Ministry for Primary Industries
Manatū Ahu Matua

Aerial-access recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2011–12

New Zealand Fisheries Assessment Report 2013/70

B. Hartill
R. Bian
N. Rush
H. Armiger

ISSN 1179-5352 (online)
ISBN 978-0-478-42328-0 (online)

December 2013

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Hartill, B.; Bian, R.; Rush, N.; Armiger, H. (2013). Aerial-access recreational harvest estimates for snapper, kahawai, red gurnard, tarakihi and trevally in FMA 1 in 2011–12.

***New Zealand Fisheries Assessment Report 2013/70.* 44 p.**

This report provides estimates of the recreational harvest of snapper, kahawai, red gurnard, tarakihi and trevally taken from FMA 1 during the 2011–12 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 here are closely based on those used in a previous aerial-access survey of the FMA 1 recreational fishery in 2004–05.

Interviewers were present at 21 boat ramps located throughout FMA 1 on 45 days randomly preselected according to a random stratified survey design, but all flights were cancelled on 6 of these days and flights were partially curtailed on another 8 survey days due to low cloud and or heavy rain. 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 (when weather was more conducive to flying and fishing) would have been positively biased. Aerial counts predicted from area specific regressions suggest that only 7.2% of the effort that took place on the 45 survey days occurred at on days when flights were cancelled, therefore any bias due to aerial counts for weather is unlikely to have a major effect on the overall estimates.

The recreational harvest estimates generated from the aerial-access survey for the 2011–12 year were: 3402 t for SNA 1; 669 t for KAH 1; 20 t for the east coast of GUR 1; 66 t for the east coast of TAR 1; and 101 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: 3456 t for SNA 1; 705 t for KAH 1; 21 t for the east coast of GUR 1; 67 t for the east coast of TAR 1; and 103 t for TRE 1.

These harvest estimates do not include any shore-based harvesting, and relative harvest by method information from a concurrent off-site national panel survey was used to account for additional harvests taken from the shore. Including shore-based harvesting increased our recreational harvest estimates to: 3754 t for SNA 1; 942 t for KAH 1; 24 t for eastern GUR 1; 67 t for eastern TAR 1; and 124 t for TRE 1.

These harvest estimates for 2011–12 are compared with those provided by a similar aerial-access survey conducted in 2004–05. Sources of bias associated with this survey method are also considered. Two other surveys were also conducted during the 2011–12 fishing year, and harvest estimates provided by these independent studies are of a similar magnitude to those provided by this survey. This suggests that the harvest estimates given here are both plausible and reasonably accurate given the levels of error associated with all available estimates.

1. INTRODUCTION

Fisheries managers require reliable estimates of all sources of fishing mortality if they are to sustainably manage fish stocks, and although annual catch data is readily available from the commercial sector, our understanding of levels of harvesting by recreational fishers has been poor. 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 (see review of past studies in Hartill et al. 2010).

Attempts to estimate recreational harvests initially focused on off-site telephone diary methods which provided estimates for all of New Zealand's recreational fisheries, but the most recent surveys in 1999–00 (Boyd & Reilly 2004) and 2000–01 (Boyd et al. 2004) generated implausibly high harvest estimates which were not considered reliable (Ministry for Primary Industries 2013). Concerns about the reliability of the telephone diary method led to the development of an on-site aerial-access survey method that is thought to provide more reliable harvest estimates, but only at the scale of a single Fisheries Management Area (FMA), and just for vessel based fisheries. Other creel survey based methods have been developed to estimate recreational harvests at even smaller spatial scales (e.g. Hart & Walker 2004).

There remains an ongoing need, however to estimate recreational harvests for all of New Zealand's recreational fisheries simultaneously, in a cost effective, defensible and rigorously tested manner. This need led to a series of workshops and working groups convened by MFish/MPI between 2008 and 2011, culminating in a multi-survey initiative that aims to develop and test the reliability of a revised form of off-site survey that uses methods markedly different from the telephone diary approach used in the past. This latest off-site survey approach is called the national panel survey method and it was used to estimate recreational harvests in 2011–12. Two other on-site surveys were conducted concurrently to provide independent harvest estimates for a subset of fisheries for comparative testing purposes, and the largest of those surveys is discussed here: an aerial-access survey of the recreational fishery in FMA during the 2011–12 fishing year.

The methods used for the 2011–12 aerial access survey are closely based on those used to survey the FMA 1 fishery in 2004–05, with some refinements informed by lessons learnt from similar recent surveys. The levels of spatial and temporal stratification used in this survey, the national panel survey and another multi method creel survey of the western Bay of Plenty have been standardised to ensure direct comparability, and the harvest estimates provided by this survey will therefore have greater utility beyond those provided by past surveys.

The overall objectives of this research were to contribute to the design and implementation of an integrated recreational harvest estimation system, and to provide absolute estimates of total recreational harvest on a stock basis to inform fisheries management.

The specific objectives of this project 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 01 October 2011 to 30 September 2012 using the aerial overflight/intercept method, and to collaborate with concurrent onsite and offsite survey projects to provide information to corroborate and if possible calibrate harvest estimates.

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). The maximum count aerial-access approach used combines data from two independent on-site surveys: an aerial survey of the fishery, and a creel survey census of fishers returning to a subsample of 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 a subsample of 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 are used 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, as this form of effort is readily enumerated from the air. 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. The four flights followed roughly the same route on each survey day, given the need to cover the survey area as efficiently as possible. Examples of each of the four flight routes are given in Figure 1.

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 nine 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 either: 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 underway were ignored, as were stationary boats obviously not involved in fishing activity, such as swimming or picnicking close inshore. Observers and pilots were instructed to classify boats as fishing when there was any doubt.

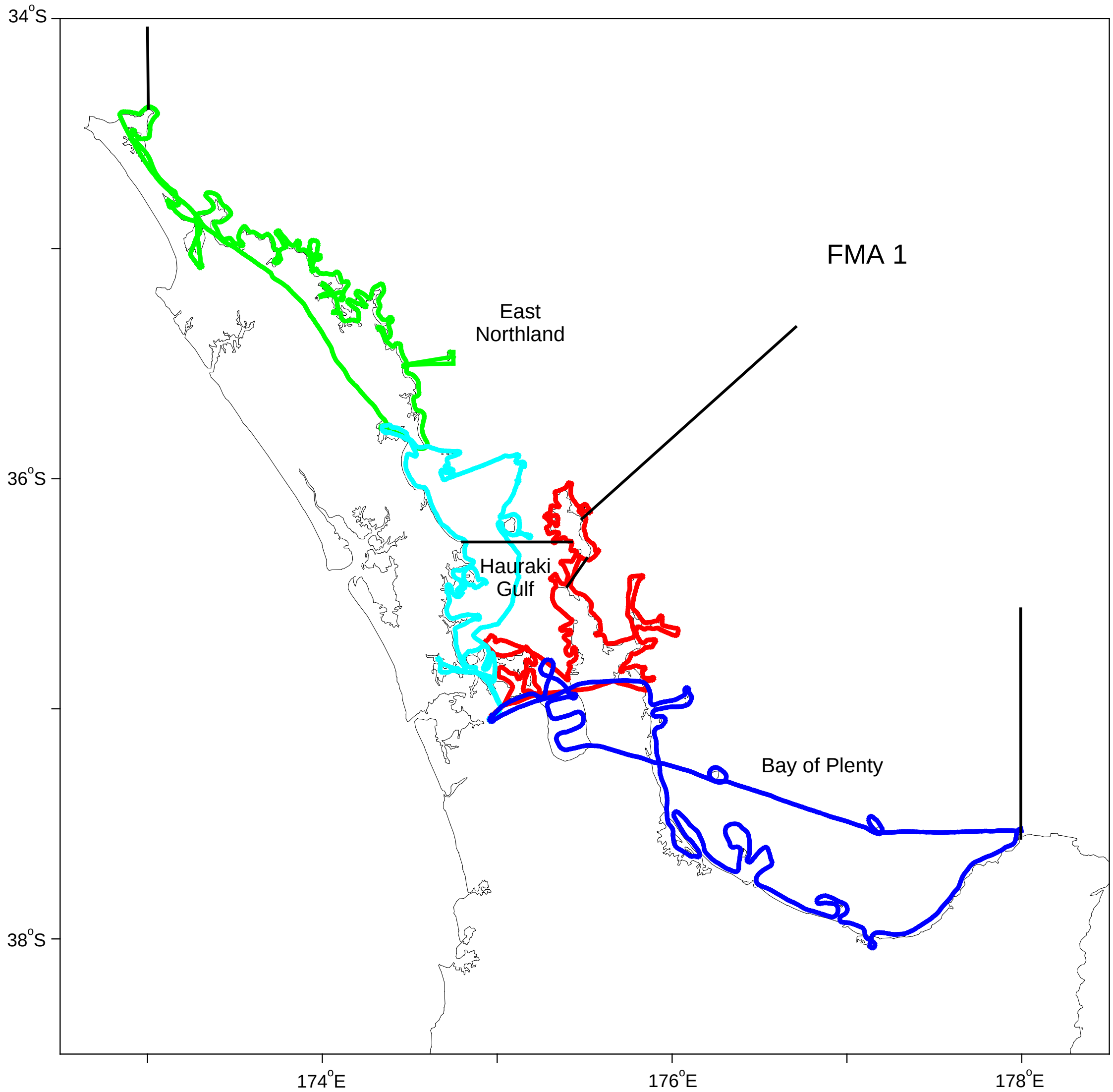
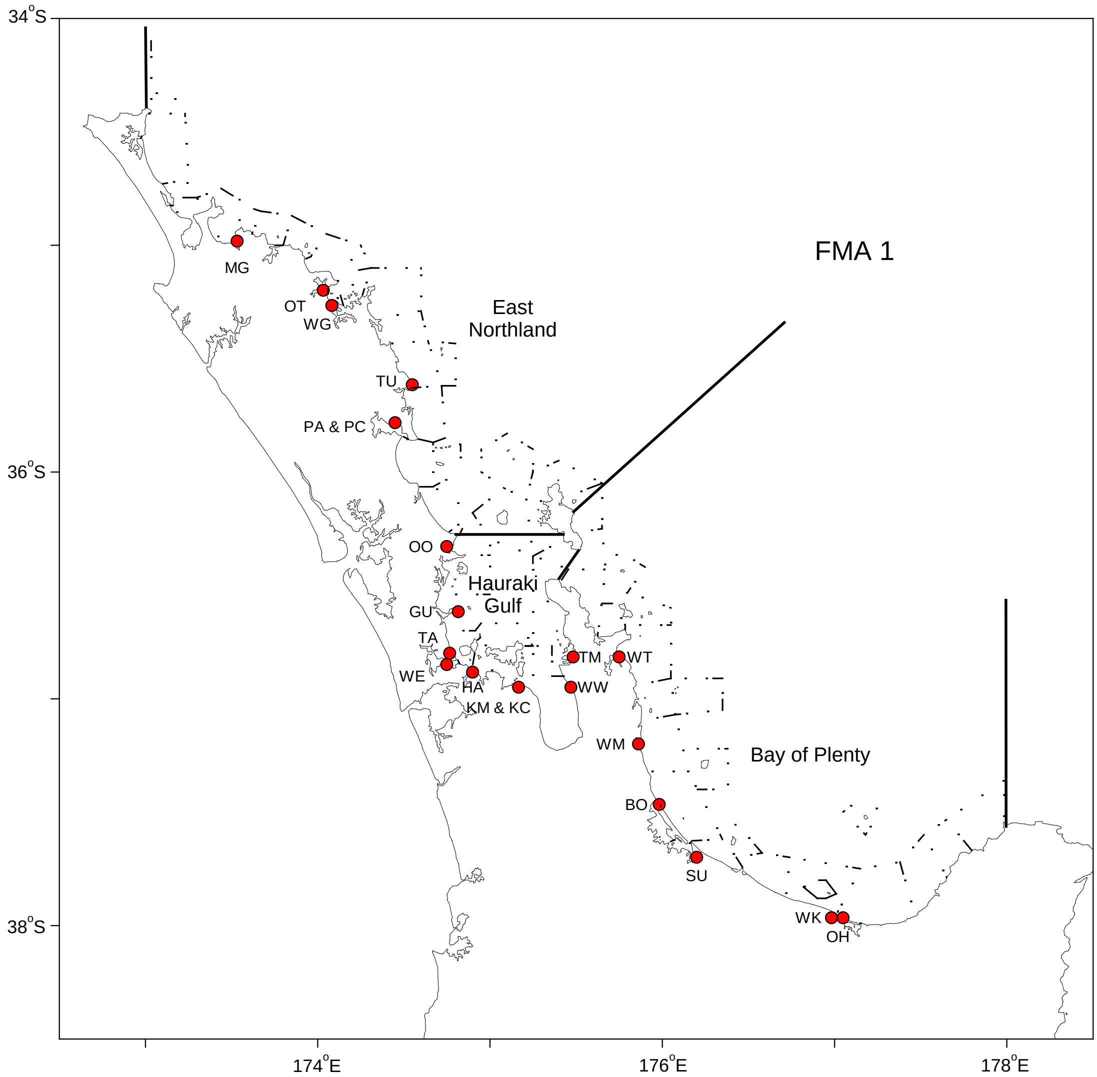


Figure 1: Examples of each of the four flight routes used to count boats actively fishing at midday throughout coastal waters of FMA 1. Single engine Cessna 172 aircraft were used on the three northern routes and a twin engine Piper Aerostar was used when flying the more extensive Bay of Plenty route.

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 were surveyed away from the shoreline. The electronic recording of aerial survey data facilitated rapid uploading, enumeration, and scrutiny of information 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 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. 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.



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)
KC Kawakawa (club 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 boats ramps and definitions of spatial strata used in both the aerial and access point surveys.

The aerial survey provided counts of all types of fishing vessels, including larger vessels that would not normally return to boat ramps, such as those surveyed in the concurrent access point survey. Although approximately 85% of vessels observed from the air were classified as trailer boats, most of the remainder (launches, and to a lesser extent yachts and charter boats) would have returned to marinas and moorings 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 that encountered at boat ramps, i.e., trailer boats. The use of scalars assumes that trailer boat fisher catch rates and fishing durations are broadly similar to those of fishing from other types vessel observed in the same area.

Flights were sometimes cancelled because of low cloud, but estimates of the number of boats fishing at around mid-day are 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 boats on days when data were available from both of these companion surveys. Separate predictive relationships were generated for each analytical 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).

The uncertainty associated with these regression based aerial count estimates was estimated by bootstrapping these regressions. Regressions were initially forced through the origin, but this resulted in bootstrap estimates which did not fully encompass the variability seen in the data for the lower levels of fishing effort (as usually encountered at access points on unflown days). Consequently, both the intercepts and the slopes of these regressions were refitted for each bootstrap, with the constraint that the intercept was zero positive (negative levels of predicted fishing effort cannot occur). An alternative approach of adding bootstrap residuals to predicted estimates for unflown days was also considered, but the spread of the residuals mostly increased with increasing levels of fishing effort, yet high levels of effort were not normally observed at access points on unflown days. Adding large negative residuals (associated with high levels of effort) to low predicted levels of effort will often result in negative aerial count estimates, which are not possible.

<u>Access point survey methods</u>

Most of the access points surveyed during this study were also surveyed in the 2004–05, aerial-access survey (Hartill et al. 2007a), 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). During the 2004–05 survey the proportion of fishers returning to surveyed ramps in the north-western Hauraki Gulf and Firth of Thames was relatively low, and an additional ramp was therefore surveyed in each of these areas (Omaha and Waikawau respectively). The decision to survey fishers returning to the Waikawau ramp proved fortuitous as a marked increase in fishing effort has occurred in the Wilson Bay mussel farm area since 2004–05.

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. Interviewers worked two consecutive 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, and pairs of interviewers were present at Half Moon Bay and Sulphur Point throughout the day because of the heavy traffic levels often experienced 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 unobserved after dark.

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 either: 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 uninterviewed boats was imputed given a chronological sequencing of these data, based on whether the next interviewed boat was used for fishing, and if so a copy of that boat's catch and effort data was attributed to the uninterviewed boat. 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 (via length weight relationships).

Temporal stratification used in both that aerial and access point surveys

Aerial and boat ramp surveys were conducted on 45 days selected according to a stratified random design closely based on that used in 2003–04 (for the Hauraki Gulf - Hartill et al. 2007b) and in 2004–05 (for FMA 1 - Hartill et al. 2007a), to ensure that the aerial-access harvest estimates were as comparable as possible over time.

This level of sampling effort was also necessary to provide the reasonably precise harvest estimates required when comparing harvest estimates generated by multiple surveys in 2011–12: this aerial-access survey, an off-site national panel survey undertaken by National Research Bureau (NRB) (National Research Bureau 2013), and a multi-method access point survey of the western Bay of Plenty undertaken by Bluewater Marine Research (BMR) (Holdsworth 2013).

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 2011 to 30 April 2012 versus winter – 1 May 2012 to 30 September 2012) and day-type (weekends and public holidays versus midweek days) to improve estimate precision. The allocation of the 45 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 the 2003–04 aerial overflight survey of the Hauraki Gulf and the 2004–05 survey of the recreational fishery in FMA 1.

Table 1: Temporal allocation of aerial-access survey days across combinations of seasonal and day-type strata for the 2011–12 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	7	0.06
	Weekends/holidays	45	7	0.16

Only seven days were allocated to each of the winter strata (Table 1), as this level of sampling effort was regarded to be the minimum allocation required given the need to allow for weather induced flight cancelations in any given temporal stratum. The allocation of sampling effort to the two busier summer strata was based on the relative allocation of sampling effort between these two strata in 2004–05. Previous quantitative optimisations of sampling effort (see Hartill et al. 2007a) suggested that there was no clear optimal allocation between day type strata within the summer season, and that any allocation of effort between the two summer day type strata would be somewhat arbitrary.

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 a subsample of access points throughout the day, both in terms of fishing effort and landed catch. Interviewers note the time at which each boat returns 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 uninterviewed 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 be 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 implemented in C++.

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).

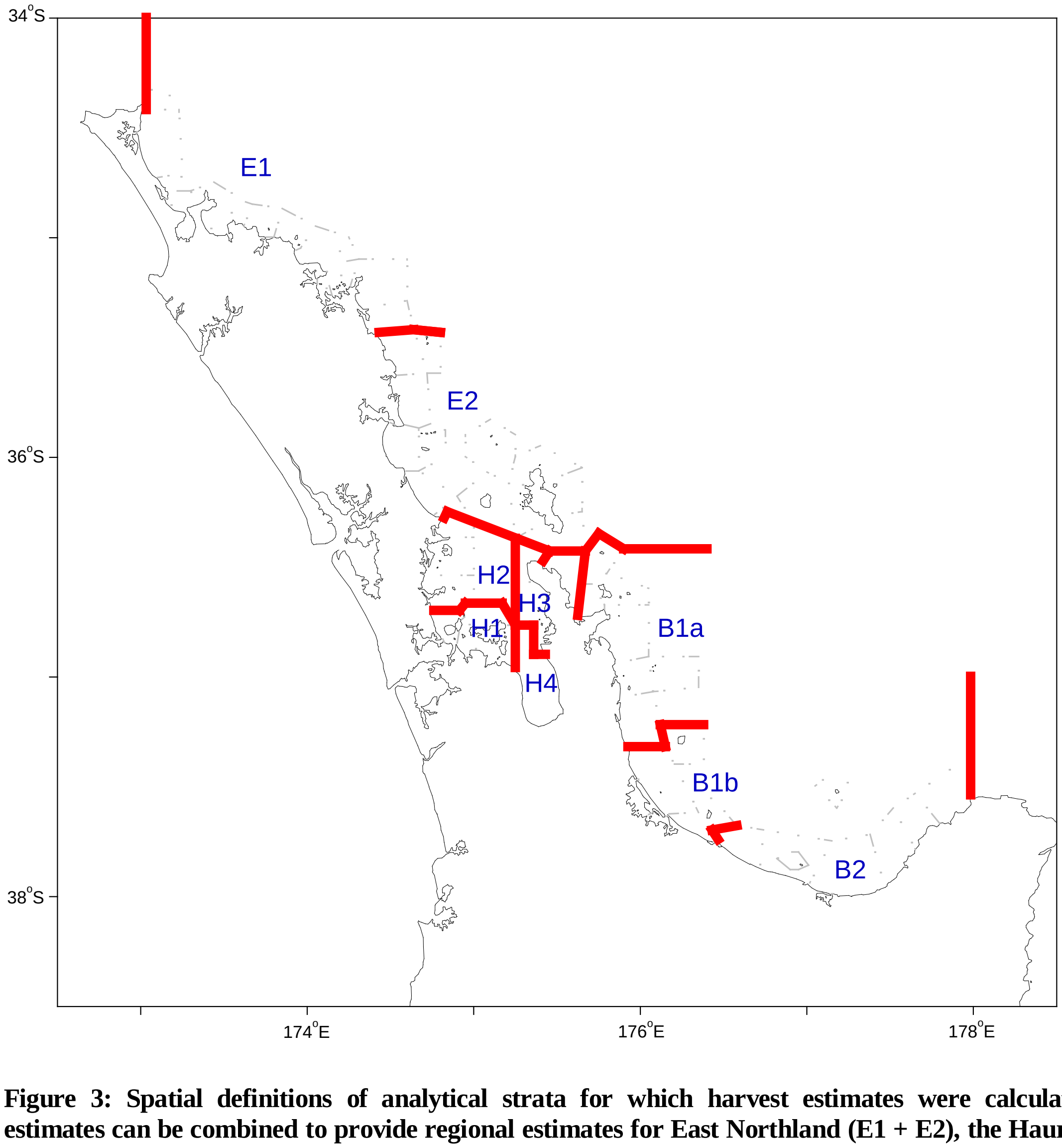


Figure 3: Spatial definitions of analytical strata for which harvest estimates were calculated. Stratum estimates can be combined to provide regional estimates for East Northland (E1 + E2), the Hauraki Gulf (H1 to H4), and for the Bay of Plenty (B1a to B2).

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 was 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 a concurrent national panel survey (National Research Bureau 2013). 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.

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 4).

3. RESULTS

Aerial survey counts of fishing vessels

The spatial and temporal distribution of fishing effort observed from the air in 2011–12 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). Weather conditions for most of the Christmas break were not conducive to fishing. 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 farming 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 found 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 (78.6% in East Northland; 85.0% in the Hauraki Gulf; 87.3% in the Bay of Plenty) with the remainder mostly comprised of launches (15.3%, 10.1% and 9.2% respectively) and yachts (2.9%, 2.2% and 0.7% 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).

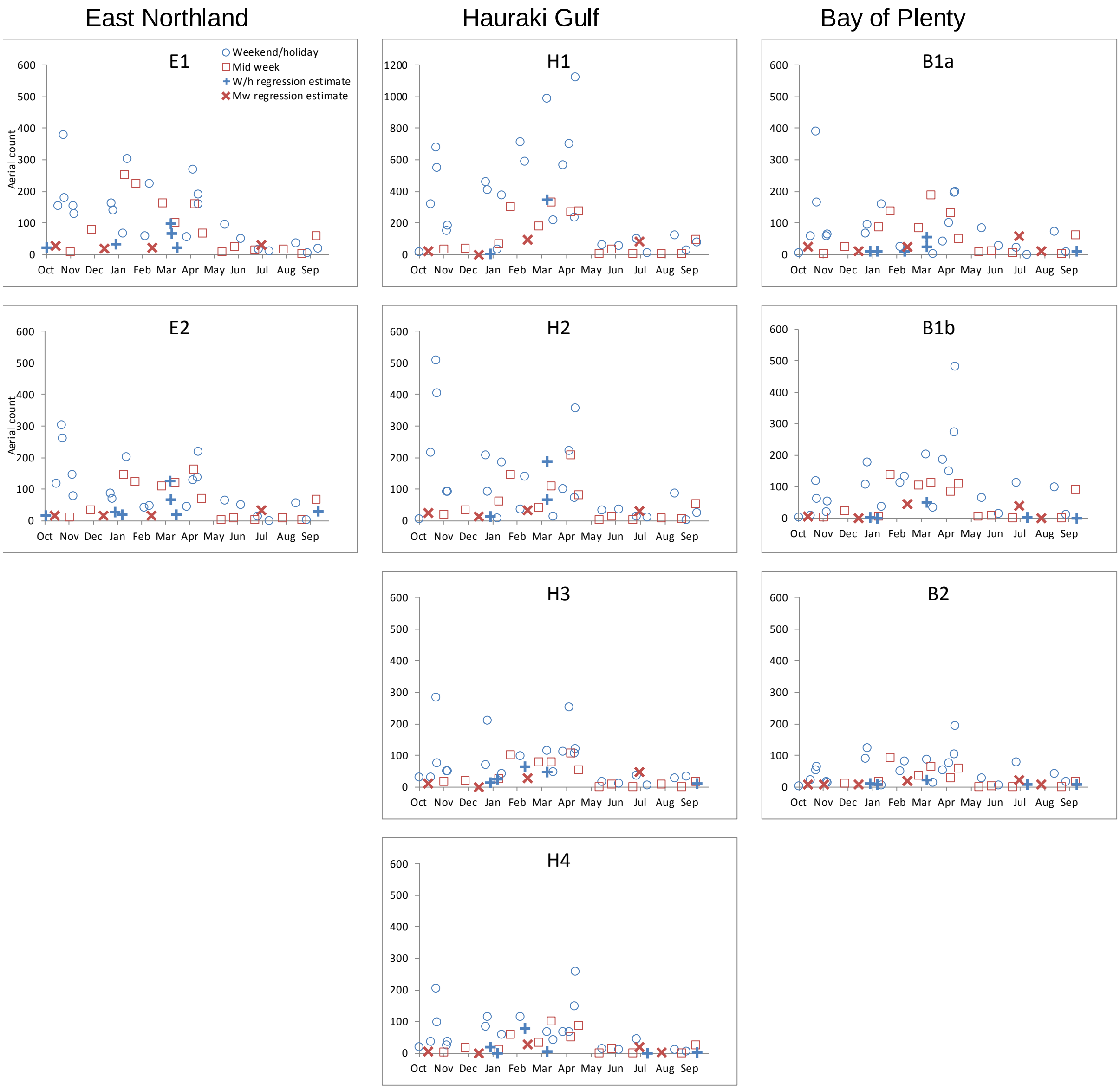


Figure 4: Daily counts of vessels fishing by analytical area, by day type. Observed counts on weekends and public holidays are denoted by open circles and mid-week counts are denoted by open squares. Flights were cancelled on some days due to low cloud, and the level of fishing effort on these days has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

The summer of 2011–12 was the cloudiest on record, with higher than average rainfall (Georgina Griffiths, NIWA climate scientist, pers. comm.). This was unfortunate as low cloud was the main reason why flights were cancelled; for safety reasons. All flights were cancelled on 6 of the 45 randomly preselected survey days, and some flight routes were not flown or only partially flown on another 8 days. The flight count on an unflown day was estimated by regressing aerial counts on flown days against 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 (Figure 5).

Although the levels of uncertainty associated with these bootstrap regressions are likely to be underestimates (because some observations fall well outside of the 95th percentiles derived from the bootstrapped estimates), the error associated with any form of regression will only contribute a very small fraction to the overall variance associated with harvest estimates. This is because the predicted level of effort for most unflown days was low, and any level of variability at this level will have little influence on an average daily harvest estimate when its magnitude is largely determined by high effort days which were observed and not estimated. These regressions suggest that only 7.2% of the effort that took place on the 45 survey days occurred at times when aerial surveying was not possible.

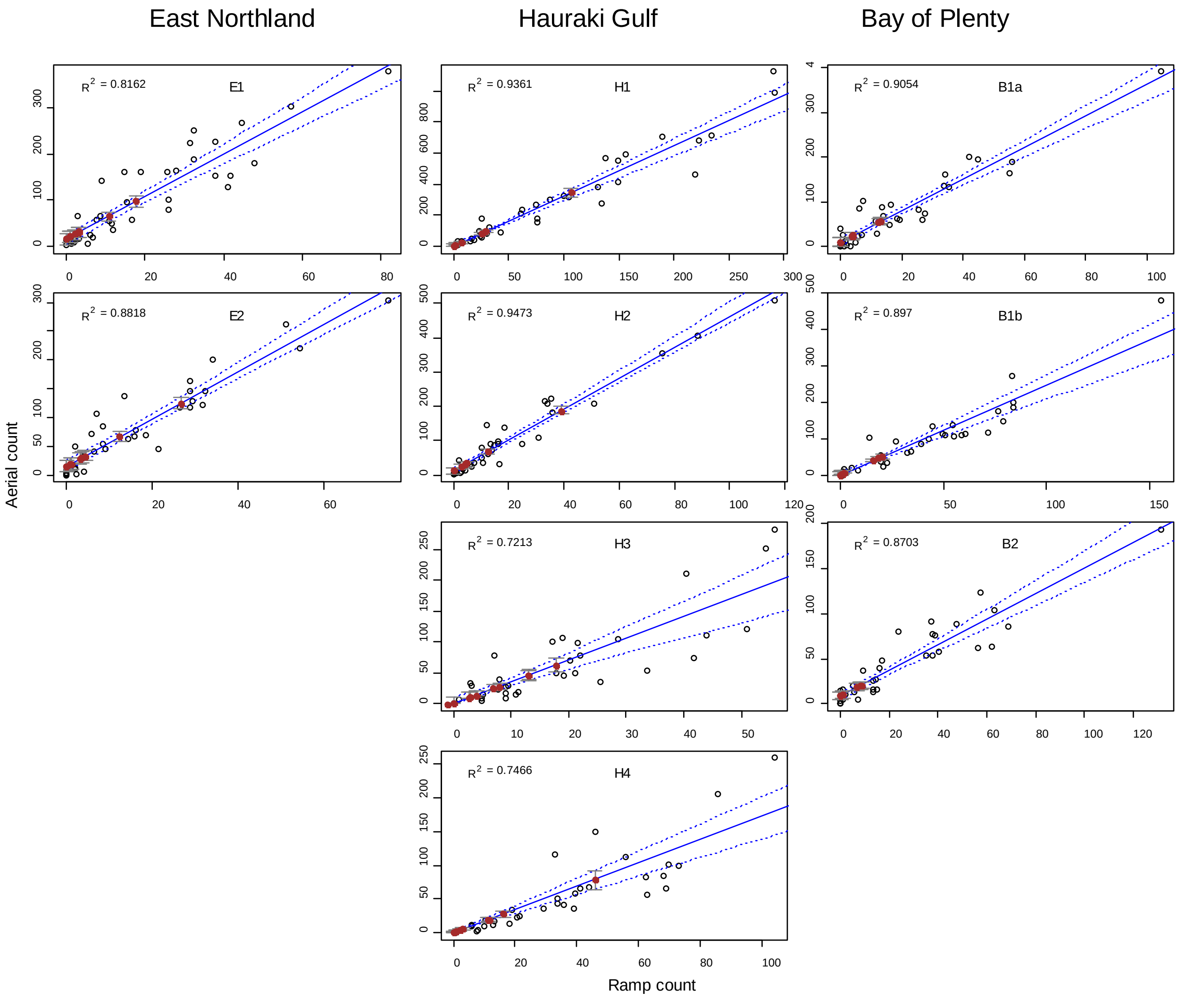


Figure 5: Regressions of aerial counts against counts of interviewed fishing parties (boats) that claimed to have been fishing at the time of the aerial survey, by analytical area. These regressions are used to estimate the number of boats that would have been seen from the air on those days when flights 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 unflown days. 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 five returned to surveyed ramps, but a far higher proportion of fishers returned to surveyed ramps in the Firth of Thames (H4), from waters off Tauranga (B1b) and in the eastern Bay of Plenty (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.

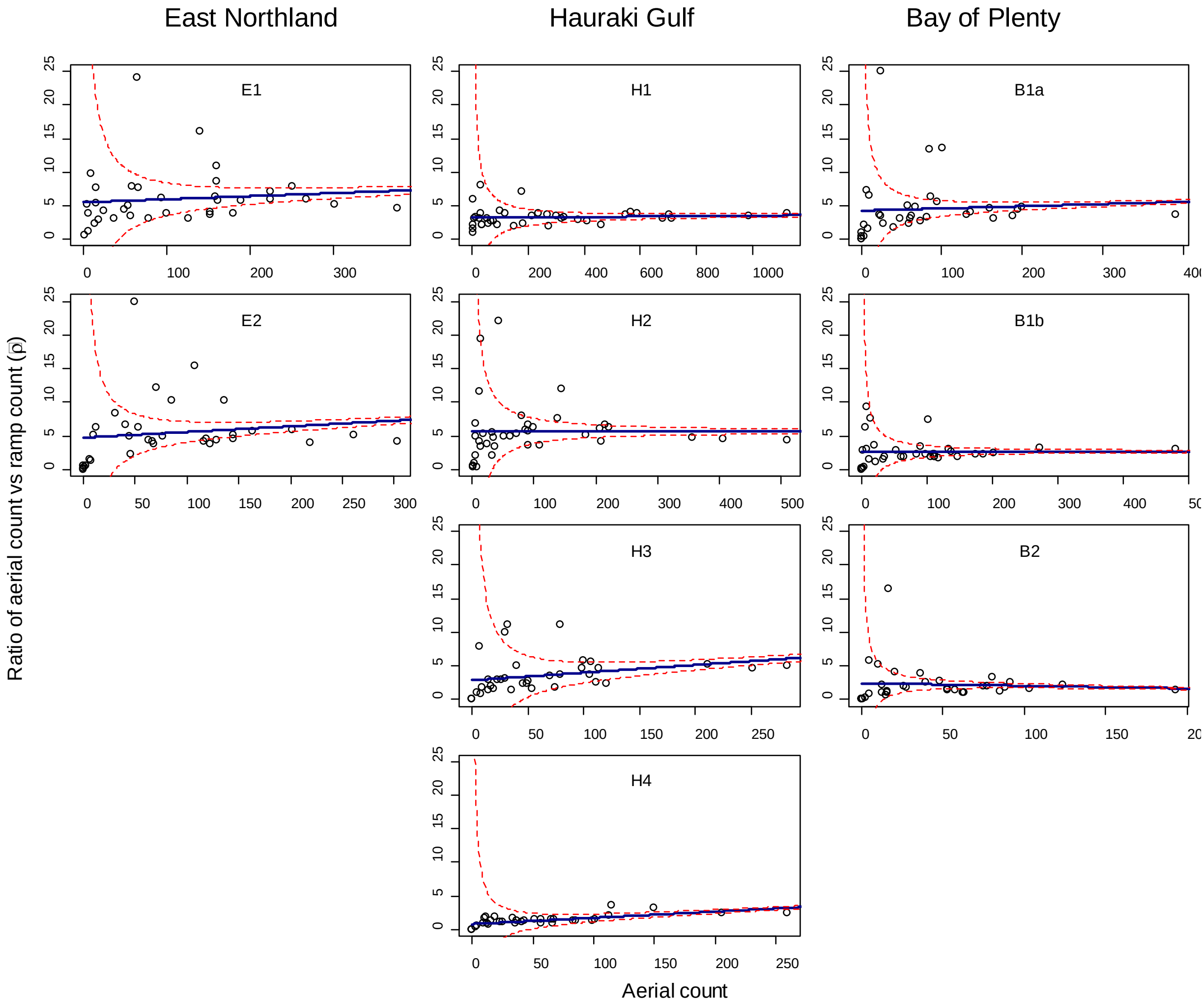


Figure 6: Estimates of the proportion of boats that returned to surveyed ramps on each survey day (ρ) by analytical area. These estimates are ratios of aerial counts against counts of fishing parties (boats) that claimed to have been fishing at the time of the aerial survey during access point interviews, 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.

Access point survey

The temporal survey design given in Table 1 was almost fully implemented with only a small number of access point survey sessions missed (Table 2). Interviewers were absent on these occasions for a variety of reasons which were not related to levels of recreational fishing effort at that time. Interview sessions were intentionally cancelled at Ohope towards the end of the winter season 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 2011–12 fishing year.

Region	Ramp	Days sampled	Hours worked	Fishing boats interviewed	Non-fishing boats interviewed	Boat activity unknown	Fishers interviewed	SNA Landed	KAH Landed	GUR Landed	TAR Landed	TRE Landed
East Northland	Mangonui	45	554	630	301	72	1 381	2 017	433	59	87	45
	Opito Bay	44	540	340	121	130	782	1 170	332	11	21	78
	Parua (public)	45	559	390	101	53	976	1 204	198	32	44	32
	Parua (club)	45	556	414	73	74	1 001	1 666	238	58	151	64
	Tutukaka	44	545	258	86	55	577	433	67	4	46	34
	Waitangi	44	551	559	259	276	1 310	1 780	429	13	38	87
	Summer	45	2 403	2 343	802	626	5 542	7 832	1 553	171	307	305
	Winter	45	900	248	139	34	485	438	144	6	80	35
	Total	45	3 303	2 591	941	660	6 027	8 270	1 697	177	387	340
Hauraki Gulf	Gulf Harbour	45	558	742	158	345	1 708	4 029	600	45	–	48
	Half Moon Bay	45	1 072	1 761	524	972	5 029	18 685	1 609	91	–	188
	Kawakawa (club)	45	560	987	87	950	2 876	11 630	1 357	132	–	107
	Kawakawa (public)	44	551	579	126	219	1 557	6 146	1 113	111	4	28
	Omaha	45	558	583	316	186	1 324	2 079	199	92	25	236
	Takapuna	43	535	764	402	555	1 997	5 704	1 069	106	–	57
	Te Kouma	44	533	831	54	201	2 829	8 122	302	22	10	262
	Westhaven	45	563	803	345	205	2 121	5 618	485	28	–	31
	Waikawau	45	554	1 394	21	747	3 791	14 669	1 090	154	–	38
	Summer	45	3 958	7 610	1 715	4 273	21 065	71 229	6 739	704	35	891
	Winter	45	1 527	834	318	107	2 167	5 453	1 085	77	4	104
	Total	45	5 485	8 444	2 033	4 380	23 232	76 682	7 824	781	39	995
Bay of Plenty	Whitianga	44	550	305	219	110	832	1 007	340	78	143	117
	Whangamata	45	561	1 030	284	226	2 507	2 657	508	408	1 172	82
	Bowentown	44	557	443	90	124	1 154	2 036	343	136	293	250
	Sulphur Point	45	956	1 644	555	315	3 977	6 316	1 499	365	866	386
	Whakatane	45	529	686	94	525	1 476	3 302	1 126	471	762	241
	Ohope	41	514	377	120	24	917	1 144	520	104	13	101
	Summer	45	2 689	3 848	1 201	1 266	9 457	14 574	3 606	1 279	2 013	1 078
	Winter	45	977	637	161	58	1 406	1 888	730	283	1 236	99
	Total	45	3 666	4 485	1 362	1 324	10 863	16 462	4 336	1 562	3 249	1 177
FMA 1	Summer	45	9 050	13 801	3 718	6 165	36 064	93 635	11 898	2 154	2 355	2 274
	Winter	45	3 404	1 719	618	199	4 058	7 779	1 959	366	1 320	238
	Total	45	12 454	15 520	4 336	6 364	40 122	101 414	13 857	2 520	3 675	2 512

Traffic rates at boat ramps in the Hauraki Gulf were generally far higher than those experienced at most ramps elsewhere (Table 2). The number of snapper landed per fishing party in the Hauraki Gulf was approximately three times that landed by boats in East Northland and the Bay of Plenty but landing rates of kahawai were broadly similar throughout FMA 1. Gurnard, tarakihi and trevally were far more common in landings from the Bay of Plenty.

Thousands of snapper and kahawai were measured, providing a good descriptor of the length composition of landings of these species from all three regions of FMA 1. 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. Seasonal regional length frequencies are given for these five species in Appendix 3. There were regional differences in length compositions of all five species, but marked seasonal differences in length structure were also very evident for kahawai.

Harvest estimates

The estimated boat-based harvest of snapper from SNA 1 during the 2011–12 fishing year was 3456 t (Table 3). Almost 70% of this harvest was caught in the Hauraki Gulf, with a further 17% of the snapper harvest landed from East Northland and the remaining 13% taken by fishers from the Bay of Plenty. The harvest of snapper taken over the 7 month summer season accounted for about 90% 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. The levels of precision associated with these harvest estimates were reasonably precise, with CVs ranging from 0.06 to 0.37 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 (National Research Bureau 2013) increases the 2011–12 aerial-access harvest estimate for SNA 1 by 9%, to 3754 t (Table 3).

Table 3: Estimates of the recreational harvest of snapper taken from three regions of SNA 1 during the 2011–12 fishing year, during summer (1 October 2011 to 30 April 2012), winter (1 May 2012 to 30 September 2012) 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 (National Research Bureau 2013) which was not part of this study.

Region	Day type	Summer	Winter	2011–12	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	543 (0.14)	56 (0.25)	599 (0.13)	2.1%	612 (0.13)	14.7%	718 (0.14)
	Weekends/ Pubic holidays	231 (0.14)	28 (0.37)	258 (0.13)		264 (0.13)		
	Midweek days	313 (0.23)	28 (0.32)	341 (0.21)		348 (0.21)		
Hauraki Gulf	All days	2215 (0.08)	168 (0.17)	2384 (0.08)	0.7%	2400 (0.08)	3.6%	2490 (0.08)
	Weekends/ Pubic holidays	1244 (0.09)	88 (0.20)	1332 (0.09)		1340 (0.09)		
	Midweek days	971 (0.14)	81 (0.27)	1052 (0.13)		1059 (0.13)		
Bay of Plenty	All days	366 (0.13)	53 (0.24)	419 (0.12)	5.7%	444 (0.12)	18.6%	546 (0.12)
	Weekends/ Pubic holidays	157 (0.17)	24 (0.22)	181 (0.15)		191 (0.15)		
	Midweek days	209 (0.19)	29 (0.39)	239 (0.17)		444 (0.12)		
SNA 1	All days	3125 (0.06)	277 (0.12)	3402 (0.06)		3456 (0.06)		3754 (0.06)
	Weekends/ Pubic holidays	1632 (0.07)	139 (0.15)	1771 (0.07)		1796 (0.07)		
	Midweek days	1493 (0.10)	138 (0.19)	1631 (0.10)		1660 (0.10)		

The second most commonly caught species in all three regions was kahawai, with an estimated 705 t taken by boat-based fishers during the 2011–12 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, especially in East Northland where only 10% of the harvest was taken during winter months. Trolling and, to a far lesser extent longlining, accounted for a further 1.6 to 9.9% of the regional boat-based kahawai catch, which was not directly assessable from the air. All harvests were estimated with a reasonable level of precision.

The addition of regional estimates of the shore-based kahawai harvests derived from a concurrent national panel survey (National Research Bureau 2013) increases the 2011–12 aerial-access harvest estimate for KAH 1 by 34% to 942 t (Table 4).

Table 4: Estimates of the recreational harvest of kahawai taken from three regions of KAH 1 during the 2011–12 fishing year, during summer (1 October 2011 to 30 April 2012), winter (1 May 2012 to 30 September 2012) and for the full fishing year. Regional harvest estimates are also given by day type. Further estimates are also given for the area covered by a concurrent multi creel survey of the western Bay of Plenty fishery undertaken by Blue Water Marine Research (BWMR) (Holdsworth 2013). 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 (National Research Bureau 2013) which was not part of this study.

Region	Day type	Summer	Winter	2011–12	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	109 (0.16)	12 (0.35)	121 (0.16)	9.9%	134 (0.16)	29.9%	191 (0.16)
	Weekends/ Pubic holidays	48 (0.19)	4 (0.49)	52 (0.18)		57 (0.18)		
	Midweek days	62 (0.25)	7 (0.45)	69 (0.23)		77 (0.23)		
Hauraki Gulf	All days	349 (0.14)	48 (0.25)	397 (0.13)	1.6%	403 (0.13)	16.5%	483 (0.13)
	Weekends/ Pubic holidays	202 (0.17)	29 (0.35)	231 (0.16)		235 (0.16)		
	Midweek days	147 (0.24)	19 (0.33)	166 (0.22)		168 (0.22)		
Bay of Plenty	All days	125 (0.12)	26 (0.18)	151 (0.11)	9.8%	168 (0.11)	37.4%	268 (0.12)
	Weekends/ Pubic holidays	56 (0.15)	17 (0.24)	73 (0.13)		81 (0.13)		
	Midweek days	69 (0.18)	10 (0.28)	78 (0.17)		168 (0.11)		
KAH 1	All days	583 (0.09)	86 (0.16)	669 (0.08)		705 (0.08)		942 (0.08)
	Weekends/ Pubic holidays	306 (0.12)	50 (0.22)	356 (0.11)		373 (0.11)		
	Midweek days	277 (0.14)	36 (0.21)	313 (0.13)		332 (0.13)		
BWMR survey area	All days	80 (0.16)	18 (0.24)	98 (0.14)	9.8%	109 (0.14)	33.9%	165 (0.15)
	Weekends/ Pubic holidays	37 (0.20)	10 (0.34)	47 (0.18)		52 (0.18)		
	Midweek days	44 (0.25)	8 (0.31)	51 (0.22)		57 (0.22)		

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 21 tonnes landed throughout eastern GUR 1 during the 2011–12 fishing year 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 levels of 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 (National Research Bureau 2013) increases the 2011–12 aerial-access harvest estimate for the east coast of GUR 1 by 14% to 24 t.

Table 5: Estimates of the recreational harvest of red gurnard taken from three regions of the east coast of GUR 1 during the 2011–12 fishing year, during summer (1 October 2011 to 30 April 2012), winter (1 May 2012 to 30 September 2012) and for the full fishing year. Regional harvest estimates are also given by day type. Further estimates are also given for the area covered by a concurrent multi creel survey of the western Bay of Plenty fishery undertaken by Blue Water Marine Research (BWMR) (Holdsworth 2013). 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 (National Research Bureau 2013) which was not part of this study.

Region	Day type	Summer	Winter	2011–12	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	2 (0.30)	0 (1.14)	2 (0.30)	5.9%	3 (0.30)	21.4%	3 (0.31)
	Weekends/ Pubic holidays	1 (0.33)	0 (1.14)	1 (0.33)		1 (0.33)		
	Midweek days	1 (0.50)	–	1 (0.50)		1 (0.50)		
Hauraki Gulf	All days	5 (0.15)	1 (0.35)	5 (0.14)	2.6%	6 (0.14)	1.7%	6 (0.14)
	Weekends/ Pubic holidays	4 (0.18)	0 (0.49)	4 (0.17)		4 (0.17)		
	Midweek days	1 (0.27)	0 (0.49)	1 (0.24)		2 (0.24)		
Bay of Plenty	All days	9 (0.14)	3 (0.28)	12 (0.12)	8.9%	13 (0.12)	12.6%	15 (0.13)
	Weekends/ Pubic holidays	4 (0.16)	1 (0.31)	6 (0.15)		6 (0.15)		
	Midweek days	4 (0.22)	2 (0.42)	6 (0.20)		13 (0.12)		
GUR 1 (east)	All days	16 (0.1)	4 (0.24)	20 (0.09)		21 (0.09)		24 (0.09)
	Weekends/ Pubic holidays	9 (0.11)	2 (0.26)	11 (0.10)		11 (0.10)		
	Midweek days	7 (0.18)	2 (0.36)	9 (0.16)		10 (0.16)		
BWMR survey area	All days	6 (0.18)	2 (0.36)	8 (0.16)	8.9%	9 (0.16)	9.6%	10 (0.16)
	Weekends/ Pubic holidays	3 (0.21)	1 (0.39)	4 (0.18)		4 (0.18)		
	Midweek days	3 (0.30)	2 (0.49)	5 (0.25)		5 (0.25)		

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 harvest estimate for eastern TAR 1 for the 2011–12 fishing year was 67 t for boat-based fishing, of which 79% was landed from the Bay of Plenty (Table 6). The seasonal harvest estimates for the Bay of Plenty region are of a similar magnitude, which suggests that higher catch rates during the winter were offset by a lower level of fishing effort during these months. Almost no tarakihi were observed in Hauraki Gulf landings and the few catches that were observed came from deeper waters in the northern Gulf. Adjustments made for tarakihi caught by other boat-based methods which were not assessable from the air only increased the harvest estimates by a very small degree (0.5% to 2.6%), 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 (National Research Bureau 2013) increases the 2011–12 aerial-access harvest estimate for the east coast of TAR 1 by less than 1 tonne (Table 6).

Table 6: Estimates of the recreational harvest of tarakihi taken from three regions of the east coast of TAR 1 during the 2011–12 fishing year, during summer (1 October 2011 to 30 April 2012), winter (1 May 2012 to 30 September 2012) 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 (National Research Bureau 2013) which was not part of this study.

Region	Day type	Summer	Winter	2011–12	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	8 (0.51)	4 (0.78)	12 (0.43)	0.5%	12 (0.43)	0.6%	12 (0.43)
	Weekends/ Pubic holidays	4 (0.36)	1 (1.21)	4 (0.36)		4 (0.36)		
	Midweek days	4 (0.89)	3 (0.92)	8 (0.65)		8 (0.65)		
Hauraki Gulf	All days	2 (1.02)	–	2 (1.02)	2.6%	2 (1.02)	3.2%	2 (1.01)
	Weekends/ Pubic holidays	0 (1.08)	–	0 (1.08)		0 (1.08)		
	Midweek days	2 (1.09)	–	2 (1.09)		2 (1.09)		
Bay of Plenty	All days	26 (0.18)	26 (0.27)	52 (0.16)	1.5%	53 (0.16)	0.3%	53 (0.16)
	Weekends/ Pubic holidays	17 (0.22)	13 (0.40)	30 (0.21)		30 (0.21)		
	Midweek days	9 (0.32)	13 (0.39)	22 (0.26)		53 (0.16)		
TAR 1	All days	36 (0.18)	30 (0.26)	66 (0.15)		67 (0.15)		67 (0.15)
(east)	Weekends/ Pubic holidays	21 (0.19)	13 (0.38)	34 (0.19)		35 (0.19)		
	Midweek days	15 (0.34)	16 (0.36)	32 (0.24)		32 (0.24)		

Although recreational harvest estimates for TRE 1 were not a specified requirement for this programme, 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 Hauraki Gulf (43%), but relatively substantial tonnages were also taken from the Bay of Plenty (35%) and from East Northland (22%). Almost all of the trevally harvest was taken during the summer. Only a very small proportion of the trevally catch in each region was taken by longlining and trolling (1.2% to 3.5%) (Table 7).

The addition of regional estimates of the shore-based harvest derived from a concurrent national panel survey (National Research Bureau 2013) increases the 2011–12 aerial-access harvest estimate for TRE 1 by 20% overall, to 124 t (Table 7).

Table 7: Estimates of the recreational harvest of trevally taken from three regions of TRE 1 during the 2011–12 fishing year, during summer (1 October 2011 to 30 April 2012), winter (1 May 2012 to 30 September 2012) 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 (National Research Bureau 2013) which was not part of this study.

Region	Day type	Summer	Winter	2011–12	Other boat methods	plus other boat methods	Shore methods	plus shore methods
East Northland	All days	19 (0.25)	3 (0.56)	22 (0.23)	2.9%	23 (0.23)	23.2%	30 (0.25)
	Weekends/ Pubic holidays	6 (0.25)	3 (0.72)	8 (0.28)		9 (0.28)		
	Midweek days	13 (0.34)	1 (0.64)	14 (0.32)		14 (0.32)		
Hauraki Gulf	All days	40 (0.22)	4 (0.34)	44 (0.20)	1.2%	44 (0.20)	15.2%	52 (0.21)
	Weekends/ Pubic holidays	18 (0.20)	3 (0.39)	21 (0.18)		21 (0.18)		
	Midweek days	21 (0.37)	2 (0.66)	23 (0.34)		23 (0.34)		
Bay of Plenty	All days	31 (0.17)	4 (0.42)	35 (0.16)	3.5%	36 (0.16)	13.1%	41 (0.16)
	Weekends/ Pubic holidays	17 (0.22)	2 (0.34)	19 (0.20)		20 (0.20)		
	Midweek days	14 (0.27)	2 (0.80)	16 (0.26)		36 (0.16)		
TRE 1	All days	90 (0.12)	11 (0.25)	101 (0.11)		103 (0.11)		124 (0.12)
	Weekends/ Pubic holidays	41 (0.14)	7 (0.30)	48 (0.13)		49 (0.13)		
	Midweek days	48 (0.20)	4 (0.43)	53 (0.18)		54 (0.18)		

How typical was the random selection of a subsample of survey days?

One of the key assumptions of this survey was that the random selection of a subsample days from each seasonal/day-type stratum was representative of all days occurring within that stratum, in terms of recreational effort and harvest. Daily boat ramp traffic data were available from a web camera overlooking the boat ramp at Sulphur Point, in Tauranga. Comparisons of the distribution of boat traffic counts on survey days relative to that on all days occurring within each temporal stratum suggest that the selection of survey days was broadly representative for the two summer strata but less so for the two winter strata (Figure 7). These data suggest that levels of fishing effort on surveyed days were lower than average during winter months, especially for the winter/weekend stratum.

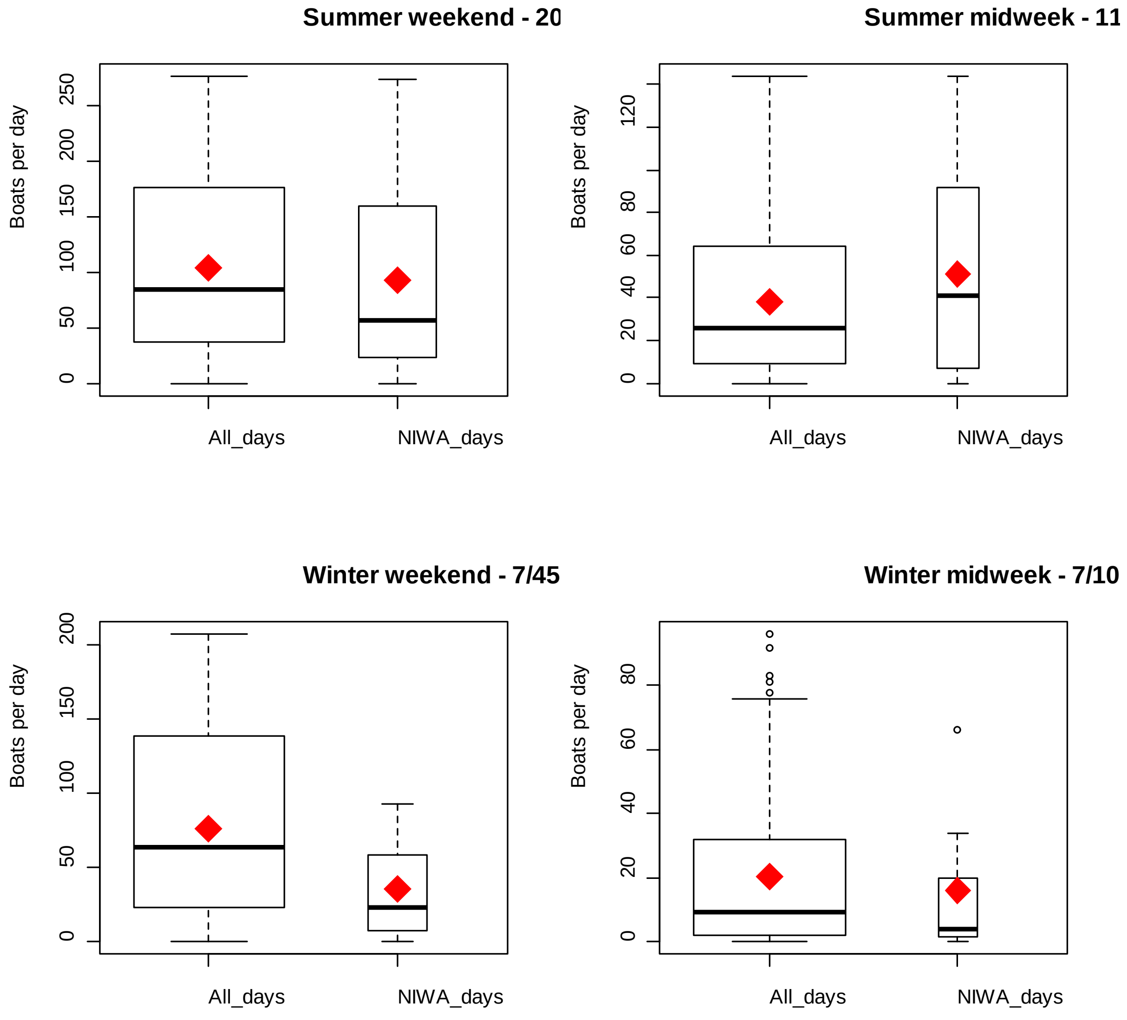


Figure 7: Comparision of the distribution of daily web camera based counts of boats returning to the Sulphur Point boat ramp on all days relative to that on scheduled survey days, by seasonal/day type strata for the 2011–12 fishing year. Box plots show quantile ranges and solid diamonds denote averaged daily boat traffic counts for each plot. Panel titles give the number of days sampled relative to the number of days falling within each temporal stratum.

Comparison of harvest estimates from the 2004–05 and 2011–12 surveys.

The methods used to estimate recreational harvests in 2011–12 were closely based on those used in 2004–05 (Hartill et al. 2007a). A comparison of estimates of total recreational harvest of snapper, kahawai, red gurnard, tarakihi and trevally provided by these two 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) and 2011–12. Numbers in brackets denote CVs

Species	Fishery	2004–05	2011–12	Difference
Snapper	East Northland	557 (0.13)	718 (0.14)	+ 29%
	Hauraki Gulf	1345 (0.10)	2490 (0.08)	+85%
	Bay of Plenty	517 (0.10)	546 (0.12)	+6%
	SNA 1	2419 (0.06)	3754 (0.06)	+55%
Kahawai	East Northland	129 (0.14)	191 (0.16)	+48%
	Hauraki Gulf	98 (0.18)	483 (0.13)	+490%
	Bay of Plenty	303 (0.14)	268 (0.12)	-12%
	KAH 1	530 (0.09)	942 (0.08)	+78%
Red gurnard	GUR 1	127 (0.14)	24 (0.09)	-71%
Tarakihi	TAR 1	90 (0.18)	67 (0.15)	-26%
Trevally	TRE 1	105 (0.18)	124 (0.12)	+18%

The most substantive differences between the 2004–05 and 2011–12 harvest estimates are evident for the Hauraki Gulf snapper and kahawai fisheries. The 490% increase in the recreational harvest of kahawai from the Gulf is substantial but not unexpected given the marked influx of schools of large fish into this region in recent years. The length and age distribution of kahawai landed by recreational fishers has been monitored in all three regions of KAH 1 during most summers since 2001, and the age composition of fish landed from the gulf was dominated by three year old fish (about 40 cm in length) up until 2006 (Armiger et al. 2013). The incidence of older and larger fish in recreational landings from the Gulf has increased markedly in recent years, however, and the presence of these fish is thought to be due to immigration from other regions.

The harvest estimate for SNA 1 in 2011–12 is over 1300 t greater than the 2004–05 estimate and this increase almost entirely took place in the Hauraki Gulf. This difference is largely explained by an increasing trend in the average weight of snapper landed per fisher trip since the early 1990s (Figures 8 and 9). Both the average snapper weight and the number of snapper landed per fisher have increased over this period.

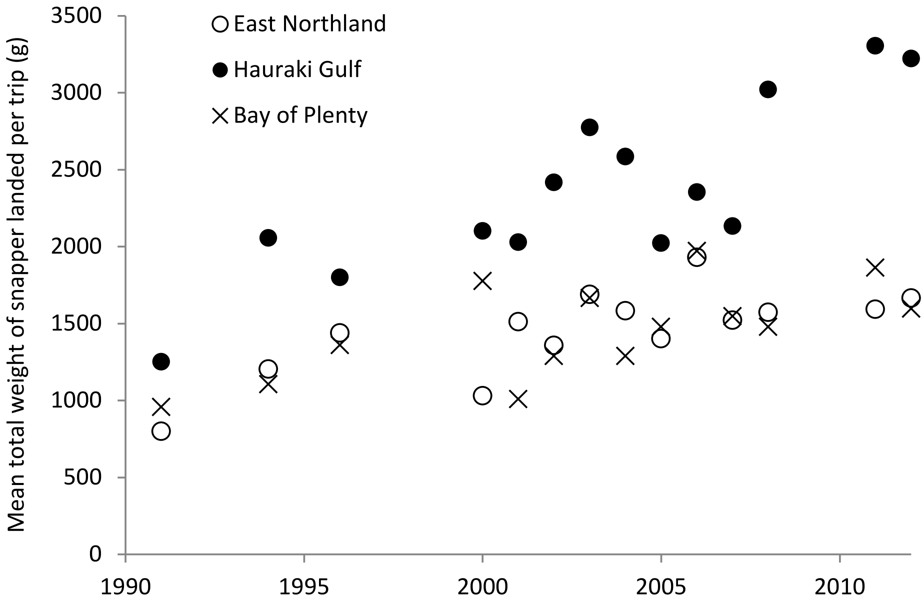


Figure 8: Changes in the average weight of snapper landed per fisher trip in the three regions of SNA 1 since 1991 based on boat ramp interview data collected during the months of January to April (Hartill 2013).

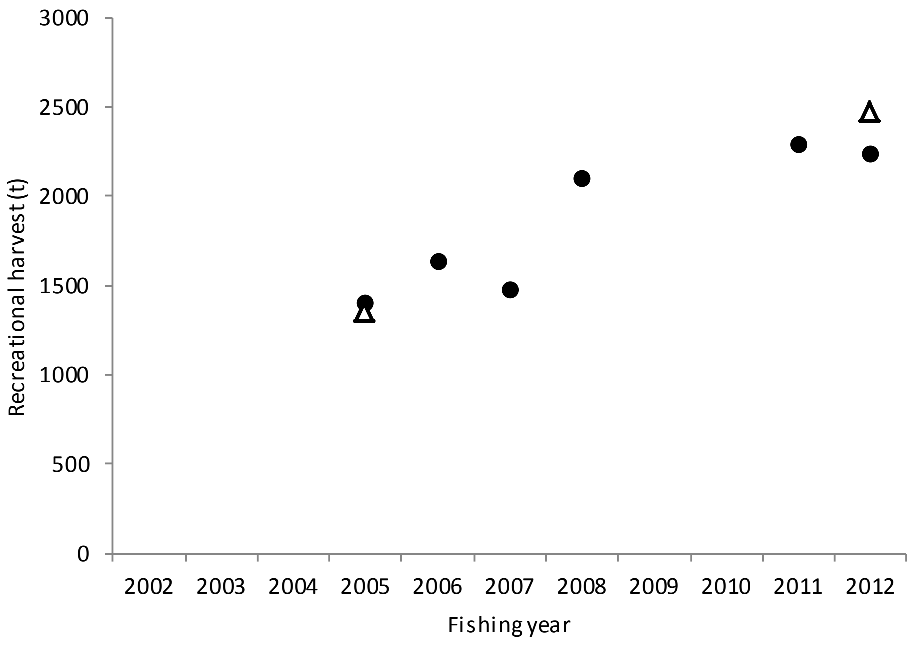


Figure 9: Difference between aerial access estimates of the harvest taken from the Hauraki Gulf in 2004–05 and 2011–12 (denoted by open triangles) explained by changes in the average weight of snapper landed per trip over the intervening period (denoted by closed circles). The geometric mean of the average trip weight estimates has been scaled to the geometric mean of the aerial-access estimates.

4. DISCUSSION

The summer of 2011–12 was the cloudiest on record, with higher than average rainfall, resulting in a greater incidence of cancelled flights than that experienced during previous aerial-access surveys. The scheduling of both the aerial and the access point surveys on the same days does, however, provide an informed means of estimating flight counts on weather affected days. Aerial counts predicted from area specific regressions suggest that only 7.2% of the effort that took place on the 45 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 likely low level of fishing effort on these unflown days.

The distribution of fishing effort in space and time and in response to prevailing weather conditions was as expected from previous studies with one marked exception. On the 5th of October the M.V. *Rena* ran aground as it approached Tauranga Harbour. An extensive exclusion zone was immediately established that prohibited anglers from fishing in one of the most heavily fished parts of the Bay of Plenty, which was mostly reopened on the 18th of November (Appendix 2). Boat ramps in Tauranga Harbour and immediately east were also closed for about a week and despite an apparent increase in fishing effort in other areas of the Bay, the recreational catch in 2011–12 would have been lower than normally expected for this reason.

The estimates provided in this report suggest that recreational harvests of snapper and kahawai from FMA 1 have increased substantially since 2004–05 (from 2419 t to 3754 t for SNA 1 and 530 t to 942 t for KAH 1; see Hartill et al. 2007a for previous estimates), when the aerial-access method was last used to assess harvests in this area. Almost all of the increased harvest of these two species occurred in the Hauraki Gulf, with only modest increases seen in harvest estimates for these species in East Northland and the Bay of Plenty.

The 2011–12 snapper harvest estimate for the Hauraki Gulf of 2490 t is almost twice that estimated in 2004–05 (1345 t). Although this increase is substantial, it is not unexpected given anecdotal reports of higher catch rates in recent times. A recent analysis of creel survey data collected since 1991 (Hartill 2013) found steadily increasing trends in both the average size of snapper landed from the Gulf and in snapper catch rates, which largely explain the difference between the 2004–05 and 2011–12 harvest estimates. Stratum specific comparisons of estimated levels of effort in 2004–05 and 2011–12 suggest that any increase in effort of this period has been modest.

The average size of kahawai and the rate at which they were landed in the Gulf was also far greater in 2011–12 than in 2004–05. Recreational landings of kahawai have been monitored almost annually since 2001 (see Armiger et al. 2013), and until recently the size composition of Gulf landings was dominated by two and three year old fish weighing approximately 1 kg. Most of the kahawai landed in recent years now weigh 2–3 kg and they are also landed more frequently than seven years ago. The size composition and abundance of kahawai in the Hauraki Gulf can vary considerably as schools move in and out of the Gulf, and the recreational harvest in this region will probably continue to vary to a considerable degree, potentially declining at times.

Conversely, there appears to have been a substantial decline in recreational landings of red gurnard taken from the east coast of GUR 1, as the 2004–05 t estimate of 127 t is five times that estimated for 2011–12; 24 t. Bottom trawl catch rates in GUR 1E have also declined substantially since a peak in 2004–05 (Kendrick & Bentley 2011). The estimated harvests from TAR 1 and TRE 1 in 2004–05 (90 t and 105 t) and in 2011–12 (67 t and 124 t) are of a broadly similar magnitude given their associated estimates of uncertainty.

Although the aerial-access survey methods used in this programme were closely based on those used in similar surveys in the past (Davey et al. 2008; Hartill et al. 2007a, 2007b, 2008), some changes were implemented in 2011–12 to improve the accuracy of this approach. These were: a greater emphasis placed on interviewers primarily detecting and recording the presence of all boats returning during interview session with interviewing being of secondary importance, extending interview sessions later into the evening past dusk, using trailer boat counts at the end of each survey day to account for the catch landed by fishers returning to a surveyed ramp after the interviewer had left, using GIS/GPS technology to ensure full coverage of these flight routes and to more accurately record the locations of fishing boats, and surveying at two additional ramps in areas where more coverage was deemed necessary. These changes will have addressed some (mostly negative) sources of bias, but it is unlikely that these biases would have had a substantial impact on past estimates.

The following sources of bias remain which should also be considered but these are not thought to be substantial.

Harvest estimates for some species (primarily kahawai and tarakihi) could have been underestimated because stationary boats fishing offshore were not detected from the air. Recreational vessels fishing within 5 km of the flight route (the width of Tamaki Strait at its narrowest point) were normally clearly visible from an altitude of 1000 feet, but beyond that distance detectability declines. The survey routes flown in 2011–12 were mostly within a few kilometres of the coast, with diversions out around offshore islands and known fishing grounds. These flight routes were designed to cover recreationally fished coastal areas in the most efficient manner possible, and were closely based on those flown during the 2004–05 survey. It is implicitly assumed that all vessels fishing within the detectable range of these flights were detected and counted, and that none of these vessels were counted twice. It is possible, however, that some boats fishing far off shore will have been missed, although these boats will have only accounted for a very small proportion of the fleet fishing on that day. Flights returning to the aerodrome at the end of a survey flight often flew direct routes home which took them over waters outside of the normal survey route, and observations of boats fishing in these areas were relatively uncommon.

Approximately a quarter of the boats counted by interviewers were not interviewed because the interviewer was still interviewing another fishing party at that time. Copies of data from the next interviewed boat were attributed to the uninterviewed boat (regardless of whether or not they were fishing) to provide an approximated census of all boats returning to that ramp on that day. The imputation of data for uninterviewed boats in this manner could lead to biased harvest estimates if non-fishing boats were preferentially selected for interviewing over those used for fishing, or vice versa. This possibility was examined by dropping data for uninterviewed boats and recalculating harvest estimates for snapper, the most commonly caught species. The resulting harvest estimate was within 2% of that calculated when all data were used, which suggests that interviewers favoured neither fishing nor non-fishing boats when they were unable to interview all boats at busy times.

The effort required to interview fishers returning to the large number of potential access points throughout FMA 1 is logistically onerous and not cost effective, and interviews were therefore conducted at a limited number of access points only. We have therefore implicitly assumed that the effort and catch of fishers returning to surveyed ramps is broadly representative of that of other fishers returning to nearby unsurveyed ramps. Creel survey data collected at secondary “non-survey” ramps were compared with that collected concurrently at nearby “survey” ramps during the 2003–04 aerial-access survey (Hartill et al. 2007b). These comparisons suggested that the catch rates and fishing durations of fishers returning to both groups of ramps were broadly similar at that time, and this assumption is still considered to be broadly valid. The location fished is of more relevance when determining fisher success rather than the location of the launch site, and this issue was a primary consideration when determining the geographical location and degree of separation between surveyed ramps.

Another key assumption of this survey was that levels of recreational catch and effort on surveyed days were representative of those experienced by fishers on all days within a given temporal stratum. This assumption is usually untested as direct observations of the fishery are not normally available for all days regardless of whether or not they were surveyed. Daily boat ramp traffic data were available for the entire 2011–12 fishing year, however, which were derived from a continuous time series of images taken by a web camera overlooking the Sulphur Point boat ramp in the Bay of Plenty. Comparisons of the distribution of boat traffic counts on survey days relative to that for all days occurring within each seasonal/day-type stratum suggest that although the summer strata survey days were broadly representative in terms of boating effort, the selection of survey days for the two winter strata favoured low effort days This would suggest that the harvests occurring during the two shorter and quieter winter strata were underestimated to some degree. A similar approach was used in 2004–05 based on images of the Takapuna ramp in the Hauraki Gulf, and no significant bias was evident in that instance. Web camera imagery suggests that very little if any recreational catch is taken during the hours of darkness.

Overall, the survey methods used for the 2011–12 survey were closely based on those used in 2004–05, and any comparison of harvest estimates collected by the same method should be valid in a relative sense, once all sources of bias are considered. Fisheries managers, however, require reasonably accurate estimates for all sources of fishing mortality in an absolute sense, and the introspective examination of data and estimates provided by a single survey method can only be used to assess the plausibility of the estimates it produces and not their accuracy. The best means of assessing the accuracy of an estimate is to compare it with another directly comparable estimate generated concurrently by another independent survey method.

At the time that this report was written, preliminary but directly comparable harvest estimates were available from two other independent surveys which were also undertaken throughout the 2011–12 fishing year. The largest of these was a national panel survey which combined information from a national face-to-face survey with diarist data reported via regular text and telephone interviews to provide harvest estimates for all of New Zealand's marine recreational fisheries. This survey was conducted by the National Research Bureau (NRB). The second and equally independent survey was a multi creel method survey of the western Bay of Plenty conducted by Blue Water Marine Research (BWMR). A cursory comparison of the preliminary harvest estimates provided by those two surveys with the harvest estimates provided by this aerial-access survey suggests that they are broadly similar given the levels of error associated with all available estimates. A more detailed and thorough comparison of the harvest estimates provided by all three surveys will be undertaken as part of a separate programme (MAF-2011/04: Calibrating between offsite and onsite recreational harvest estimates).

5. MANAGEMENT IMPLICATIONS

This survey was conducted concurrent to a national panel survey of New Zealand's marine recreational fisheries and a multi-creel survey method study of the western Bay of Plenty which were provided independently by two other research providers. A comparison of harvest estimates provided by these three concurrent surveys suggests that the estimates provided here are unlikely to be biased to any great degree, although the estimates of uncertainty associated with each estimate should be considered when considering their accuracy.

We estimate that the recreational harvest from SNA 1 in 2011–12 was 3754 t, which exceeds the current recreational catch allowance of 2600 t. The 2011–12 harvest estimate for this fishery is far greater than that estimated by a similar survey in 2004–05 (2419 t) and almost all of this increased catch was taken from the Hauraki Gulf, where the average size of fish landed and catch rates have both increased progressively over the past decade. The commercial longline fishery in the Hauraki Gulf has also experienced increasing catch rates over this period (Ministry for Primary Industries 2013).

The recreational harvest estimate for KAH 1 is 942 t, which is very close to the current recreational catch allowance of 900 t. This estimate is substantially greater than the 2004–05 estimate of 530 t but this increase appears to be mostly due to an influx of larger kahawai into the more heavily fished Hauraki Gulf in recent years, which will not necessarily occur in future years. Recreational harvests of kahawai in each region of KAH 1 can fluctuate substantially as numerous schools of fish move in and out of areas commonly fished by anglers.

These results suggest that recreational harvests can change substantially over a relatively short period of time in response to both localised fish abundance and prevailing weather conditions that influence levels of fishing effort. The 2011–12 harvest estimates for these fisheries are therefore only broadly indicative of likely recreational harvesting levels in the future, which could either increase or decrease to an unknown degree.

6. 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 2011–12 fishing year. An aerial survey and an access point survey was used to estimate harvests taken by the recreational fishery on 45 days randomly preselected according to a stratified temporal design, following methods used in a similar survey in 2004–05.
- The aerial-access approach provides estimates of the harvest taken from stationary boat fishing methods only, which account for the majority of the recreational harvest from the fisheries of interest. Harvests taken by unassessed methods (longlining, netting, trolling, diving and shore-based fishing) were estimated indirectly, based on concurrent ancillary data on catch by method.
- The aerial-access survey harvest estimate for SNA 1 for the 2011–12 fishing year is 3402 t, which increased to 3754 t once the harvest taken by other fishing methods was taken into account.
- Two thirds of the estimated commercial harvest for SNA 1 was taken from the Hauraki Gulf (2490 t) where fishers have experienced increasing catch rates and catch size compositions over the past decade.
- The harvest estimate for KAH 1 for 2011–12 is 669 t which increases to 942 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 (483 t), where there appears to have been an influx of schools of large kahawai in recent years.
- The Quota Management Area GUR 1 falls on both the east and west coasts of the upper North Island and a harvest estimate is only available for eastern GUR 1 as no data are available from the west coast. The estimated harvest taken by all forms of recreational fishing from eastern GUR 1 was estimated to be 24 t, of which 15 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 67 t of which an estimated 53 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 124 t was harvested by recreational fishers.
- Two other surveys were also conducted by two other research providers during the 2011–12 fishing year, and preliminary harvest estimates provided by these independent studies are of a

similar magnitude to those provided by our survey. 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 all three surveys will be undertaken as part of a separate programme – MAF-2011/04: Calibrating between offsite and onsite recreational harvest estimates.

7. ACKNOWLEDGMENTS

This work was funded by the Ministry of Primary Industries project MAF-2011/02. The authors wish to thank the numerous aerial observers and boat ramp interviewers who made this study possible. Special thanks are also due to David Fisher, Brian Sanders, Jeremy Yeoman and the data management team in Wellington for quickly processing large volumes of data forms. This project has also benefitted from suggestions made by members of the Marine Amateur Fisheries Working Group. This report was internally review by Jeremy McKenzie (NIWA) and externally by Jeremy Lyle (University of Tasmania, Australia) and Ken Pollack (North Carolina State University, USA).

8. REFERENCES

Armiger, H.; Hartill, B.; Rush, N.; Buckthought, D.; Smith, M. (2013). Length and age compositions of recreational landings of kahawai in KAH 1 from January to April in 2011 and 2012. Final Research Report for MPI project MAF-2010/03. 39 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Bickel, P.J.; Freedman, D.A. (1984). Asymptotic normality and the bootstrap in stratified random sampling. *The Annals of Statistics 12*: 470–482.

Booth, J.G.; Butler, R. W.; Hall, P. (1994). Bootstrap methods for finite populations. *Journal of the American Statistics Association 89*: 1282–1289.

Boyd, R.O.; Gowing, L.; Reilly, J.L. (2004). 2000-2001 National marine recreational fishing survey: diary results and harvest estimates. 81 p. (Unpublished report held by Ministry for Primary Industries, Wellington).

Boyd, R.O.; Reilly, J.L. (2004). 1999/2000 National marine recreational fishing survey: harvest estimates. 84 p. (Unpublished report held by Ministry for Primary Industries, Wellington).

Chao, M. T.; Lo, S. H. (1985). A bootstrap method for finite population. *Sankhya A 47*: 399–405.

Davey, N.K.; Hartill, B.; Cairney, D.G.; Cole, R.G. (2008). Characterisation of the Marlborough Sounds recreational fishery and associated blue cod and snapper harvest estimates. *New Zealand Fisheries Assessment Report 2008/31*. 63 p.

Hart, A.; Walker, N. (2004). Monitoring the recreational blue cod and sea perch fishery in the Kaikoura – North Canterbury area. *New Zealand Fisheries Assessment Report 2004/45*. 30 p.

Hartill, B. (2013). Analyses to inform the management of the SNA 1 recreational fishery. Final Research Report for MPI project MAF-2011-02. 52 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Hartill, B.; Bian, R.; Armiger, H.; Vaughan, M.; Rush, N. (2007a). Recreational marine harvest estimates of snapper, kahawai and kingfish in QMA 1 in 2004–05. *New Zealand Fisheries Assessment Report 2007/26*. 44 p.

Hartill, B.; Bian, R.; Davies, N. (2010). Review of recreational harvest estimates and approaches. Final Research Report for Ministry of Fisheries Project REC-2004/06. 60 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Hartill, B.; Vaughan, M.; Rush, N. (2008). Recreational harvest estimate for SNA 8 in 2006–07. Final Research Report for Ministry of Fisheries Project REC-2005/01. 48 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Hartill, B.W.; Watson, T.G.; Bian, R. (2011). Use of a modified maximum count aerial-access design to survey a large scale recreational fishery in New Zealand. *North American Journal of Fisheries Management 31:6*. 1197–1210.

Hartill, B.; Watson, T.; Cryer, M.; Armiger, H. (2007b). Recreational marine harvest estimates of snapper and kahawai in the Hauraki Gulf in 2003–04. *New Zealand Fisheries Assessment Report 2007/25*. 55 p.

Hoenig, J.M.; Robson, D.S.; Jones, C.M.; Pollock, K.H. (1993). Scheduling counts in the instantaneous and progressive count methods for estimating sportfishing effort. *North American Journal of Fisheries Managemen*t 13: 723–736.

Holdsworth, J.C. (2013). Amateur harvest estimates from an access point survey in the eastern Coromandel and Bay of Plenty, New Zealand in 2010–11 and 2011–12. Draft *Fisheries Assessment Report* held at MPI, Wellington. p 45.

Kendrick, T.H.; Bentley, N. (2011). Fishery characterisations and catch-per-unit-effort indices for three sub-stocks of red gurnard in GUR 1, 1989–90 to 2008–09. *New Zealand Fisheries Assessment Report 2011/4*. 81 p.

Ministry for Primary Industries (2013). Fisheries Assessment Plenary, May 2013: stock assessments and yield estimates. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1357 p.

National Research Bureau (2013). NZ Recreational Marine Fishing Survey 2011-2012: harvest estimates. Draft Final Research Report for Ministry of Primary Industries project MAF-2010/01. 73 p. (Unpublished report held by Ministry for Primary Industries.)

Pierce, R.B.; Bindman, A.G. (1994). Comparison of absolute fishing effort and hourly instantaneous angler counts in a small lake. *North American Journal of Fisheries Management* 14: 447–448.

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 change 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)* in 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.

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

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

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

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.

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

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.

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

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 we 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 1,000 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.

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

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

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

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

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

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).

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

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,

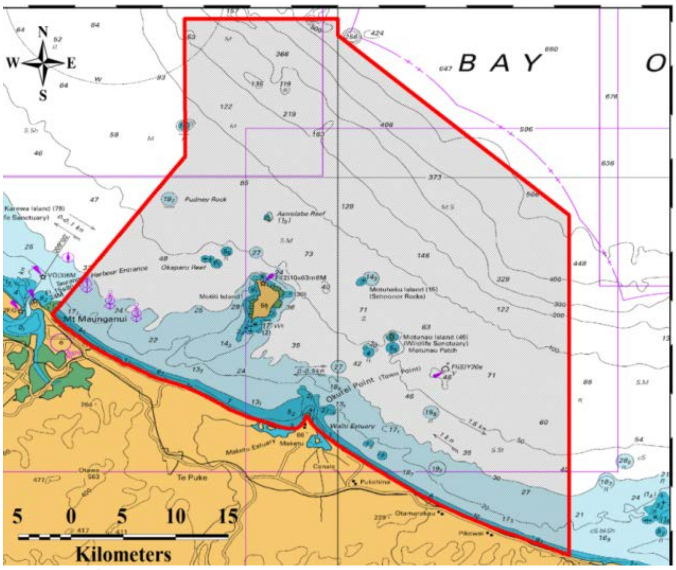
$$e_d = \sum_{k=1}^{K} e(k) = \sum_{k=1}^{K} \tilde{e}(k) \cdot \rho_d , \quad (15)$$

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

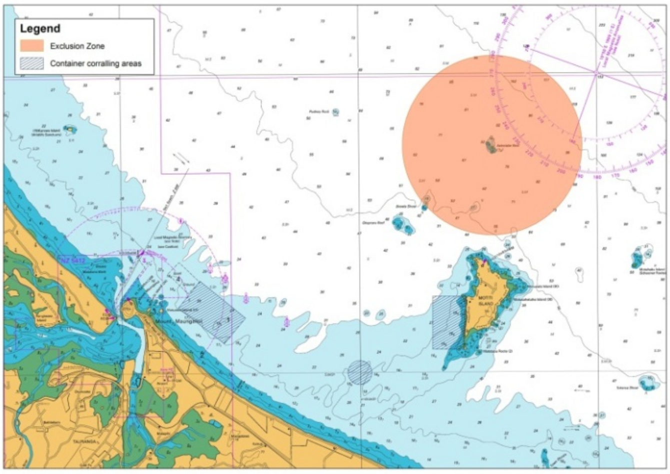
$$\hat{e}_d = \frac{1}{n_t} \cdot \sum_{d=1}^{n_t} e_d . \quad (16)$$

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.

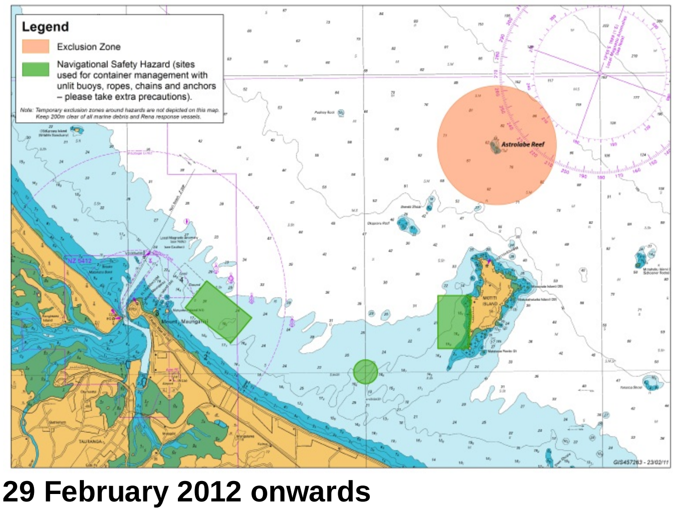
APPENDIX 2: Fishing exclusion areas established following the grounding of the M.V. *Rena*



5 October 2011



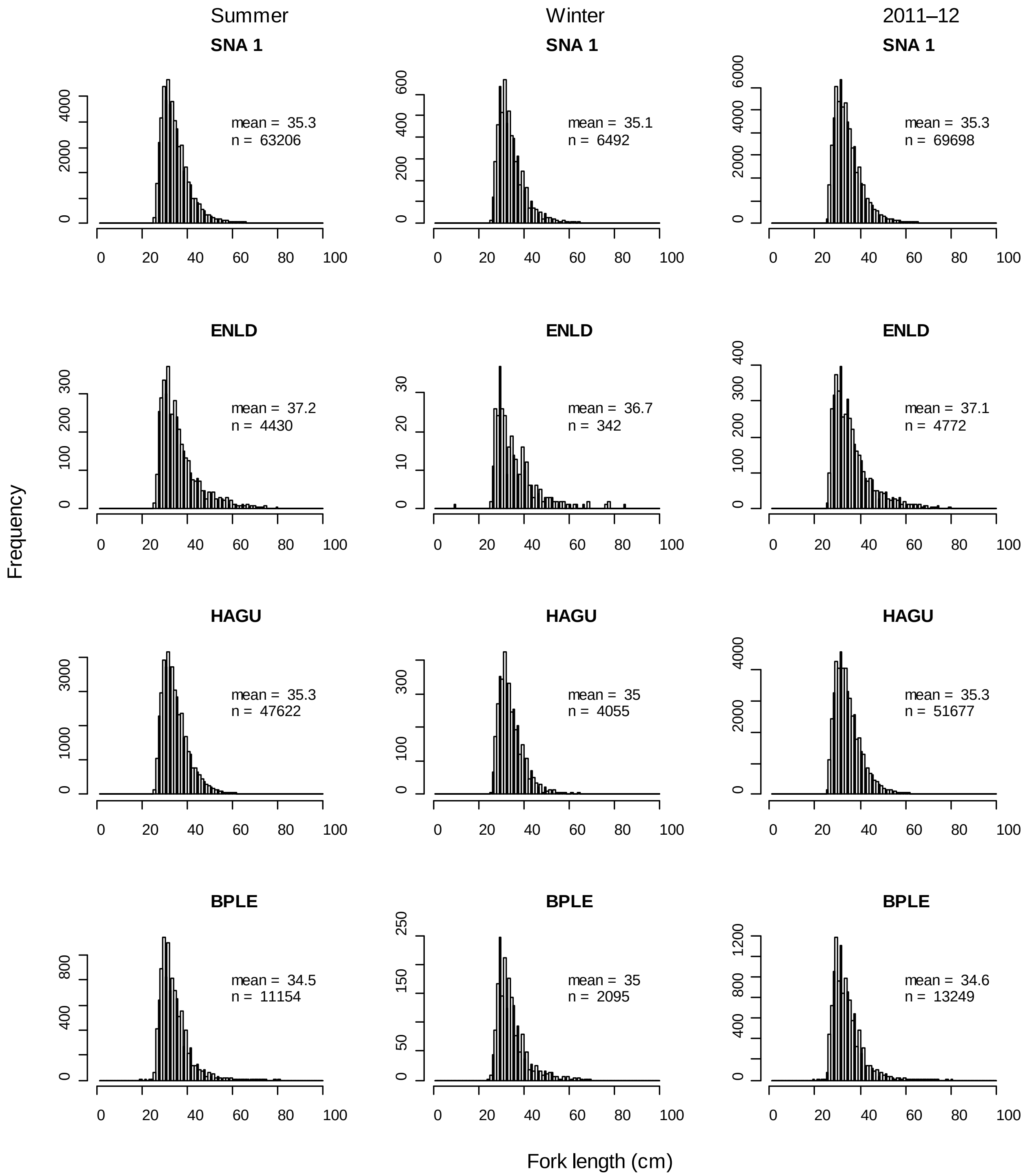
18 November 2011



29 February 2012 onwards

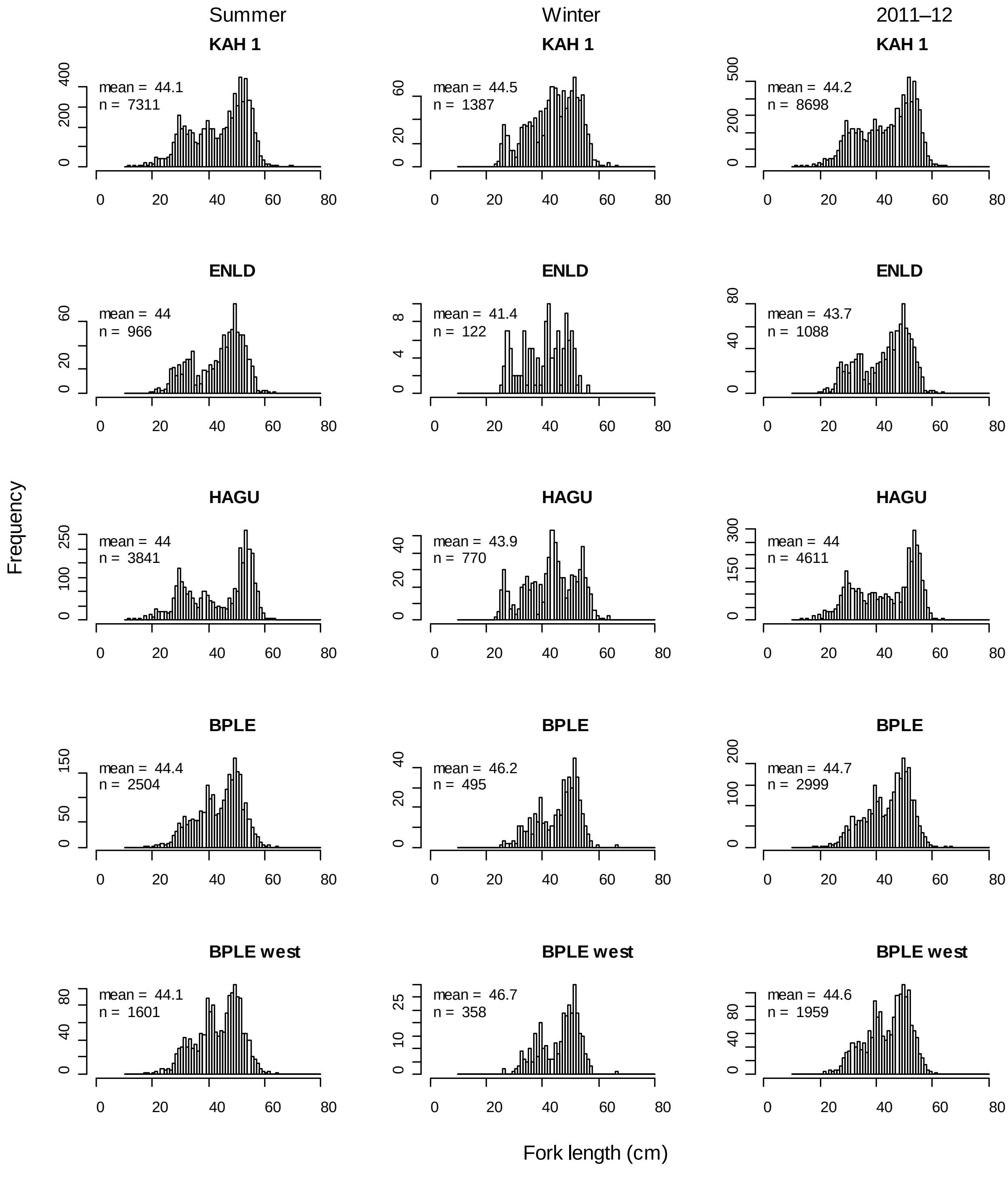
APPENDIX 3: length frequency distributions for species for which harvest estimates are provided by region and season

Snapper length frequencies



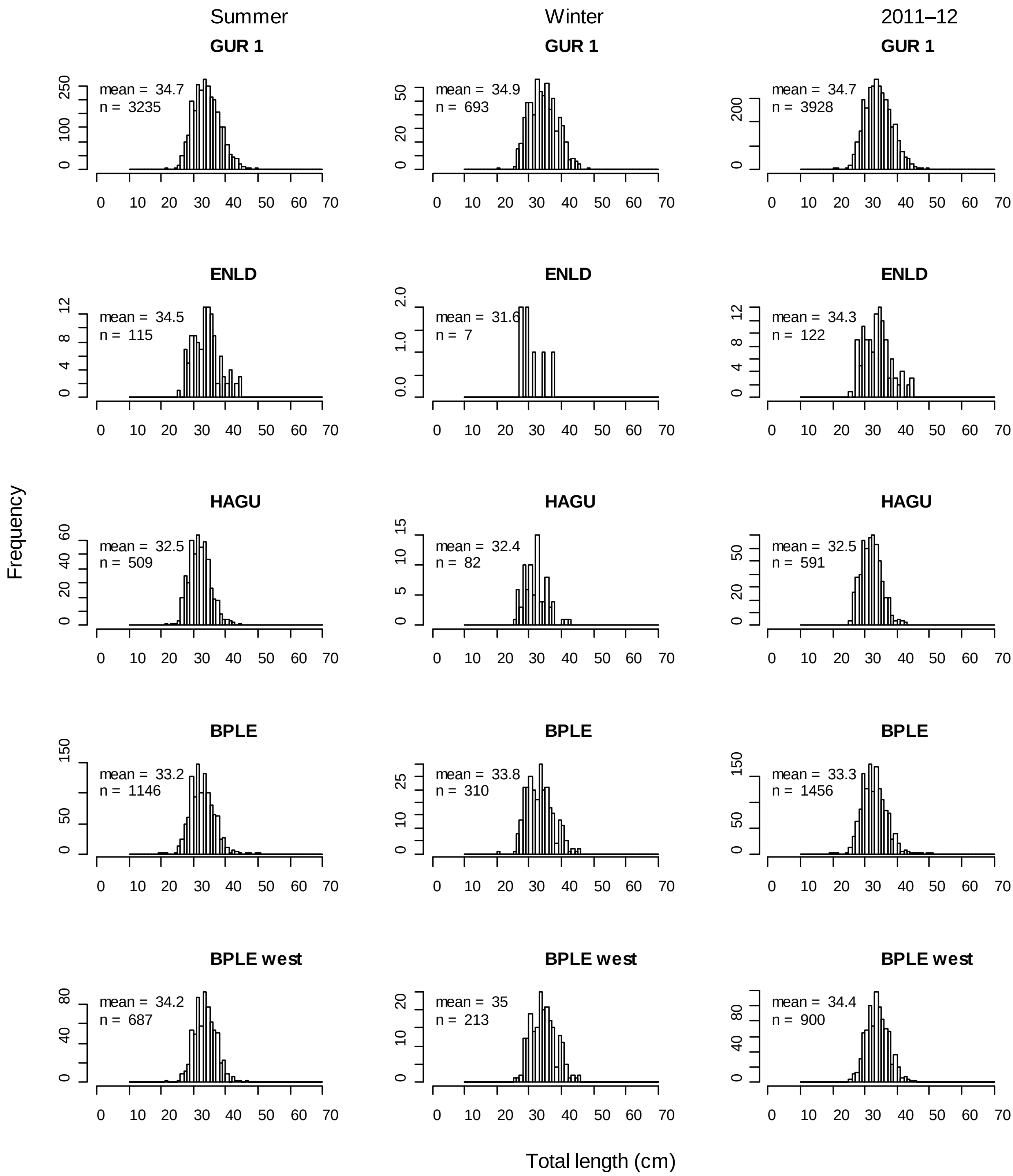
APPENDIX 3: continued

Kahawai length frequencies



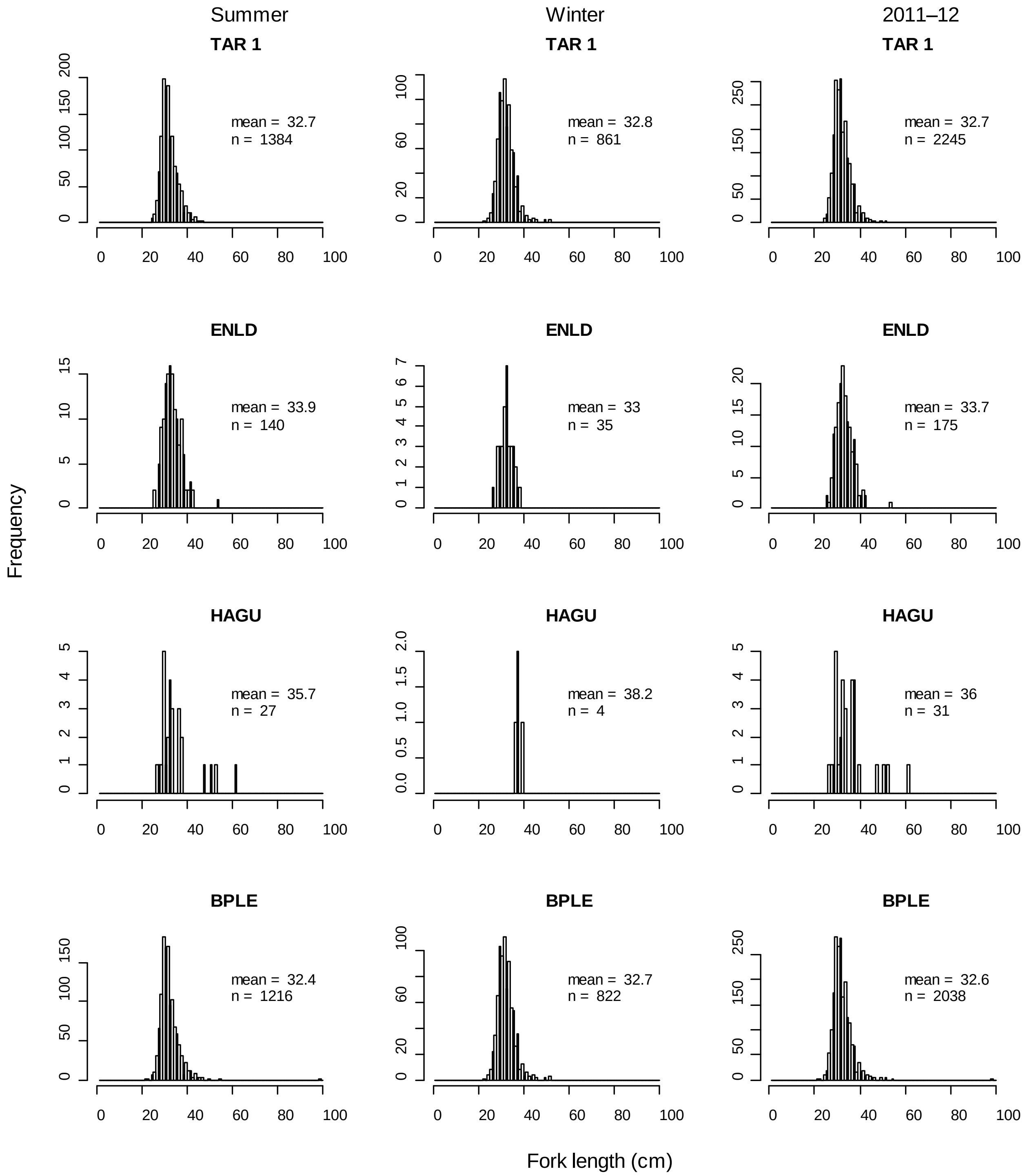
APPENDIX 3: continued

Red gurnard length frequencies



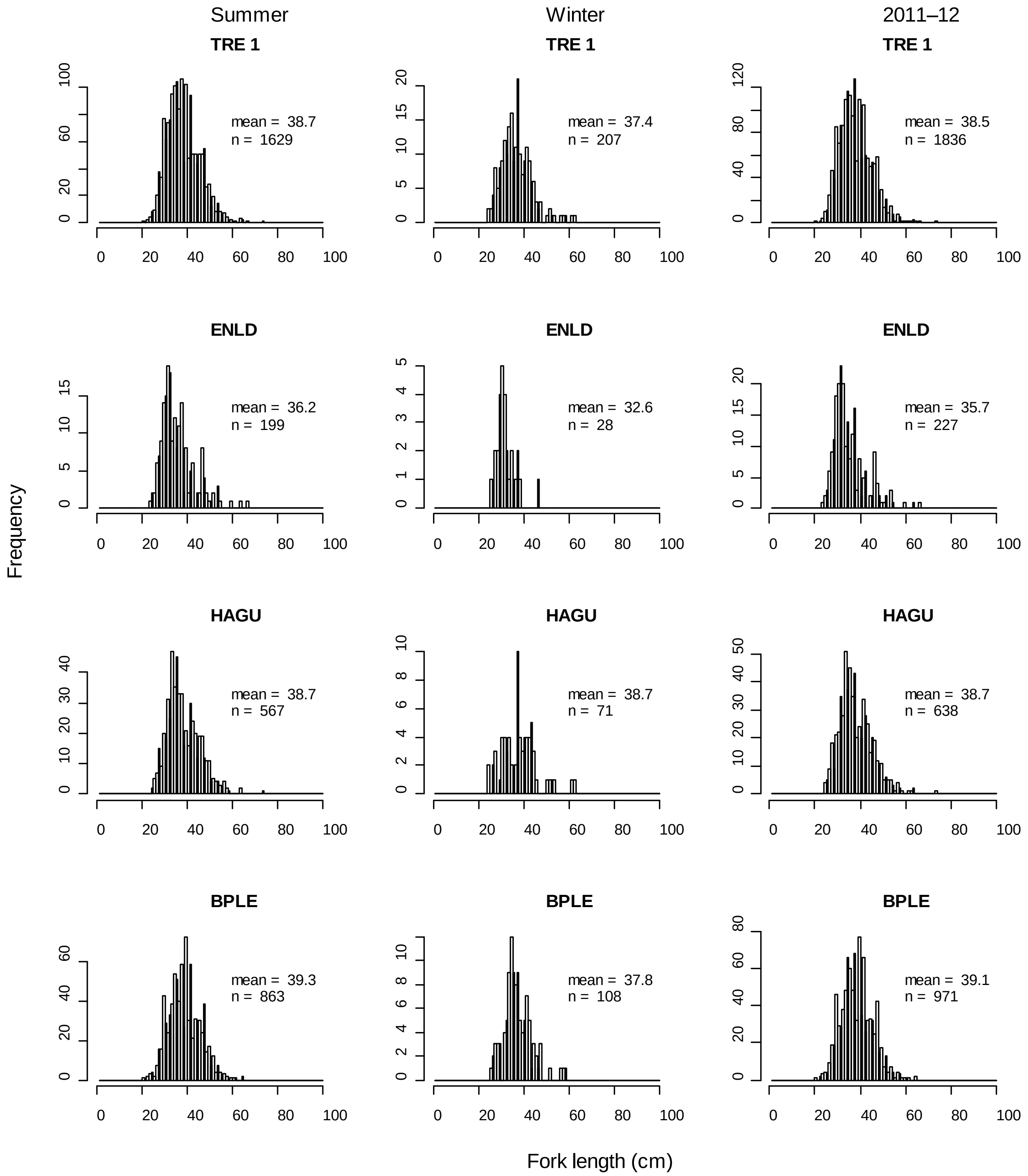
APPENDIX 3: continued

Tarakihi length frequencies



APPENDIX 3: continued

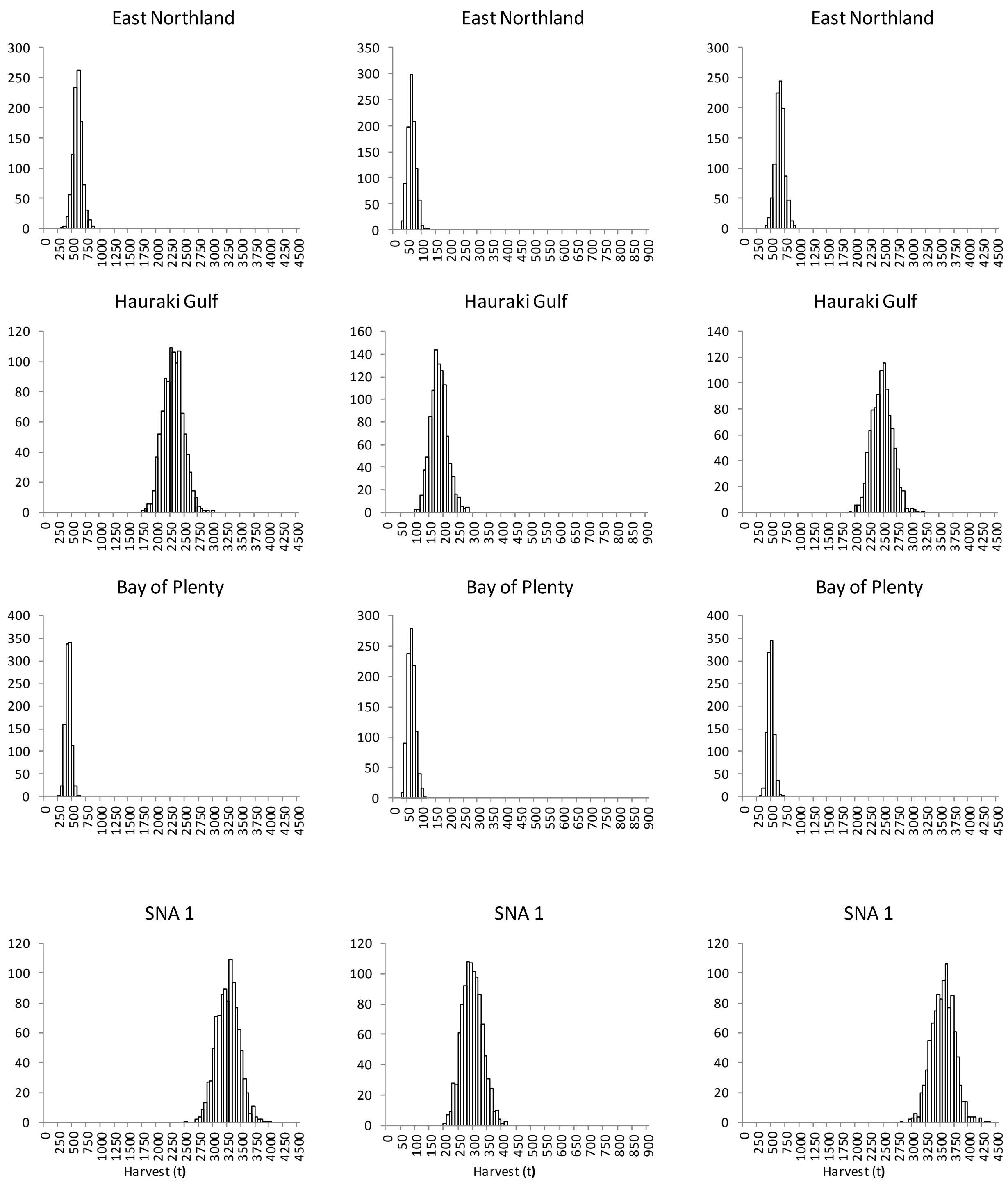
Trevally length frequencies



APPENDIX 4: Distribution of bootstrap harvest estimates for the five most frequently landed species.

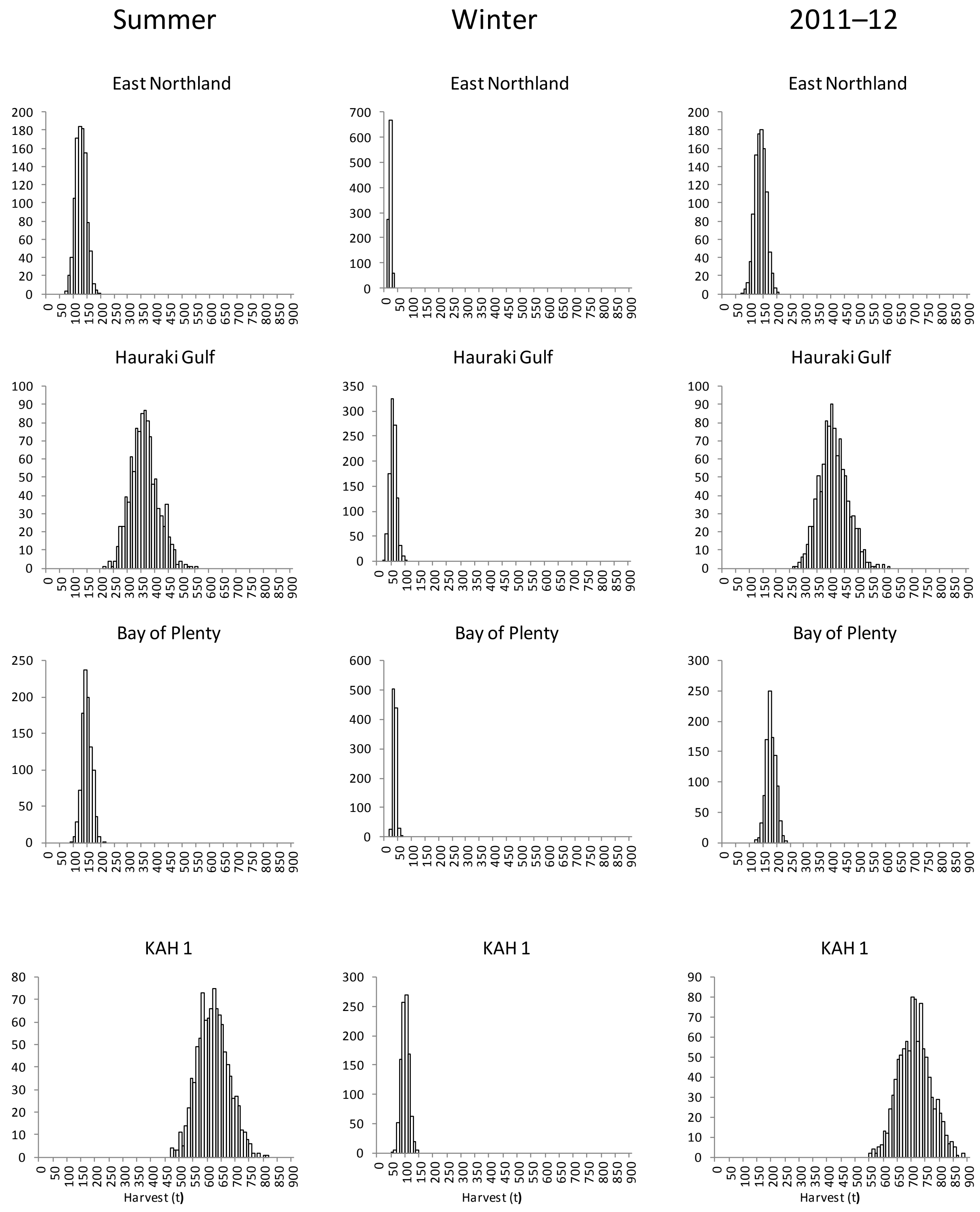
Distributions of bootstrap harvest estimates for snapper

Summer | Winter | 2011–12



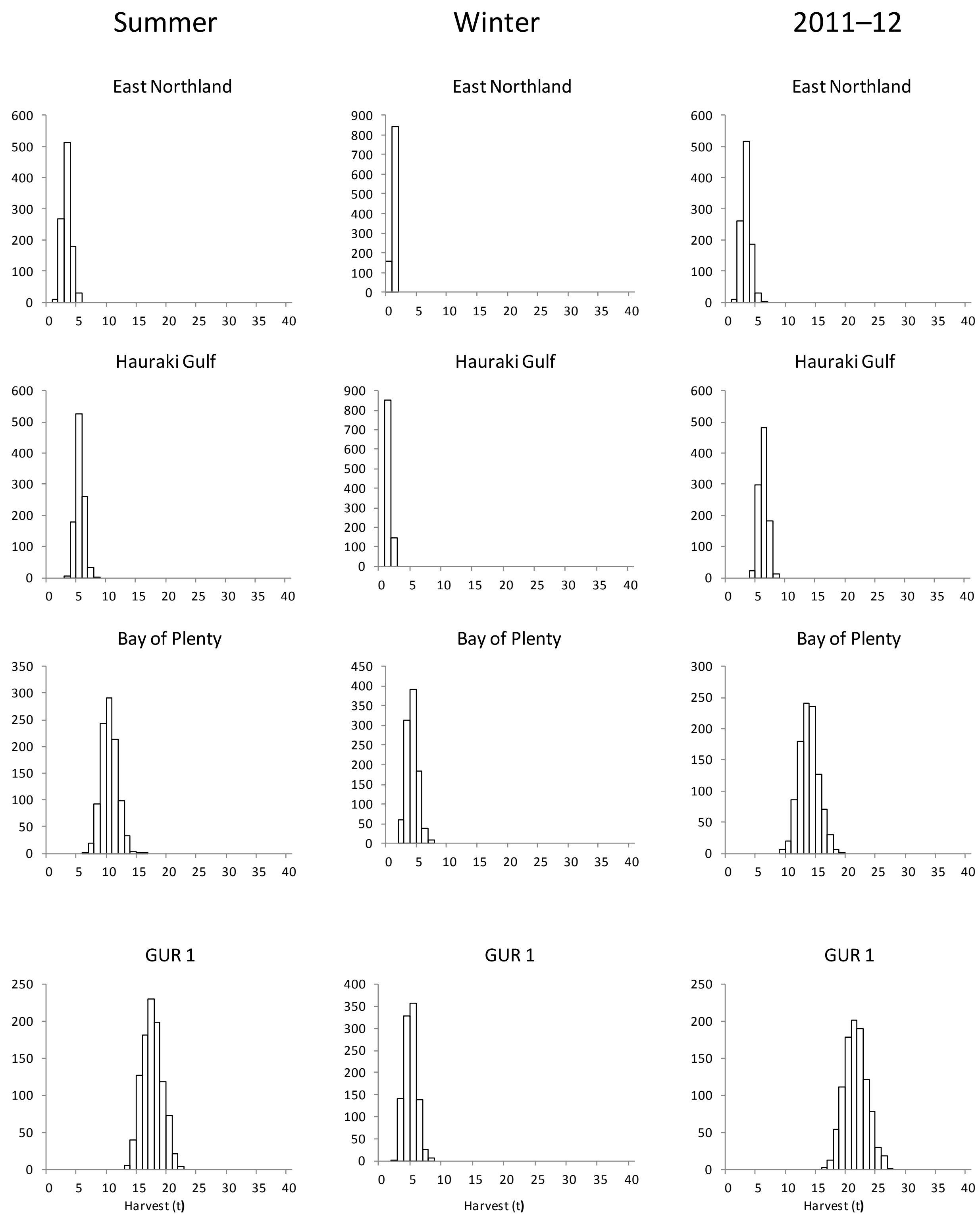
APPENDIX 4: continued

Distributions of bootstrap harvest estimates for kahawai



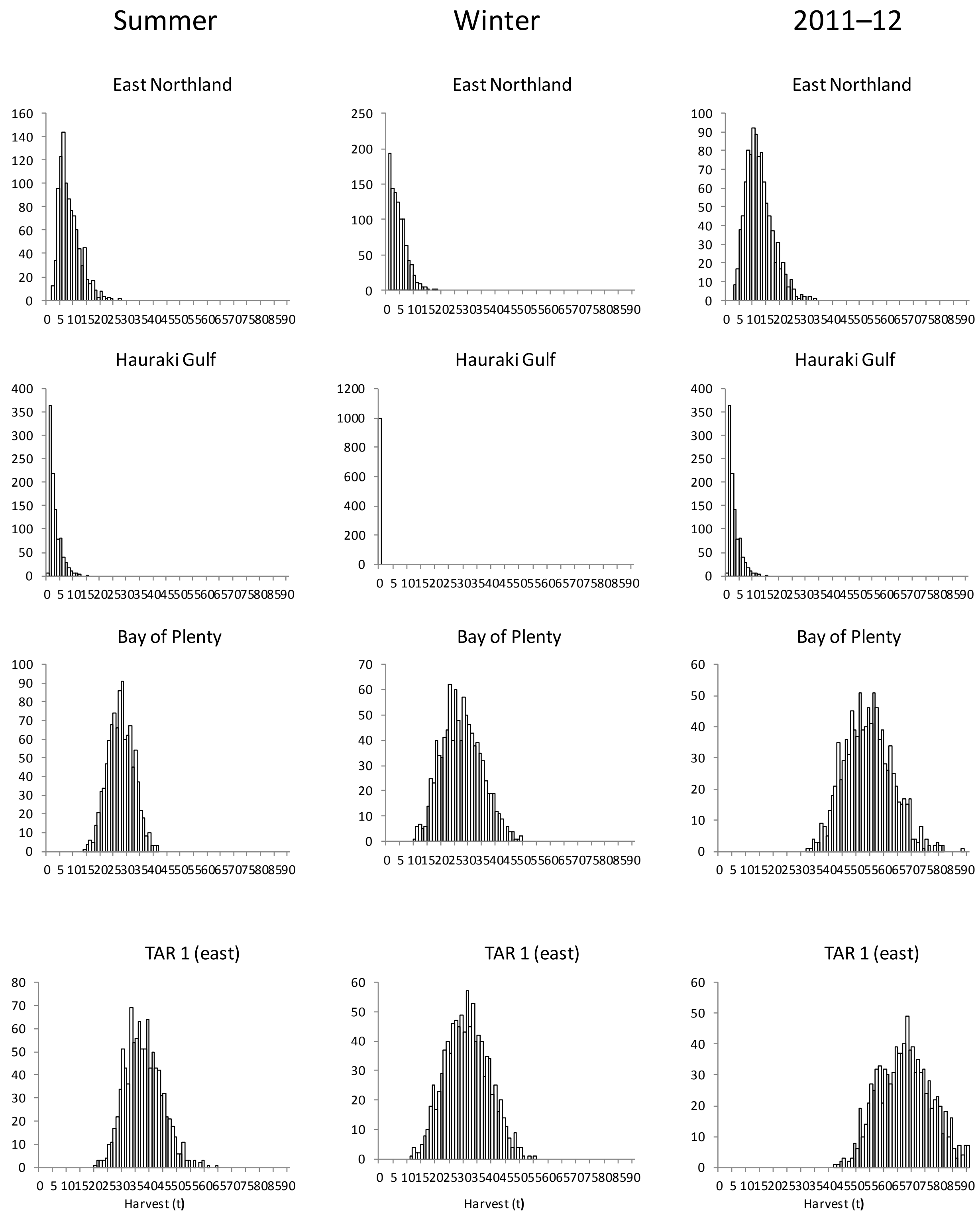
APPENDIX 4: continued

Distributions of bootstrap harvest estimates for red gurnard



APPENDIX 4: continued

Distributions of bootstrap harvest estimates for tarakihi



APPENDIX 4: continued

Distributions of bootstrap harvest estimates for trevally