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Integrated survey methods to estimate harvest by marine recreational fishers in New Zealand

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ABSTRACT

Marine recreational fishing is a popular pastime in a growing number of countries. Obtaining reliable harvests estimates is important to produce more accurate stock assessments and more certain management decisions, however, accurate measurement of marine recreational harvest is challenging.

Previous national fisher diary surveys undertaken in New Zealand during the 1990s gave inconstant estimates of marine recreational harvests. Landline telephone listings and interviews were used to estimate the proportion of New Zealand residents who had fished during the previous 12 months and to recruit diarists. Slight changes in survey method produced variable and at times implausible results.

After three years of planning and pre-testing a large-scale project was undertaken to develop a robust off-site harvest survey method and corroborate the results using with two concurrent on-site survey methods. For the off-site survey, the method was based on a national population proportionate sample of dwellings to recruit a panel of 7000 fishers and 3000 non-fishers using a face-to-face household survey. Panellists were contacted regularly by SMS and telephone for a year with a 94% completion rate. Computer assisted telephone interviews collected details of all species of fish harvested by fishing method. The second was a regional aerial-access survey that collected peak period vessel counts from the air to scale up boat-based harvest from concurrent all-day creel surveys on 45 days. Harvest estimates were generated for the most commonly encountered species, snapper, kahawai, trevally, tarakihi and red gurnard. The third and smallest survey was a combined access point survey in a sub-region using fixed and bus route creel surveys covering all significant access points on different set of random stratified days to the areal access survey. The main objective was to estimate the boat-based harvest by specialist fishers targeting scallop and rock lobster. The three concurrent surveys were designed to generate harvest estimates by fishing platform (boat or land based) at overlapping spatial scales. Harvest, in numbers of fish, were estimated independently for recreational fishers using boats. However, the on-site surveys relied on the proportion of harvest from land-based platforms provided by the off-site survey to derive total regional harvest estimates for all methods. The off-site panel survey relied on average weight data for each fish stock provided by the on-site surveys to convert harvest numbers to weight for management purposes. Choosing a sample frame and survey method that is reliable and repeatable into the future is critical to providing comparable estimates and the ability to monitor trends over time.

Harvest estimates for the most common species in Fisheries Management Area 1, snapper and kahawai, were very similar. The estimates for snapper ranged from 3754 t (cv 0.06) to 3981 t (cv 0.08) and for kahawai 983 t (cv 0.32) to 942 t (cv 0.08). There were greater differences in estimates between surveys for secondary species. Each survey had independent error structures and this multi-method approach has provided valuable insight into likely sources of bias. High quality recreational harvest estimates are important to support management changes in high profile fisheries.

1. Introduction

In many countries commercial fishers are licenced and required to report their catch and fishing effort. These data may be used to monitor relative abundance of a stock where the fishery is extensive and there is a reliable unit of fishing effort or time (Quinn and Deriso, 1999). Non-

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commercial fisheries, such as marine recreational or traditional (customary) fisheries tend to be smaller and use less efficient methods than commercial fisheries. While in some jurisdictions marine fisheries are licensed, there are usually numerous exemptions and comprehensive catch reporting is rare.

The need to account for and manage recreational harvests has come about as the scale and sophistication of recreational fishing effort has increased (Cooke and Cowx, 2006; Ihde et al., 2011). There are a variety of survey techniques used to collect information from recreational fishers, depending on the type of fishery, spatial scale, and resources available (Pollock et al., 1994). Generally, resources are limited and few studies have deliberately set out to undertake concurrent surveys to compare the results (Hartill and Edwards, 2015; Ryan et al., 2013).

Commercial, recreational and customary (traditional) fisheries are important in New Zealand for the economic, social and cultural well-being of the nation. A comprehensive quota management system has been introduced that sets catch limits for over 600 stocks from about 100 mainly marine species. The Total Allowable Catch (TAC) for each stock comprises allowances for recreational and customary fishers, and other sources of fishing related mortality, while commercial catch is authorised through Individual Transferable Quota (ITQ) as shares in the Total Allowable Commercial Catch (TACC). There are strict reporting requirements for commercial catch and landing of quota species (Connor and Shallard, 2010; Mace et al., 2014). Periodically the Minister of Fisheries reviews the TAC for a species and sets a new allowance for recreational fishing interests based on the best available information. This may be an increase, to allow for current harvest, or changes to size and bag limits to ensure that harvest remains within the new allowance.

About 20% of New Zealand residents identify as recreational fishers and, in some areas, they take a significant proportion of the Total Allowable Catch for the main recreational target species (MPI, 2017). As the fisheries management system has evolved, various survey methods have been used to estimate the annual harvest by recreational fishers. Initially the main method used was off-site surveys, where information is self-reported by fishers away from fishing sites via diaries or telephone interviews. These surveys covered large geographical areas and all fishing methods with data collected from individual fishers over an extended period (Pollock et al., 1994). On-site surveys, where data are collected by survey staff at specific access points, were used to gather accurate information on the size and number of fish caught at the time fishers return to shore. This can complement data collected in off-site surveys or be used to estimate harvest for an area when estimates of total effort are available (Pollock et al., 1994).

Several major off-site phone-and-diary surveys randomly sampled the New Zealand population to estimate the proportion who fished in the sea over the last 12 months and to recruit diarists to record harvest in 1993, 1996, 2000 and 2001 (Teinery et al., 1997; Bradford, 1998; Boyd et al., 2004; Boyd and Reilly, 2004). Though the methods used in the surveys were the most sophisticated and defensible available at that time, both were subsequently judged to contain serious but different methodological errors. The large differences in harvest estimates for several species were found to be due to changes in survey methodology, rather than large changes in recreational catch (Hartill et al., 2012; MPI, 2017). As a result, there was government and stakeholder scepticism regarding the overall utility of off-site surveys so regional scale on-site survey methods were developed in Fisheries Management Area 1 (Fig. 1). A combination of aerial boat counts and creel surveys at boat ramps produced satisfactory results at a regional level for species with relatively large recreational catch taken by boat-based fishers (Hartill et al., 2011, 2012).

In 2009 the Ministry of Fisheries (now part of the Ministry for Primary Industries) initiated a programme of work to improve national recreational harvest estimation. The result was political and financial support for the three harvest surveys that would be run concurrently using different methods, at different spatial scales, using independent research providers. This integrated system of surveys was developed to expand data collection and enable the cross-checking of estimates generated using different methods. The off-site survey design needed accurate information on fish weight collected by on-site interviewers. Fish lengths and existing length weight relationships were used to estimate mean weight by species and area and convert harvest numbers to total weight. The on-site surveys of boat-based fishing needed off-site survey estimates of the proportion of catch taken by land-based methods to estimate harvest weight by all methods. The intention was to corroborate the new national off-site panel survey method and to identify and reduce possible biases in a more comprehensive way than ever before (Hartill and Edwards, 2015).

Here we compare harvest estimates from three concurrent and independent surveys: a national off-site panel survey, an on-site aerial-access survey of Fisheries Management Area 1 (FMA 1) and an on-site combined access survey of the western Bay of Plenty (Fig. 1). The surveys estimates include some or all of seven species that are commonly caught off north eastern New Zealand: snapper (*Pagrus auratus*), kahawai (*Arripis trutta*), trevally (*Pseudocaranx georgianus*), tarakihi (*Nemadactylus macropterus*), red gurnard (*Chelidonichthys kumu*), scallop (*Pecten novaezelandiae*), and rock lobster (*Jasus edwardsii*).

Fisheries scientists and managers in New Zealand require recreational harvest estimates as inputs to stock assessments and when considering allowances or management settings for recreational fishers. This information forms the basis of management options released for public consultation and final advice for fisheries managers to the Minister of Fisheries. In 2013, the results of two of these surveys were used as the basis for a review of New Zealand's largest recreation fishery, snapper in Fisheries Management Area 1 (Fig. 1).

2. Methods

Fieldwork for all three harvest surveys occurred between 1 September 2011 and 30 October 2012. Surveys were designed so that results could be directly compared to help assess the potential reliability of each survey method (Heinemann et al., 2015). Survey area boundaries were selected to ensure that harvest estimates could be generated at each on-site survey scale. The temporal stratification of days used in the on-site surveys, such as season, weekend/holiday and weekday where mirrored in the off-site survey. Fishing platform was separated by boat type, land-based or other.

2.1. Off-site panel survey

The off-site survey design was based on a detailed consideration of each step needed to construct an unbiased harvest estimate. Specifically, the process was for the research provider and science advisors in the Marine Amateur Fisheries Working Group to consider whether bias was possible and if so, how it could be minimised or eliminated at each step. The sample frame needed to be robust and repeatable to facilitate future surveys and comparable harvest estimates.

In New Zealand there is no population register or marine fisher licence to use as a complete list of all sampling units (sampling frame), but a reasonably high proportion of the resident population fish. Following consideration of the landline phone sampling option, it became clear that this sampling frame was open to bias due to the low level of public acceptance of contact by this mode and the diminishing use of landline telephone connections. A dwellings-based sample with data updated by the five-yearly Census was identified as supporting both the sampling for fishers and the subsequent expansion of the survey harvest quantities to national population equivalents. For a detailed description of the off-site survey method implemented by National Research Bureau (NRB) refer to Heinemann et al. (2015).

The primary sampling unit was 1000 small geographical units called

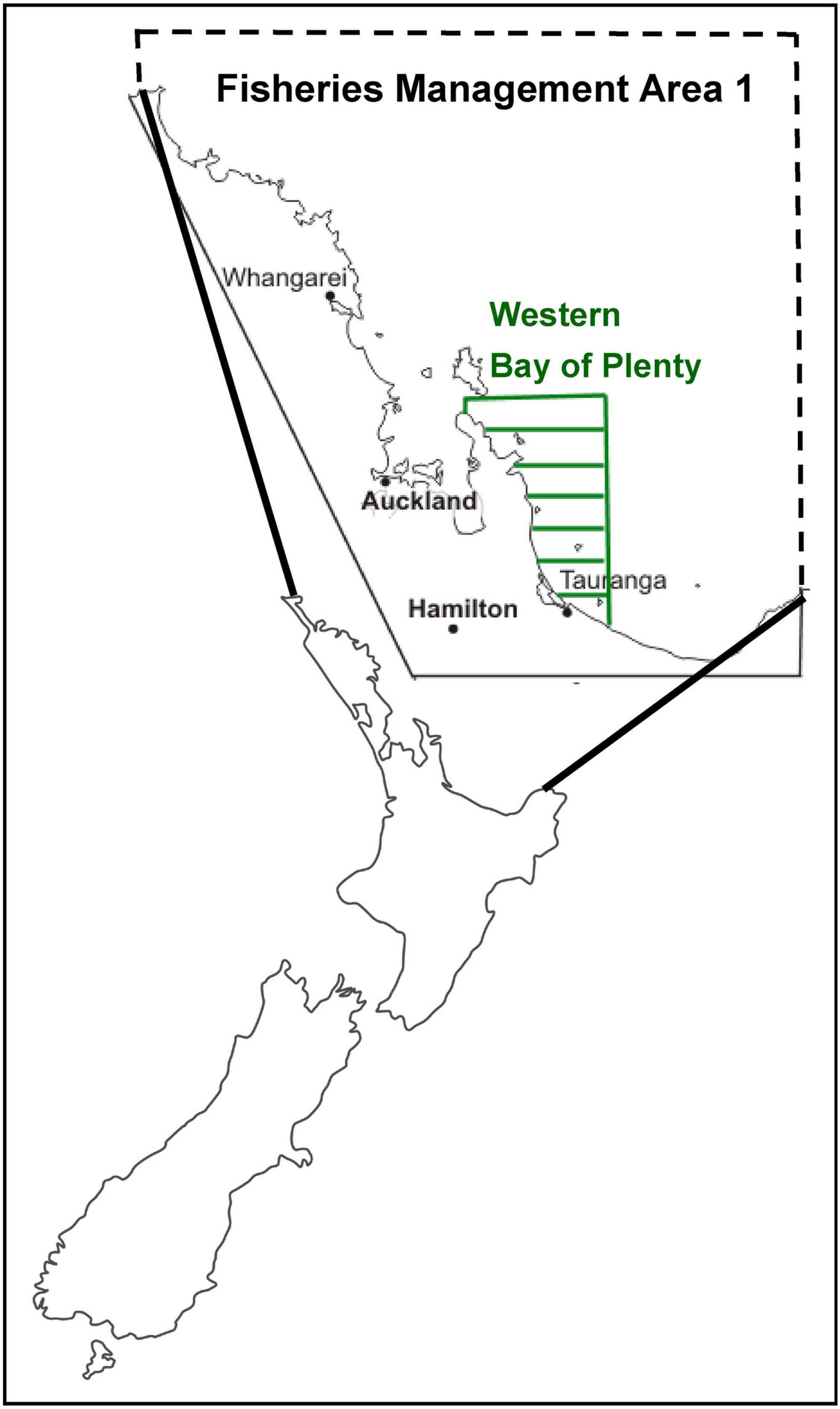

Fig. 1. The relative spatial scale of the harvest survey areas, national (all New Zealand), Fisheries Management Area 1 (FMA 1), and western Bay of Plenty.

meshblocks drawn from 42,946 meshblocks nationwide (Table 1). Meshblocks are defined by Statistics New Zealand and give true nationwide coverage.

The off-site survey design retained both fishers and non-fishers. Monitoring fishing behaviour during the survey year was used to determine their actual fishing avidity, including whether or not they had

Table 1
Main attributes of the three concurrent surveys of harvest by marine recreational fishers in the 2011–12 fishing year.

Survey method	Off-site panel survey	Aerial-Access survey	Combined access point survey
Sample frame	NZ residents 15 years and older, all platforms	365 days in the year Boat-based harvest	365 days in the year Boat-based harvest
Sample area	Main Islands of New Zealand	FMA 1. One of 10 Fisheries Management Areas in New Zealand	Part of FMA 1.
Primary sampling unit	Meshblock, a small statistical unit of dwellings	Survey days in four strata	Survey days in four strata
Other sampling units	Dwelling Then one randomly chosen fisher per dwelling, if any. Also sample of non-fishers	Maximum count of boats from the air and creel surveys at 21 access points	All boat access points (46) in the survey area and on returning boats
Sample size	7013 fishers 1780 non fishers	45 days 19,856 boats interviewed	45 days 11,346 boats interviewed
Sample intensity	7099 fisher respondents from a survey estimate of 695,000 fishers (1.02%)	12% of days	12% of days
Number of species with harvest estimates	87 +	5	4
Complemented data	Average fish weight from national creel survey	Panel survey proportion of fish (by species) caught with land-based or set line methods in FMA1	Panel survey proportion of fish (by species) by boat-based methods outside the survey area and by land-based methods

actually gone fishing during that period. Where the screening survey determined there were those who identified as fishers in the household, these were enumerated, and one fisher selected at random and invited onto the survey panel. A random sample of all non-fishers was also contacted at the end of the summer and winter seasons, to see how many had been fishing despite not initially classifying themselves as fishers. Data available from the most recent census was used to estimate the selection probability of each respondent. This allowed for accurate weighting of collected data up to population estimates.

A regime of periodic texting to those fishers who had cell phones, and phone calls to those who had only landlines, was devised to engage reporting of harvest with the minimum delay between the fishing activity and the interview. Panellists were asked via SMS if they had been fishing since the last message. If they answered yes, they had been fishing in the period specified, this would instigate a telephone interview. Avid fishers were contacted more frequently than occasional fishers.

Self-motivated detailed reporting of trip catch and effort via paper or electronic “diaries” was rejected because of high respondent burden, and concerns about inadequate compliance and consequent memory loss and recall error (Heinemann et al., 2015). A structured and carefully-designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. This reduced respondent burden and the conditional branching in the interviewer-administered computer survey made it possible to collect a level of detail that would not be possible in any self-completion mode (Weeks, 1992). This included details of fishing platform used. This differentiated between land-based fishing and boat-based fishing which was divided into: trailer boat; larger motor boat; yacht; kayak or row-boat.

Harvest estimates by area and platform were generated for the number of fish harvested by multiplying each respondent’s data by the inverse of their probability of selection using meshblock data and census data on age, gender and ethnicity (Wynne-Jones et al., 2014). Variances were estimated using a delete-1 jackknife (Wolter, 2007) where the units deleted were the primary sampling units, meshblocks.

Fish lengths collected by the on-site surveys in FMA 1 (31,202 boats intercepted) and a concurrent national creel survey (3641 boats intercepted) were used to estimate mean fish weights for each species by fish stock using existing length weight relationships, and to convert harvest in numbers to weight (Hartill and Davey, 2015).

2.2. *On-site aerial-access survey*

A large-scale on-site survey was implemented by National Institute of Water and Atmospheric Research (NIWA) in the Fisheries Management Area (FMA) where most recreational fishing effort takes place (Fig. 1). The maximum-count aerial-access survey method was used (Hartill et al., 2011, 2013). This complemented survey design uses a snapshot aerial count of boats fishing throughout a survey area to scale up the catch landed throughout the day at a subsample of access points to provide an estimate of the harvest landed at all possible access points on a surveyed day.

In 2011–12, 45 randomly selected survey days were assigned to each seasonal strata, spring/summer, autumn/winter and day type strata weekend/holiday, week day based on non-parametric simulations of aerial count data collected in the Hauraki Gulf in 2003–04 (Hartill et al., 2007). While the decision to survey 45 days over a 12-month period was primarily based on budgetary constraints, previous aerial-access surveys in the study area had yielded harvest estimates with acceptable levels of precision with this level of sampling (Hartill et al., 2007, 2013).

On each survey day, a count of recreational fishing vessels was made by observers from fixed wing aircraft flying at an altitude of between 150 and 300 m during the middle of the day when data collected during previous aerial-access surveys suggested that diurnal effort profiles would peak (Hartill et al., 2007). Four simultaneous flights were required to cover coastal waters of FMA 1 during the late morning/early afternoon. The coastal extent of FMA 1 was divided into 69 fine-scale survey strata and counts of vessels fishing within each were treated as instantaneous counts (the time taken for an aircraft to traverse each area was very short compared with the speed of the vessels being counted). Boats were classified as being: trailer boats; larger motor boat; yachts; charter boats; kayaks or row boats. Boats which were underway were not counted, neither 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. Counts of vessels other than trailer boats were scaled on the basis of relative occupancy rates, so that all aerial counts could be expressed in terms of trailer boat counts. The occupancy rates were derived from data collected during on-the-water surveys in the Hauraki Gulf during the summer of 2004 (Hartill et al., 2007). These were: trailer boats, 2.5 fishers; launches, 2.9 fishers; yachts, 2.6 fishers; charter boats, 10.4 fishers. This use of relative boat type occupancy 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 (Hartill et al., 2013).

On days when the weather did not allow flights and aerial counts, area-specific regressions of aerial counts relative to creel survey based effort data collected on each survey day were used to predict the aerial count when only creel survey data were available.

Creel surveys on 21 boat ramps collected information from returning fishers about where fishing took place, the start time and finish time of fishing, 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 each fish, but when this was not possible, a count or estimate of the number of fish of each species was recorded. When it was not possible to intercept all boats the return time of uninterviewed boats was recorded and data from the next interviewed boat was assigned to the uninterviewed boat, as a form of imputation. From these data it was possible to estimate average harvest rates in terms of the number of fish and the weight of fish (via length weight relationships). High-traffic access points spread across the FMA were selected to obtain as many interviews as possible given the resources available. This subsampling of access points necessitated the implicit assumption that the catch rates and trip durations reported by fishers returning to surveyed access points were broadly representative of those experienced by fishers returning to un-surveyed boat ramps nearby (Hartill et al., 2013).

The census of fishers returning to surveyed ramps throughout each survey day was used to describe the temporal distribution of effort on that day. The fishing times reported by the censused anglers were expressed cumulatively to determine how many of the interviewed parties had fished at any point in time during the surveyed day, including the time at which the aerial count was made. The ratio of the aerial count of fishing boats relative to the interview-based count of parties claiming to have fished at that time provided a scalar that was used to scale the catch landed by the censused fisher population to account for the catch landed by all fishers at all access points in the survey area that day (Hartill et al., 2011).

Daily harvest estimates were averaged within each temporal stratum and multiplied by the inverse of the sampling intensity for that stratum to provide harvest estimates for each temporal strata and summed for the whole year. Stratum specific and overall estimates of uncertainty were generated by a nonparametric bootstrapping procedure (Hartill et al., 2013).

The aerial-access method does not account for the harvest taken by some boat-based fishing methods, such as long lining and set netting, nor that taken by land-based fishers. To estimate the harvest for all methods in the survey area, creel survey data were used to estimate the proportion of harvest taken by boat-based methods that were not quantifiable from the air (Hartill et al., 2013). Similarly, data from the national off-site panel survey were used to estimate the proportion of the total recreational harvest taken by land-based fishers. These proportional estimates were then used to scale up boat-based harvest estimates for each combination of species, area and season (Hartill et al., 2013).

2.3. On-site combined access survey

A regional scale on-site survey was implemented in the Western Bay of Plenty, which is part of FMA1 (see Fig. 1). The area is well known for boat-based recreational scallop and rock lobster fisheries (Owen, 1986; MPI, 2017). There are a few high-use access points, including four marinas, and many smaller launch sites for trailer boats. A combination of three on-site survey approaches were used.

1. Six major boat ramps were surveyed using a standard all-day access point creel survey design (Pollock et al., 1994).
2. Four marinas were surveyed by two interviewers for 7 h per day.
3. Thirty-six secondary access points were divided into six routes covered using an all-day bus route access point survey design (Pollock et al., 1994; Robson and Jones, 1989).

The same two seasonal strata (spring/summer and autumn/winter) and day type strata (weekend/holiday and week day) as the aerial-access survey were used, but 45 different random days were selected for the survey (Table 1). The similarity of survey design with the aerial-access survey meant that the estimates of precision were more comparable. The primary objectives were to estimate recreational harvest of scallop and rock lobster, which are specialist fisheries that are difficult to assess using large scale off-site surveys (Pollock et al., 1994; Hartill et al., 2012). Harvest estimates were also calculated for kahawai and red gurnard to broaden the comparison with other concurrent recreational harvest surveys. The interview for fishers returning to the access point was deliberately kept short to minimise the chance of missing boats that may have scallops or rock lobster, especially during busy periods. A subsample of between 10 and 20 scallops was selected at random from each boat landing this species, and the lengths measured in millimetres (rounded down). Interviewers were trained to measure the tail width and record the sex of all rock lobster. For a detailed description of the off-site survey method implemented by Blue Water Marine Research see Holdsworth (2016).

Expansion of harvest recorded by interviewers at the main ramps and marinas was straightforward, with most boats intercepted and average catch that day assumed for vessels that were missed or for groups that refused to be interviewed. The direct expansion method used in the bus route component of the survey takes the completed fishing trips observed per minute wait time at a ramp and expanded it by the number of minutes in the fishing day to get total effort (trips per day) for the route, which was multiplied by the mean catch per trip that day to estimate harvest for the route (Robson and Jones, 1989). Total fishing effort, in terms of hours fished, was not used in this survey because the harvest of scallop and rock lobster is often determined by the bag limit, number of pots lifted, or number SCUBA tanks available, rather than total time fishing.

Daily harvest estimates were averaged within each temporal stratum and multiplied by the inverse of the sampling intensity for that stratum to estimate harvest for each temporal stratum. These were then summed to provide estimates of the year's harvest by species (Holdsworth, 2016). Stratum-specific and overall estimates of variance were generated for the combined access survey using parametric formulae based on finite population sampling principles (Manly, 2009).

To estimate the harvest by all methods in the survey area, data from the national off-site panel survey were used to estimate the proportion of the total recreational harvest taken by land-based fishers. The inverse of this proportion was then used to scale up boat-based harvest estimates for each species, to account for the additional land-based harvest. Similarly, national off-site panel survey data were used to estimate the proportion of annual catch taken in the Western Bay of Plenty compared with the whole of the respective Fisheries Management Areas for kahawai, red gurnard, scallop and rock lobster. The inverse of this proportion was used to estimate the harvest by all methods for the FMA (Holdsworth, 2016).

3. Results

Harvest estimates from each survey were generated independently by the respective survey agencies who conducted them.

Overall response rates for the national off-site panel survey were very high, face-to-face interviews completed with 86% households during the screening survey, 91% panel enrolment of selected fishers, and 94% completion rate of the year-long catch effort reporting. All data were reweighted at the meshblock level to account for non-responding households (Heinemann et al., 2015). This assumes that the response group is representative of the non-response group. Overall non-response biases are likely to be low, given the high response rates achieved by this survey.

The off-site panel survey estimated that a total of 2.48 million fishing trips (cv 0.039) were made by New Zealand residents over 15 years old who caught and kept marine species in 2011–12. Their harvest was over 8.7 million finfish (cv 0.049) and 8.3 million non-finfish (cv 0.088), comprising mainly of shellfish, cephalopods, crustaceans, and sea urchins (Wynne-Jones et al., 2014). Most boat- and land-based fishing trips (58%) in the national off-site panel survey were conducted in FMA 1 and, of those, 69% were from trailer boats or moored boats.

The aerial-access harvest estimates were based on 85,000 boats counted from the air that were engaged in fishing in FMA 1 during the 45 days that were surveyed. The creel survey encountered 26,220 boats returning to monitored access points and 19,856 (75.7%) of these parties were interviewed. Seventy-eight percent of these trips involved some fishing and a total of 40,122 fishers were interviewed.

On the six days when the weather did not allow flights to collect aerial counts, area-specific estimates of predicted aerial counts were made based on creel survey vessel counts (Hartill et al., 2013). These suggest that only 7.2% of the total effort on all 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 the days when flying was not possible (Hartill et al., 2013).

The combined access survey in the Western Bay of Plenty was based on 12,514 boat trips of which 11,346 (90.7%) were interviewed. Eighty-one percent of these trips involved some fishing and a total of 25,170 fishers were interviewed. The largest proportion of uninterviewed boats (6.7%) were for boat trailers remaining in the car park at the end of the survey day on the six all-day boat ramps. Just 1.6% of returning boats were not interviewed and only 0.5% refused to answer questions.

Under-coverage in access only surveys is a very common problem (Pollock et al., 1994). The combined access survey did not intercept boats that were on multi-day fishing trips, and other boats returning to access points outside the surveyed area. Rock lobster potters often check their pots at first light to ensure that they are the first to lift their pot that day. The creel survey start time of 07:00 a.m. may miss this important segment of rock lobster catch, especially during longer summer days. This is less likely to be a problem for scallop and finfish harvest.

A key assumption of the two on-site surveys was that levels of recreational catch and effort on surveyed days were representative of those experienced by fishers on all other days within a given temporal stratum. Both designs are statistically unbiased (because they use probabilistic random sampling) but this assumption is usually untested, as direct observations of the fishery are not normally available for all days of the year. Daily boat ramp traffic data were available for the entire 2011–12 fishing year for the busiest access point in FMA 1. Counts of returning boats 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 surveyed days relative to that for all days within each seasonal/day-type stratum suggested that summer strata survey days were broadly representative in terms of boating effort, but the selection of survey days for three of the four temporal strata used in the aerial-access survey, by chance, encountered more low-effort days (Hartill and Edwards, 2015). The main difference was during the two shorter and quieter winter strata so the harvest estimates from these strata are likely to have been underestimated.

The initial blind comparison between the three surveys was for annual harvest in numbers of fish by boat-based methods for overlapping areas and species. Total recreational harvest is required for management purposes so data from parallel surveys were used to scale up these estimates so that they accounted for the catch taken by all fishing methods, from all fishing platforms, and were therefore of comparable scope. The estimates for the two largest recreational fisheries in FMA 1, for snapper and kahawai, were remarkably similar (Table 2, Fig. 2). The aerial-access survey estimates for trevally, tarakihi and red gurnard were lower and significantly different to the FMA 1 estimates from the off-site panel survey (Table 2). The combined access point survey estimates scaled to FMA 1 for kahawai and red gurnard had high coefficients of variation (cv) but were similar to the off-site panel survey estimates. Rock lobster have a smaller Fisheries Management Area (CRA 2) and the scaled estimate from the combined access point survey was lower and significantly different to the off-site panel survey, while the scallop quota management area (SCACS) estimate was higher than the off-site panel survey (Table 2, Fig. 2).

Survey estimates for the off-site panel and aerial-access surveys for the Western Bay of Plenty generally have higher coefficients of variation as the sample size diminishes and uncertainty in disaggregated data increases. The aerial-access survey estimates in the Western Bay of Plenty were lower and significantly different than the off-site panel survey for all species except red gurnard.

4. Discussion

Large-scale surveys of annual harvest by recreational fishers are expensive and logistically intensive. Given this and the great uncertainty around the results of previous off-site surveys in New Zealand, an integrated approach using concurrent surveys to help corroborate different survey methodologies was considered essential.

Off-site longitudinal studies, such as the New Zealand panel survey, are suited to national or state-wide scales. They can provide comprehensive coverage across species, fishing methods and fishing platforms (Pollock et al., 1994; Wynne-Jones et al., 2014). Well-designed CATI systems with short recall times and highly structured/sequenced questionnaires provide high quality data and reduce respondent burden. Regular automated polling of panel members using SMS messages was pre-tested and proved effective during the survey, reducing the burden on the survey agency and respondents (Heinemann et al., 2015). Further research is required to determine whether panellist under or over-reporting is more likely compared with personal telephone calls as the main contact method (Hartill and Edwards, 2015). There is no fisher registration or licence frame in New Zealand, but the proportion of the population who fish in the sea (16–20%) is high enough to allow population based sample frame and scaling. There is, however, under-coverage with respect to fishers under 15 years old and international visitors. The Ministry of Business, Innovation, and Employment funds an International Visitor Survey (IVS) which estimated that in 2013 4% of visitors to New Zealand took part in marine fishing activities (Southwick et al., 2018, this issue). While the number of visiting people fishing may be relatively large, the additional annual harvest for the main species may not be significant as specialist fisheries that attract tourists are mainly catch and release. It is recommended that this assumption is tested in future surveys.

On-site surveys collect information using fishery independent observations of recreational effort and harvest. They also provide greater certainty in species identification and reliable length frequency information. Boat-based fishing is responsible for a large proportion of marine harvest in New Zealand, particularly in the relatively sheltered waters of the northeast coast. Access points such as trailer boat launch sites and marinas are the obvious places to intercept fishers at the end of their trip and reasonable sample sizes can be obtained from 45 survey days per year. Confidence in on-site harvest estimates is generally higher than off-site surveys because they are based on direct observations of fishers and catch, rather than self-reported data. They also include the harvest of fishers of all ages and international visitors. The main limitations of on-site surveys are that they are very expensive at large spatial scales, do not collect information from land-based fishers, and they difficult to implement for fisheries using diffuse access points.

A comparison of the independent harvest estimates from boat-based marine recreational fishers from the panel survey and the aerial-access

Table 2
Estimated harvest (tonnes) and coefficient of variation (cv) taken by marine recreational fishers by survey for two spatial scales, Fisheries Management Area 1 (FMA 1), and the western Bay of Plenty (WBOP) in the 2011–12 fishing year.

		Combined access point survey BWMR		Aerial-Access Survey NIWA		Off-site panel survey NRB	
Species	Area	Harvest (t)	cv	Harvest (t)	cv	Harvest (t)	cv
Snapper	FMA 1	–		3754	(0.06)	3981	(0.08)
	WBOP	–		363	(0.14)*	540	(0.15)
Kahawai	FMA 1	983	(0.32)	942	(0.08)	958	(0.07)
	WBOP	251	(0.09)	165	(0.15)*	239	(0.14)
Trevally	FMA 1	–		124	(0.12)*	165	(0.12)
	WBOP	–		26	(0.18)*	51	(0.23)
Tarakihi	FMA 1	–		67	(0.15)*	97	(0.22)
	WBOP	–		39	(0.20)*	66	(0.27)
Gurnard (Red)	FMA 1	62	(0.45)	24	(0.09)*	49	(0.16)
	WBOP	15	(0.10)	10	(0.16)	16	(0.35)
Rock Lobster	CRA 2	22	(0.47)*	–		41	(0.24)
	WBOP	9	(0.17)	–		15	(0.44)
Scallops	SCACS	114	(0.57)	–		67	(0.27)
	WBOP	24	(0.18)*	–		14	(0.26)

* Denotes significant differences at the 5% significance level ($p < 0.025$) between panel survey and other survey estimates.

survey found that they were remarkably similar for the snapper and kahawai (Hartill and Edwards, 2015). They used boosted regression tree analysis to explore spatially disaggregated harvest estimates for possible causes for the discrepancies observed between the harvest estimates calculated at coarser scales. Day type stratum was the most influential factor, more important than species, season, or region. There was evidence from web camera-based traffic counts at the main boat ramps of bias towards sampling lower effort days in three out of the four temporal strata used in the aerial-access survey and this explained much of the difference between the harvest estimates between the surveys, particularly for the secondary species (Hartill and Edwards 2015).

The combined access survey sampled different days to the aerial-access survey days across the same temporal strata and, by chance, surveyed a more representative sample of days according to boat ramp traffic data from web camera monitoring (Edwards and Hartill, 2015). The focus of the combined access survey was to collect data on scallops and rock lobster and a high proportion of returning boats were interviewed. Under-coverage of access points was still an issue and will probably have biased these estimates low.

Using the off-site panel survey from the Western Bay of Plenty to scale the combined access survey data for all methods and the whole management area gave plausible estimates for kahawai and red gurnard, which recorded catch for 269 and 102 off-site panellists in the Western Bay of Plenty respectively. The estimates for scallop and rock lobster harvest suffer from low sample size, with 27 and 29 panellists recording catch in the Western Bay of Plenty respectively.

The sample size of panellists at management area scale are adequate for scallop (98) and rock lobster (69), but not as large as kahawai (1697) and red gurnard (717) for their respective management areas. For management purposes, the harvest estimates from the off-site panel survey, based on a survey of entire Fisheries Management Areas, should be given more weight than the expanded Western Bay of Plenty estimates. For spatial management at a local scale the two on-site surveys provide a much larger sample of recreational catch and effort and good quality fish size and bag information, as well as detailed fishing locations (aerial-access method). The selection of survey method therefore depends on the survey objectives and possible management responses.

The national off-site panel survey and the FMA 1 aerial-access survey are being repeated in 2017–18. While reviews of the project identified some refinements, no significant changes will be made to the methods used to ensure comparability with the previous harvest estimates is maintained. On-site surveys, focused on specific fisheries on a smaller scale, are undertaken in the years between the large-scale surveys to spread demands on funding and resources.

4.1. Management implications

In 2013 the snapper harvest estimates for three regions in FMA 1 were used to update the catch history and selectivity estimated for recreational fishing in a spatially disaggregated stock assessment model (Francis and McKenzie, 2015). The Ministry for Primary Industries used the survey harvest estimates, daily catch per fisher and stock assessment results in a management review that proposed a range of options, including large cuts to recreational bag limits for snapper and an increase in minimum legal size. Most recreational fishers agreed that snapper catch rates had been particularly high in 2011–12 but were concerned about how the TAC was allocated between the sectors. This resulted in a lively media and public debate about the fishery. The recreational snapper harvest estimates from the off-site panel survey and aerial-access survey stood up well to scrutiny.

The final decision made by the Minister of Fisheries took account of a combination of harvest, science, social, political and economic factors. It is important to have defensible harvest estimates to support management changes in high profile fisheries.

Recreational harvest estimates and length frequency information from these concurrent surveys have also been used in stock assessments for kahawai, tarakihi, trevally and rock lobster. Recreational catch per unit effort from creel surveys in FMA1 are the basis for the only index of abundance used in the stock assessment for kahawai. Total fishing related mortality and stock status are required to monitor sustainability and develop management proposals if changes are required.

A project to estimate the economic contribution of recreational fishing such as expenditures, jobs, tax revenues, and income, used the number of fishers and total number of fishing trips estimated from the panel survey as the best available estimates of recreational fishing activity to scale up average expenditure from a separate economic survey (Southwick et al., 2018, this issue).

5. Conclusion

The three concurrent surveys provided insight into strengths and weaknesses of different survey methods for estimating recreational harvest of fish and how to address potential biases. Careful planning and alignment meant independent estimates of boat-based harvest could be generated and that data could be usefully integrated across surveys. While no survey on its own was fully capable of providing weight-based harvest estimates of good precision for all species and management areas, the new off-site method provided a more fulsome account of recreational harvest in New Zealand. In addition, providing two or three comparable harvest estimates for the largest fisheries has

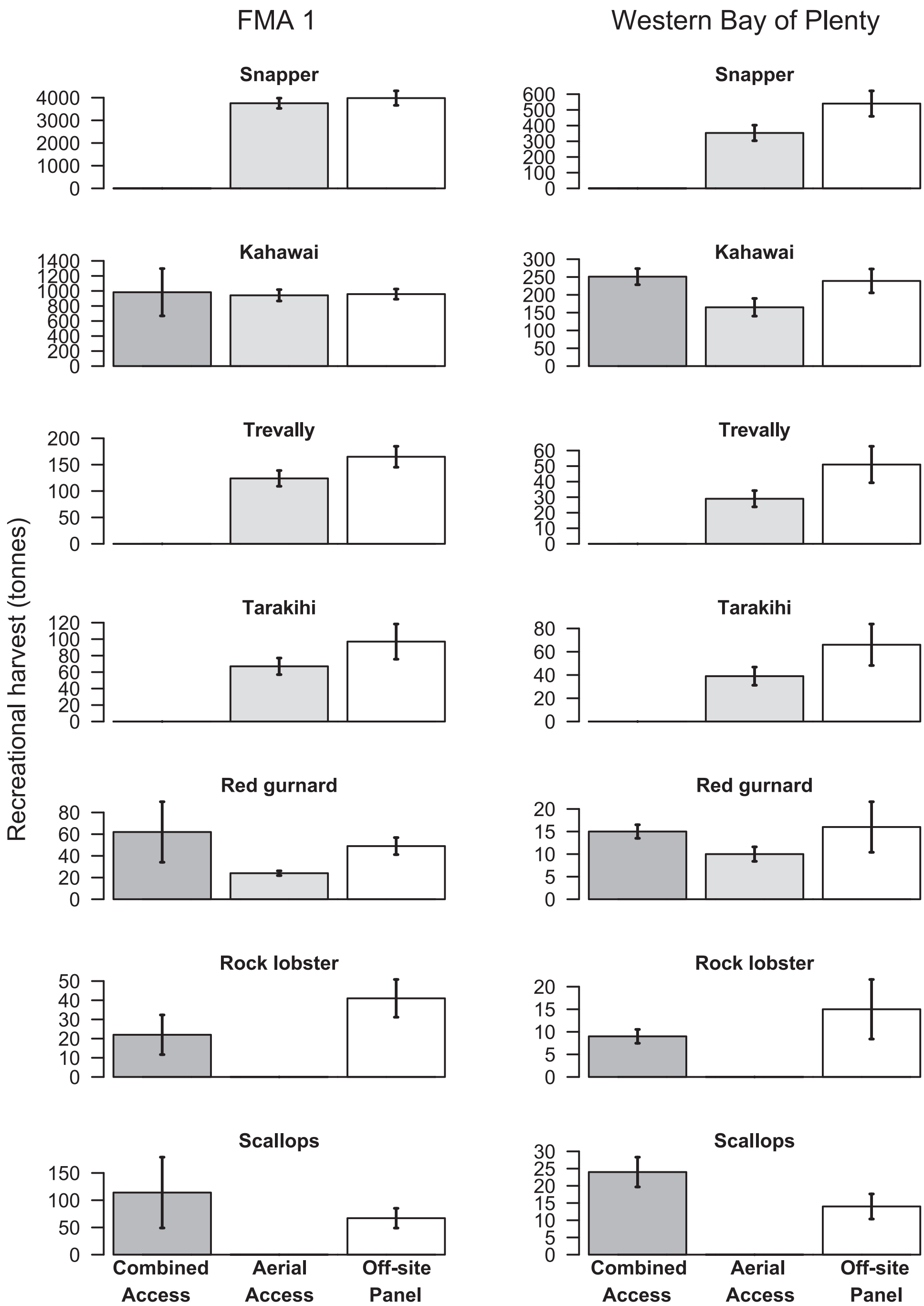

Fig. 2. Comparison of harvest estimates (tonnes) provided by the three surveys, by species for fisheries Management Area 1 (FMA 1) and the western Bay of Plenty with associated 95% log-normal confidence intervals.

increased stakeholder confidence in the results and supported a response by fisheries managers.

As with most survey methods, a known probability of sample selection and large enough sample size improve the accuracy and precision of the results. Increasing the number of panellist in the off-site survey and increasing the number of survey days in the on-site surveys could improve these estimates if required. There are always cost constraints to be considered and these surveys will be repeated only every five or six years. Choosing sample frames and survey methods that are reliable and repeatable into the future is critical to providing comparable estimates and the ability to monitor trends over time. While there is no 'sample versus census' level of validation to refer to, corroboration of harvest estimate from large scale off-site surveys is worthwhile, particularly where they form the basis for important management decisions.

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