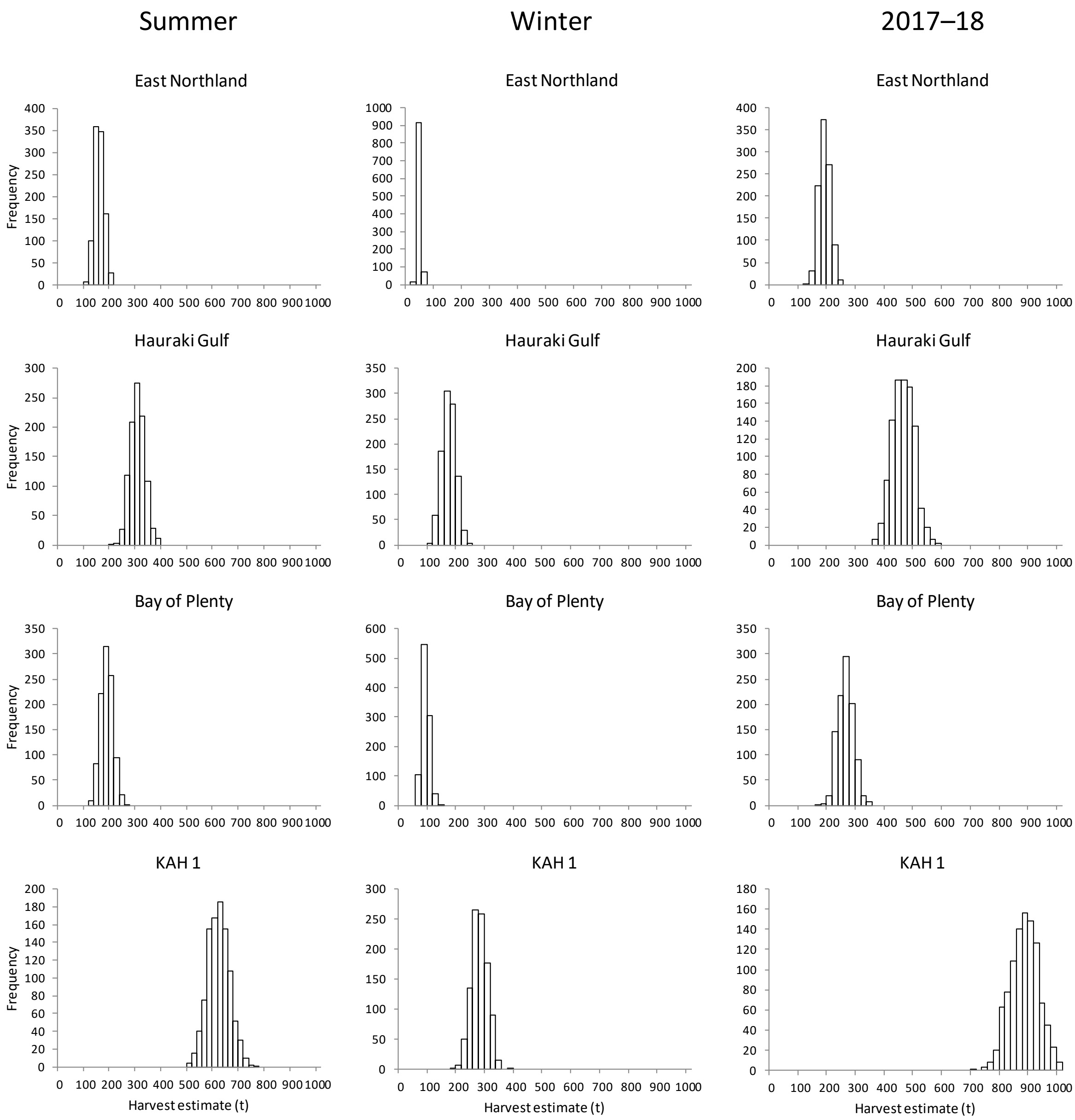
APPENDIX 3: Distribution of bootstrap harvest estimates for the five most frequently landed species.

Distributions of bootstrap harvest estimates for snapper



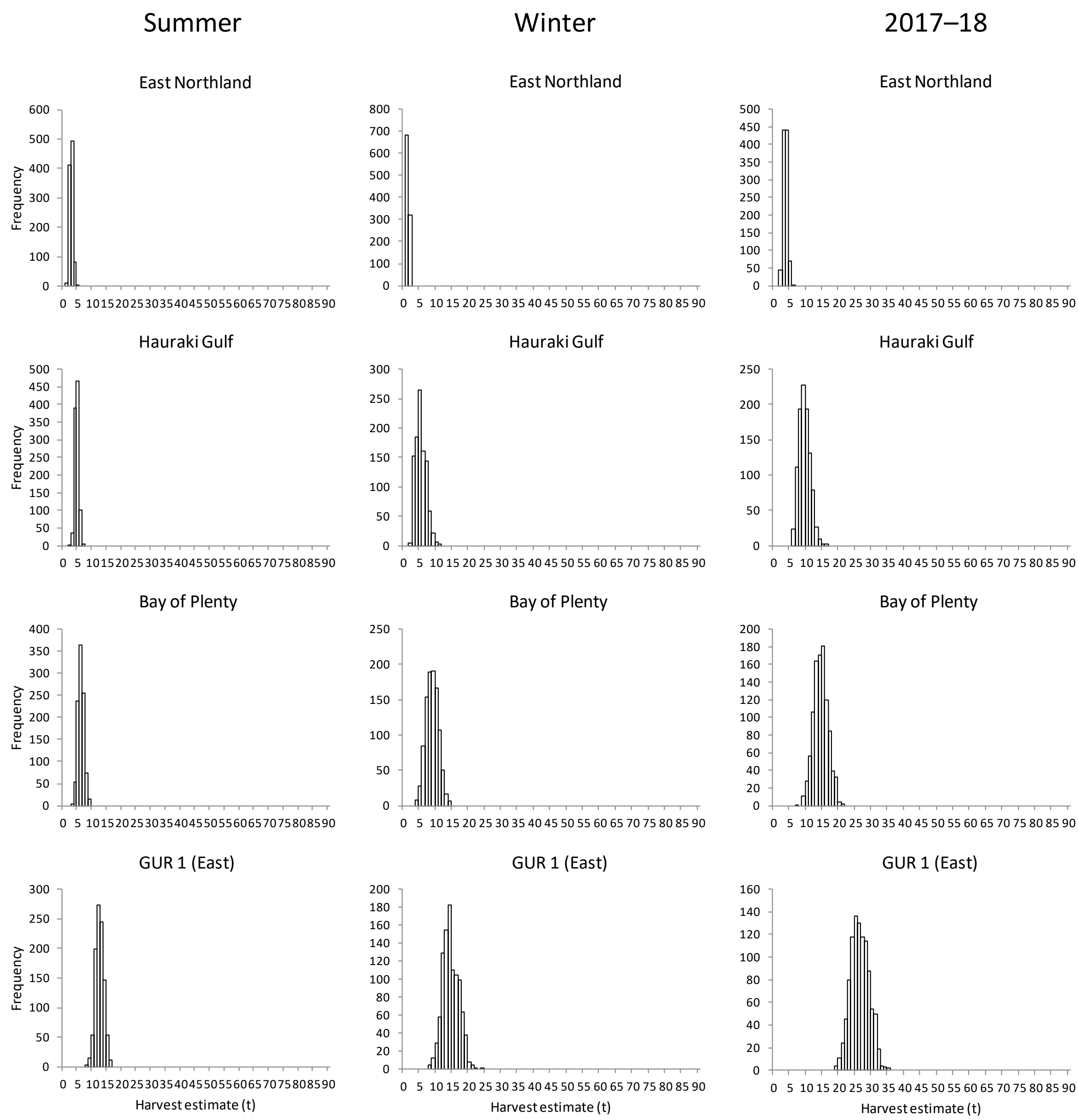
APPENDIX 3: continued

Distributions of bootstrap harvest estimates for kahawai



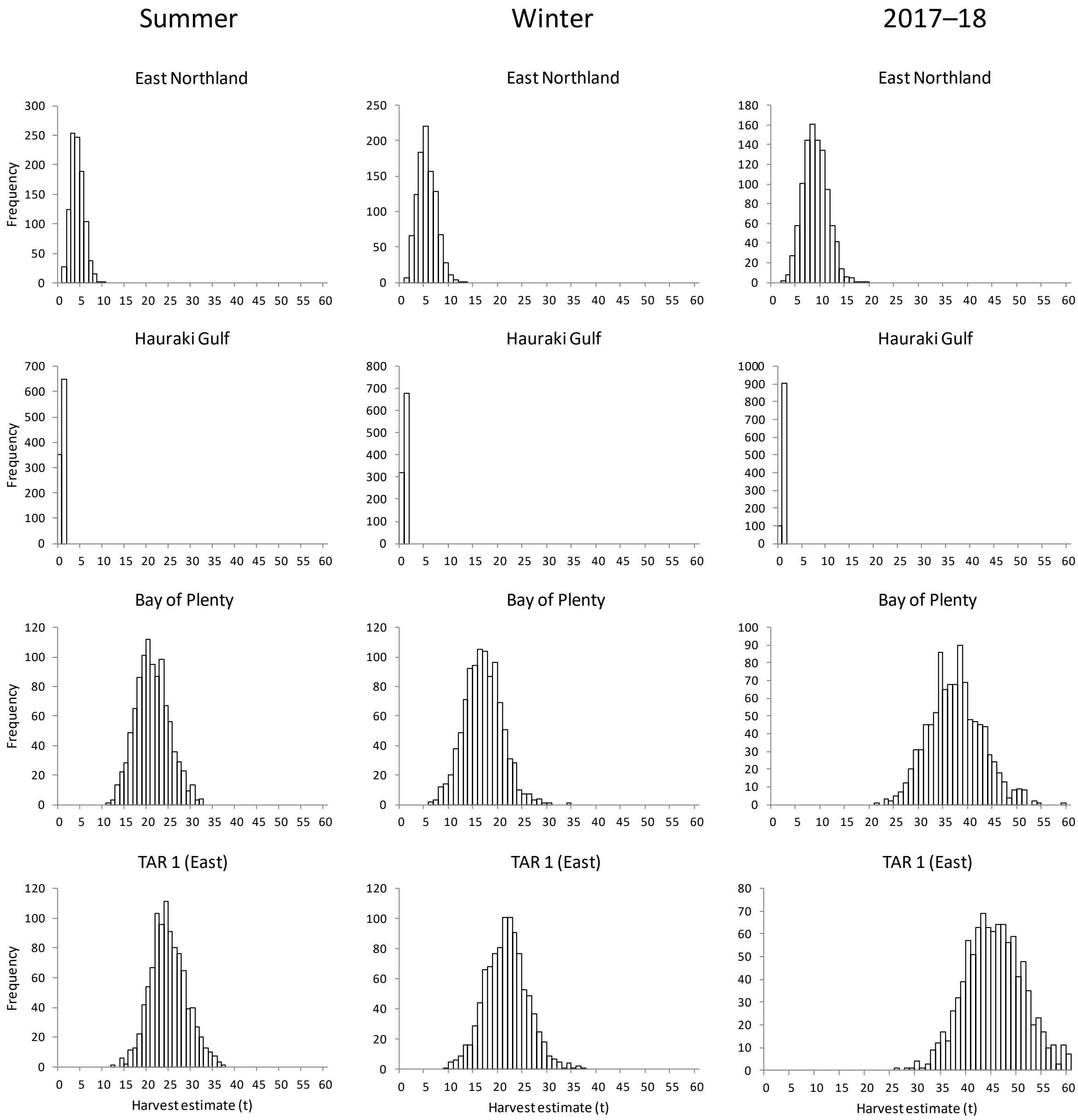
APPENDIX 3: continued

Distributions of bootstrap harvest estimates for red gurnard



APPENDIX 3: continued

Distributions of bootstrap harvest estimates for tarakihi



APPENDIX 3: continued

Distributions of bootstrap harvest estimates for trevally