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Tini a Tangaroa

Camera and creel survey monitoring of trends in recreational effort and harvest from 2004–05 to 2018–19

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Digital camera systems were first installed to monitor the number of recreational boats returning daily to two boat ramps in the Hauraki Gulf in 2004–05, and additional cameras were installed at another thirteen high-traffic ramps throughout FMAs 1, 2, 7, 8, & 9 over the following decade. Each camera system records a time-stamped image of the ramp every 60 seconds, which can be viewed in series to provide a count of the number of boats returning to that ramp during a 24-hour period. Images are stored for all days, but only those from a stratified random sample of 60 days per fishing year are viewed, and the resulting daily traffic counts have been used to generate indices of boating effort. Although similar trends in effort are apparent between ramps located within the same FMA, or region of FMA 1, there is no consistent trend across all areas.

Trends in recreational boating effort only partially explain trends in recreational harvesting, however, because boats can also be used for a variety of other purposes, and because catch rates can also differ over time. A concurrent creel survey was therefore initiated in 2012–13 to collect effort and catch data per trip at each of the sites where cameras were already used to monitor recreational ramp traffic. These interviews have followed an existing format, so that comparisons can be made with data collected during previous creel surveys conducted for other purposes. Four-hour interview sessions were scheduled on the same 60 days per fishing year during which image based indices of boat ramp traffic were derived, so that estimates of the number of boats used for fishing and their landed catch could be calculated for each scheduled survey day. Although there appears to be little interannual variability in the proportion of recreational boats that were used for fishing (which was consistently high at all but one of the monitored ramps), there has been considerable interannual variability in the catch rates of the most commonly caught species that are landed at most ramps. Indices of the annual harvest of species commonly landed at each ramp calculated by combining daily camera based effort and creel survey based catch per fishing trip data, suggest that the harvest taken by the recreational sector is often far more variable than that taken by the commercial sector.

Most of these harvest indices suggest a similar degree of change in harvesting to that inferred from point-in-time aerial-access survey harvest estimates for FMA 1 in 2004–05, 2011–12, and 2017–18; and from National Panel Survey estimates for 2011–12 and 2017–18 for a wide range of fisheries. However, in the Hauraki Gulf (FMA 1) there was a marked difference between the camera/creel survey harvest indices and the corresponding snapper and kahawai aerial-access harvest estimates. A comparison of the snapper harvest index with spatially disaggregated aerial-access harvest estimates calculated for four quadrants of the Hauraki Gulf has shown that trends in the catch landed at the two monitored ramps in urban Auckland no longer describe trends further afield, especially in the Firth of Thames and in the north-western Hauraki Gulf, where there have been marked increases in recreational fishing effort in recent years. Creel surveying has therefore been initiated at two additional boat ramps in the Hauraki Gulf, and also in the Bay of Plenty, to improve the spatial coverage of this monitoring programme.

Creel surveys were initially intended to provide data on boat usage and boat trip catch rates to be used in conjunction with camera counts of the number of boats returning daily to each ramp. However, the creel survey data also provide a concurrent count of the number of boats returning to a monitored ramp during a consistently scheduled 4- hour period that is timed to coincide with peak expected traffic. Annual traffic indices can therefore be calculated from these creel survey data alone. A comparison of the annual harvest indices calculated from these two alternative traffic indices suggests that either approach could be used to monitor recreational effort and harvest. This suggests that future long-term monitoring of these fisheries

could be based solely on the creel survey data, and that there may be no need to persist with camera monitoring of recreational boat ramp traffic. The number of camera systems that will be maintained from 2019–20 onwards has been reduced from 13 to 7 cameras for the next 5 years.

1. INTRODUCTION

Mutually corroborating survey methods have now been developed to estimate harvests taken by recreational fishers both nationally and for specific Fisheries Management Areas (FMAs), but the cost of conducting these large surveys annually is prohibitive. Although the estimates provided by National Panel Surveys (e.g., Wynne-Jones et al. 2014, 2019) and smaller scale aerial-access surveys (e.g., Hartill et al. 2007a, 2019) can be used to gauge levels of recreational harvesting when they are undertaken every six or seven years, some form of interpolation is required to estimate the harvest landed in intervening years. This is necessary because levels of recreational harvesting are only loosely constrained by daily bag and minimum legal size limits and can vary considerably over time given changes in the localised availability of fish and prevailing weather conditions.

Cost-effective methods are therefore required to monitor relative trends in recreational effort and harvest, to gauge the recreational harvest landed by these fishers during the intervening years when large scale harvest estimation surveys are not conducted.

Anglers fishing from trailer boats account for most of the recreational harvest taken from most recreational finfish fisheries, and boat ramps act as choke points through which most fishers pass. A network of digital cameras was therefore installed to monitor traffic returning to two high traffic boat ramps in the Hauraki Gulf in late 2004, and in East Northland and the Bay of Plenty in 2005 (Hartill et al. 2010). This network of monitoring cameras was further extended in following years, to monitor traffic returning to selected high traffic boat ramps in FMAs 2, 7, 8, and 9 (Hartill et al. 2015a, 2015b). Trends in boat ramp traffic only partially describe trends in recreational harvesting, however, because some of the boats returning to these monitored ramps will not have been used for fishing, and because estimates of the average catch landed per fishing boat are also required to convert image based indices of recreational effort into harvest indices. A companion creel survey was introduced for this purpose in 2011–12 to monitor concurrent trends in boat usage and landed catch rates in FMAs 1, 8, and 9.

This report provides an update of existing recreational effort and harvest indices for key recreational boat based fisheries in FMAs 1, 8, and 9 (given by Hartill et al. 2015a) and new indices for FMAs 2 and 7, for the 2014–15 to 2018–19 period. All harvest indices have been scaled to the absolute harvest estimates provided by concurrent but infrequent National Panel Surveys (NPS) and aerial-access surveys to produce annual estimates of the tonnage landed by recreational fishers, to inform the management of these fisheries.

This report fulfils the final reporting requirement of Fisheries New Zealand research project MAF2014-04.

Overall objective

To monitor changes in marine amateur fishing trailer boat effort in FMAs 1, 2, 7, 8, and 9.

Specific objectives

1. To maintain and operate the web camera network in FMA 1, FMA 2, FMA 7, FMA 8, and FMA 9 for the 2014/15 through 2018/19 fishing years.

2. To derive regional indices of recreational fishing effort in FMA 1, FMA 2, FMA 7, FMA 8, and FMA 9 using web camera data collected from boat ramps for the 2014/15 through 2018/19 fishing years.

3. To monitor boat ramp traffic to distinguish between trailer boat effort and fishing effort at selected web camera sites for the 2014/15 through 2018/19 fishing years.

2. METHODS

2.1 Overview of the camera monitoring network

Digital cameras were first installed overlooking five high traffic ramps in FMA 1 in 2004–05, followed by two further installations in FMA 9 and at a single site in FMA 8 in 2006–07 (Hartill et al 2015a) (Figure 1). New monitoring sites were then established: at Gisborne and Napier in FMA 2 and at Twin Bridges in southern FMA 8 in 2014–15 (as part of MAF2013-03 – Hartill et al. 2017b); and at Nelson and Waikawa in FMA 7 in 2015–16 (as part of MAF2015-03 – Hartill et al. 2017a).

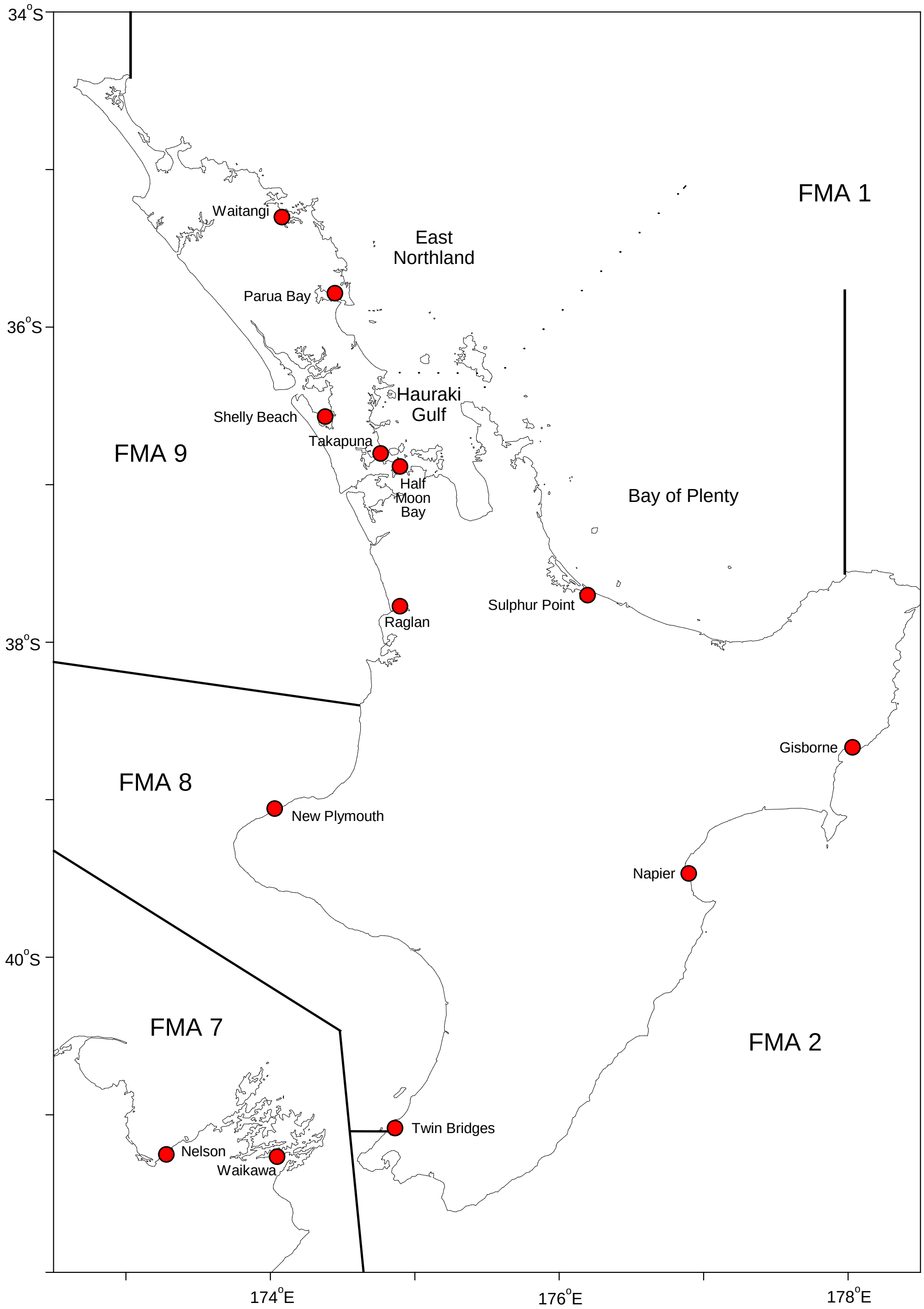

Figure 1: Locations of boat ramps where digital cameras are currently installed, in FMAs 1, 2, 7, 8, and 9. Two camera systems are installed at Shelly Beach and at Raglan.

The digital camera systems used to monitor boat ramp traffic have been progressively improved since the first camera systems were installed in 2004–05, for system reliability and image quality. At the beginning of the 5-year period covered by this report (2014–15), all camera systems consisted of a digital video camera that continuously transmitted images, either wirelessly or via a coaxial cable, to a nearby PC. Frame grabber software was used to capture a time stamped static image every 60 seconds, and this was saved to the PC hard drive before batches of images were transmitted to a secure central NIWA server. Each camera system generates a daily email describing the number of images transmitted and other metrics, which are used to monitor system performance.

Although these camera systems were usually reliable, prolonged outages were experienced at times because third parties such as local councils have taken time to reinstate power to or repair streetlight poles that the cameras have been mounted on, when these structures were accidentally or deliberately knocked down or damaged. There was also been an increasing incidence of radio interference degrading the quality of images transmitted from a pole-mounted camera to a nearby PC connected to the internet. Radio interference has increased with the proliferation of communication devices transmitting on the 2.4 GHz frequency and this problem was initially resolved partially by shifting to the less commonly used 5.8 GHz frequency.

The camera systems have since been further re-engineered to overcome other issues, such as an over-reliance on the owners of the buildings in which the PCs were housed, who sometimes unintentionally disconnected the power or internet or failed to pay their utility bills on time. A fully integrated pole-mounted camera system has now been developed that integrates an internet protocol camera with a Raspberry Pi single-board computer (www.raspberrypi.org). Images are stored on a Secure Digital (SD) memory card on the Raspberry Pi and are uploaded at regular intervals to the central server, via a 3 GHz cellular phone network. The coverage of the 3 GHz phone network is far more extensive than the landline broadband network that these systems were previously connected to, and camera systems can therefore be deployed to remote locations where a landline connection is not available. If a cellular internet connection goes temporarily offline, the images remain on the SD card until the connection is re-established, when they are automatically uploaded. Remote control software on the Raspberry Pi allows access via the Remote Desktop Connection (provided standard in all Windows operating systems since Windows XP) from any PC connected to the internet. The integration of all components within a single enclosure negates the need for a vulnerable wireless or coaxial link between the camera and a remote PC. Less power is required to run these integrated systems and they are consequently easier to run on solar power and can therefore be installed in a wider variety of situations.

Most of these re-engineered cameras have been installed on the same structures as the original cameras, but the camera at New Plymouth has been moved to a 17-m high steel pole that was specifically designed, constructed, and installed as part of this study. Cameras at this site were previously installed at two other locations several hundred metres away from the ramp, because there was no nearby structure that a camera could be mounted on. Neither of these distant mounting structures provided an adequate view of activity at the ramp, however, so permission was sought from the Taranaki Port Authority to install a pole directly overlooking the ramp; the authority gave permission and constructed and installed the pole in 2018.

The images generated by these camera systems have been the sole source of information used to monitor the traffic returning daily to most of the boat ramps indicated in Figure 1, though there is one site where image data are used to augment traffic monitoring, rather than as a primary source. The Outboard Boating Club of Northland maintains an enclosed multi-lane boat ramp at Parua Bay (in Whangarei Harbour) which can be accessed by only club members with electronic swipe cards. Each swipe card has a unique identification number and each swipe of the card is electronically logged. Daily traffic counts derived from swipe card record data were highly correlated with manual image interpretation counts in 2011–12 (R^2 = 0.99), and most of the daily traffic counts since this time have been based on swipe card data. The interpretation of this swipe card data is far more cost effective than the manual interpretation of images taken by the camera monitoring traffic at this site. There have, however, been a few periods when the club have been unable to provide swipe card data, and the traffic counts for these days were based on the images taken by the camera at this site instead.

2.2 Temporal subsampling of image data

Time-stamped images of each ramp are stored in a separate subdirectory for each day and can be viewed as a sequential time lapse video. Each camera system collects 525 600 images a year, and the effort required to manually interpret all the images collected at all ramps is considerable. Some form of stratified random subsampling is therefore required if indices of effort are to be generated in a cost-effective manner. Parametric bootstrapping of daily traffic counts from FMA 1 collected throughout 2004–05 suggested that a stratified random sample of 60 days per fishing year should yield a reasonably precise estimate of the number of boats using a ramp annually (Hartill et al. 2007b, Figure 2).

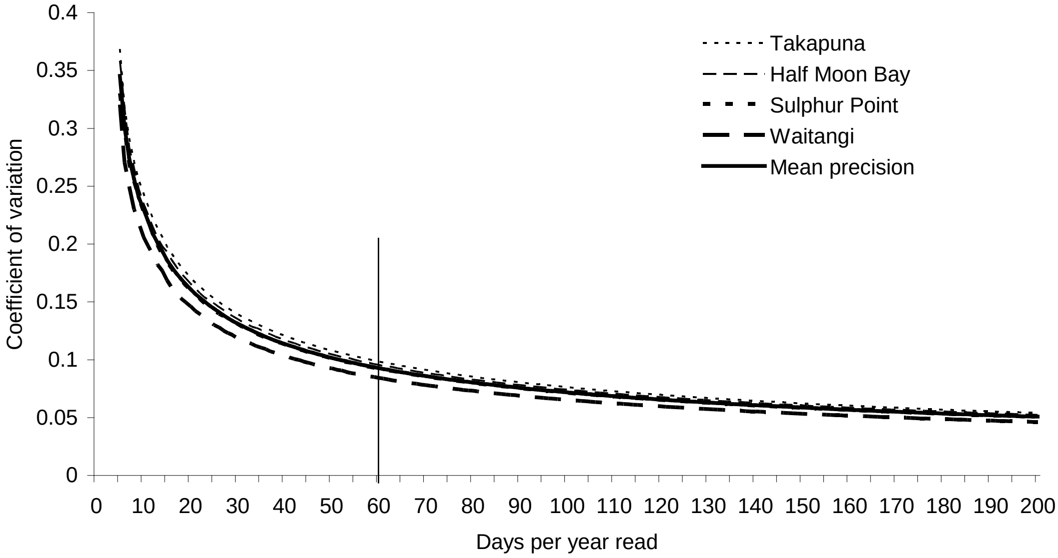

Figure 2: Relationship between precision and optimal allocation of sampling effort across temporal strata, by ramp. The average level of precision is also given, because this was used to determine the overall level of sampling effort beyond which there was little improvement in estimates of average daily boat ramp traffic (from Hartill et al. 2007b).

The temporal strata considered in this optimisation were based on combinations of seasons (Summer – 1 October to 30 April versus Winter – 1 May to 30 September) and day-types (Midweek days versus Weekend/public holiday days). Midweek days were defined as Monday to Friday, excluding any days that fall on a public holiday. The optimal allocation of 60 days across these temporal strata is given in Table 1.

Table 1: Temporal sampling design and the resulting intensity of sampling effort. The number of days within each temporal stratum differs from year to year depending on when public holidays (PH) fall and whether neighbouring days might be treated as an extended weekend break.

Season	Day type	Sampled days	All days	Sampling intensity
Summer	Weekend/PH	24	71–78	30.8%–33.8%
	Midweek	20	134–141	14.2%–14.9 %
Winter	Weekend/PH	8	43–45	17.8%–18.6%
	Midweek	8	108–110	7.3%–7.4%

This temporal sampling design has been used for monitoring in all FMAs except FMA 7, where a closed season on blue cod harvesting in the Marlborough Sounds was introduced in 2012. Some fishers may choose to fish elsewhere during the early summer when the Marlborough Sounds is closed to blue cod harvesting, so the summer season stratum for this FMA was split into two further seasonal strata. The seasonal strata for this FMA are defined as: Closed Summer – 1 September to 19 December; Open Summer – 20 September to 30 April; and Winter – 1 May to 31 August. The timing of the survey year in FMA 7 differs from the standard finfish fishing year, because it coincides with the beginning of the closed season on 1 September. The number of days surveyed and their allocation across temporal strata in FMA 7 was based on the intensity at which days were sampled in each temporal stratum in FMA 1 (see Table 1).

The subsequent and ongoing generation of regional effort indices has been based on counts of boats returning to at least one high traffic indicator ramp in each region/FMA on days pre-selected from each fishing year according to the temporal sampling design given in Tables 1 and 2. In the first index year, the surveyed days were selected randomly, but in all subsequent years the selection of days has been closely based on that in the first year. This non-random selection of days in subsequent years is necessary because recreational activity can be influenced by the proximity of public holidays, fishing contests, and other social phenomena. It is therefore desirable, where possible, to hold these influences constant across years, because interannual consistency in methods is desirable with any long-term index. The selection of survey days in the first year took the following considerations into account.

- Temporal strata conform to the fishing year.
- The random allocation of days resulted in a roughly even spread of samples over the months considered.
- Public holidays which could either fall on a midweek day or weekend day were not selected because they may or may not result in a long weekend, which can influence levels of fishing effort on neighbouring days in a given season (namely Waitangi Day and Anzac Day).
- The timing of public holidays that can vary from year to year; namely the Easter holidays.

The total number of boats returning to each ramp within each seasonal/day type stratum is the product of the average level of traffic on sampled days and the inverse of the sampling intensity for that stratum (see Tables 1 and 2). Sampling intensities for any given temporal stratum can vary from year to year because the total number of days falling within the two summer strata varies over time, due to the extra day occurring in each leap year and because Waitangi Day and ANZAC Day were not “Monday-ised” before 2015. Further, normal working days that are bracketed by a public holiday and a weekend day are often popular choices for annual leave, and levels of traffic on these days are often more similar to those seen on weekends and public holidays. Such days were classified together with weekends and public holidays.

Table 2: Temporal sampling design and the resulting intensity of sampling effort for FMA 7.

Season	Day type	Sampled days	All days	Sampling intensity
Closed summer	Weekend/public holiday	10	32	31%
	Midweek	11	78	14%
Open summer	Weekend/public holiday	17	49	19%
	Midweek	12	84	12%
Winter	Weekend/public holiday	6	36	22%
	Midweek	7	87	9%

2.3 Predicting traffic counts on days when system outages occur

Digital camera systems sometimes fail for a wide range of unforeseeable reasons (see section 2.1). These outages are regarded as random events as they are unlikely to be related to levels of fishing effort occurring at the time the outage occurred. Some of the system outages in FMA 1 have been prolonged, however, and in these instances the temporal coverage of the remaining data was not considered sufficiently representative to provide an unbiased estimate of the average daily level of traffic crossing these ramps, within the affected seasonal strata.

There appears to be a reasonable degree of correlation between relative levels of effort across the three regions of FMA 1. Daily traffic counts at Waitangi, Takapuna, and Sulphur Point are available for 349 days between 25 December 2004 and 24 December 2005 and Pearson correlation coefficients calculated from pairwise comparisons of ramp counts ranged from 0.776 (between Waitangi and Sulphur Point) to 0.881 (between Takapuna and Sulphur Point) (Hartill et al. 2007b). These levels of correlation are high enough to suggest that meaningful predictions of effort can be made for one ramp on a day when an outage occurs, based on counts made at the other two ramps where the digital camera systems were both fully operational on the same day. Generalised Linear Models were therefore used to predict levels of traffic for the 208 instances where a system outage was experienced on a preselected survey day by one of the three ramps considered here (out of a combined sample size of 2568 survey days falling between 1 April 2005 and 30 September 2019 across these three ramps).

Separate models were generated for each region to determine the relationship between daily traffic counts at each ramp relative to those observed at the other two ramps given the fishing year, season, and day type in which these observations were made. Counts from the other two ramps were square root transformed to produce a more even spread of observations along the predicted space and, in doing so, to reduce the leverage of extreme observations on the fit to the model. These counts were fitted as third-order polynomials to allow for any non-linearity in their relationship with concurrent counts at the response ramp. Year:Ramp interaction terms were also offered to each model, to allow for the fact that the relationship between levels of traffic at each ramp can change over time. Each model was fitted in a stepwise manner to determine whether each variable should be selected, and the order in which those variables should be fitted (see Appendix 1 for model selection statistics and diagnostic plots at each ramp). Main effect terms were retained if they improved the explained deviance by at least 1% and fishing Year:Ramp interaction terms were retained if they improved the explained deviance by more than 0.5%. These generalised models were then used to predict missing observations (and associated estimates of error for these estimates) when counts were available from the other two ramps on those days when outages occurred at the response ramp.

This is the first time that image based boat ramp traffic indices have been generated for the Half Moon Bay boat ramp in the Hauraki Gulf, and a Generalised Linear Model (GLM) was used to predict boat counts for this site too, for days when image data were not available because a camera system outage had occurred. This GLM was based on the same methods described above, to predict counts for outage affected days at Takapuna.

Levels of correlation across ramps monitored within each of the other FMAs were too low to support the use of the GLM approach used in FMA 1. This means that system outages that coincide with pre-selected sample days reduce the number of observations available to inform any index of effort and, potentially, the extent to which that index describes the true level of effort throughout an affected temporal stratum.

2.4 Generating digital camera vessel effort indices

Separate traffic effort indices were calculated for each region of FMA 1, and for FMAs 2, 7, and FMAs 8 and 9 combined, based on the counts available from the ramp selected from that region. Daily counts from sampled days were averaged for each seasonal/day type stratum, and these averages were scaled by the number of days occurring within each stratum to provide an estimate of the number of boats that returned to the ramp on those days. These stratum-specific estimates of traffic volume were then combined to produce an estimate of the number of boats that had returned to a given ramp during each fishing year (and also for each season within each year).

A two-stage bootstrapping procedure was used to estimate variances. Daily counts were selected with replacement from each temporal stratum, and these counts were averaged and combined in the manner described above. When a sample day was selected for which the boat count was predicted rather than observed, the variance associated with this estimate (which was derived from the Generalised Linear Model) was used to generate a random normal deviate, which was added to the predicted count for that day. Standard error estimates were calculated from 1000 bootstrap estimates generated for each stratum.

Although these indices are actually estimates of the number of boats returning each fishing year to the ramp of interest, it is assumed that the relative trends observed at this ramp broadly would reflect those occurring at other unobserved ramps within the same region. This assumption has been further investigated and discussed by Hartill (2015).

2.5 Collection of concurrent interview data

Some of the boats observed returning to a ramp will have been used for purposes other than fishing, and any index of effort based solely on digital camera imagery will therefore describe trends in boating effort rather than fishing effort. Additional data are therefore required to estimate the proportion of observed boats that have been used for fishing, which can only be determined reliably from face-to-face interviews with fishers (creel surveys) returning to the same ramp.

Creel survey interviews conducted by NIWA have followed a standard format since the early 1990s, with data collected on whether a boat was used for fishing, and, if so, on the methods used, areas fished, hours spent fishing, and on the composition of the catch (which is measured when possible). Data from these interviews have been used to generate ramp-specific indices of the proportion of boats used for fishing; these indices have been combined with digital camera indices of boating effort from the same ramp to generate indices of the number of fishing boats returning to the ramp over time.

Catch per trip data from interviews have also been used to generate species-specific indices of the average weight of fish landed per boat trip at each ramp over time. These catch per trip indices have been combined with the fishing boat effort indices to generate indices of the harvest landed to each boat ramp over time. Annual harvest indices are of greater interest to fisheries managers than boat traffic indices, because they provide a means of monitoring trends in recreational harvest. Creel survey data have been intentionally collected for this purpose, since 1 October 2012, and intermittently for other purposes since 1990. The temporal sampling design used in recent creel surveys is the same as that used when subsampling camera data (see Tables 1 and 2), so that both forms of data are collected concurrently.

The collection of creel survey data is, however, relatively expensive, and interviews have been restricted to a 4-hour period on each survey day. These 4-hour fisher survey sessions were timed to coincide with the period when returning ramp traffic was expected to peak (Table 3), based on an analysis of interview data collected throughout the day, in 2011–12, for an aerial-access survey in FMA 1 (Hartill et al. 2015a). Midweek interview sessions were scheduled for 2 hours later than sessions on weekends and public holidays to coincide with a later peak in fishing effort on these days.

Table 3: Scheduled timing of fixed 4-hour interview sessions by month and day type.

	Weekends/public holidays (h)	Midweek days (h)
October to December	1230 to 1630	1430 to 1830
January to March	1230 to 1630	1430 to 1830
April	1200 to 1600	1430 to 1830
May to September	1200 to 1600	1300 to 1700

Fixed session start times were adopted for several reasons. The analysis given by Hartill et al. (2015a) suggested that start times randomised to start at any time of the day would result in sample loss of 15–35% of boats during the weekend and 25–40% on midweek days. These and past analyses have also shown that the proportion of boats used for fishing during the busiest time of day, and the catch rates reported by those boats, was usually broadly representative of that occurring at other times during the same day, apart from a brief spike in catch rates at dawn and dusk. Fixed session times are also desirable from a logistical point of view, because previous experience suggests that interviewers tend to be more reliable when their working routine is clearly defined and verifiable by site visits timed to coincide with predictable work times. But perhaps the most significant benefit of a consistently implemented creel survey schedule is the consistent measure it provides of not only changes of boat usage and catch rates over time, but also of changes in daily fishing effort. As will be seen, an index of fishing effort based on the number of boats intercepted at a monitored ramp during a consistently defined 4-hour period follows a very similar interannual trend to that inferred from the interpretation of camera image data collected over a full 24 hours.

2.6 Generating indices of fishing effort and harvest from camera and creel survey data

Digital camera boat counts were combined with creel survey interview data on the proportion of boats that were used for fishing on the same day to estimate the number of fishing boats that return to a given ramp on a given day. This count of fishing boats was then multiplied by the average weight of fish landed per fishing boat on the same day to produce an estimate of the weight of fish of a given species landed at that ramp on that day. The resulting daily landed catch estimates were then used to generate an annual harvest index for each surveyed ramp. Although both camera boat count and creel survey data were usually available for each ramp on each scheduled survey day, this did not always occur; for example, when a camera system failed or, less often, when an interviewer was not present at their ramp when required. It was therefore sometimes necessary to use to GLM predicted boat counts or creel survey data at the same ramp on other days within the same temporal stratum to impute for missing data.

Alternative harvest indices were also calculated for each ramp, based solely on creel survey data. For these indices, the ramp traffic index was based on the creel survey clerk record of the number of boats returning to the ramp during each 4-hour interview session, rather than a camera based count of boats returning to that ramp throughout the full 24-hour period, on the same day. This index was also multiplied by the same creel survey based boat usage and catch rate indices as that used to calculate the camera/creel annual harvest index, as described above. Although the resulting daily harvest estimates only account for that landed at the ramp during each 4-hour survey session, rather than for the whole day, comparisons of the creel only and camera/creel based harvest indices calculated for each ramp have shown that they provide a similar relative measure of the annual trend in recreational harvest.

Indices of fishing effort and harvest were generated from these survey day statistics in a similar manner to that used to generate the digital camera traffic indices discussed earlier in section 2.4. Effort and harvest statistics calculated for each day within a temporal stratum were averaged and then scaled up by the number of days occurring within that stratum. Estimates for each stratum were then combined to provide estimates for each fishing year. Variance estimates were calculated by a two-stage bootstrapping procedure, whereby boat specific catch and effort data were bootstrapped within days, and days were bootstrapped within temporal strata.

3. RESULTS

3.1 FMA 1

East Northland

The digital camera systems overlooking the public boat ramp at Waitangi in the Bay of Islands and the club ramp at Parua Bay in Whangarei Harbour were usually operational during most fishing years, but radio interference and occasional power failures prevented image collection at Waitangi on almost half of the scheduled survey days in 2014–15 and 2015–16 (Table 4). For Parua Bay, this is the first time that traffic count data have been reported; until recently the images were collected, but not interpreted, because monitoring activity for this region focused solely on activity at Waitangi. Counts of the number of boats returning to the Parua Bay ramp on scheduled survey days since the beginning of the 2011–12 fishing year have been retrospectively determined from either club barrier arm swipe data or, when this was not possible, the interpretation of images, because this period coincides with the initiation of regular creel surveying at this site.

Traffic counts are therefore available for all 60 survey days per fishing year for the ramp at Parua Bay, although GLM predictions of boat counts were required for some days for Waitangi, when camera system outages had occurred (see Appendix 1 for GLM diagnostics). The ramp traffic indices based solely on boat counts on those days when the camera system at Waitangi was operational, and for both observed and predicted counts on all 60 days per fishing year, follow a very similar trend (Appendix 2). This was also the case for the other three FMA 1 ramps where GLM modelling was used to predict counts for outage affected days.

Several hundred fishing parties were interviewed when their boats returned to Waitangi and Parua Bay during the sixty 4-hour creel survey sessions scheduled for each survey year (Table 4). Figures 3 and 4 show the resulting creel survey indices of: the number of boats returning annually to each ramp; the proportions of boats used for fishing; and the average landed weight of fish per boat trip at each ramp for snapper (Figure 3) and for kahawai (Figure 4). Both the camera and creel survey indices of boat traffic follow broadly similar trends at each ramp since 2011–12, with there being relatively little change in effort at Waitangi over the following seven fishing years, whereas boating effort at the more southern Parua Bay ramp has increased progressively since 2014–15. The proportion of boats returning to boat ramps that were used for fishing was high and relatively constant, at around 80% during most fishing years. The average annual rate at which snapper and kahawai were landed per boat trip was more variable, both between ramps and through time, with no apparent common trend. When these three indices are combined to produce species-specific relative indices of the annual harvest landed at each ramp, there is a marked pairwise similarity between the indices based on camera counts for a full 24-hour period each day, compared with those based on counts of boats made during creel surveys conducted on the same day during a briefer 4-hour period (bottom panels of Figures 3 and 4). The annual harvest indices vary through time and do not follow any apparent long trend in this region.

Table 4: Availability of digital camera and creel survey data collected at two high-traffic boat ramps in the East Northland region of FMA 1. The first year in which creel survey data were intentionally collected in conjunction with digital camera data was 2011–12, although interview data collected for other purposes are also available for some previous years. Annual totals are further broken down by seasonal/day type stratum for the 2014–15 to 2018–19 fishing years, because these were the years during which survey was undertaken as part of this study.

			Waitangi				Parua Bay			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2004–05			16	60	40	298	–	60	41	344
2005–06			60	60	–	–	–	60	–	–
2006–07			60	60	–	–	–	60	–	–
2007–08			50	60	–	–	–	60	–	–
2008–09			47	60	–	–	–	60	–	–
2009–10			48	60	–	–	–	60	–	–
2010–11			59	60	–	–	–	60	–	–
2011–12			53	60	50	325	60	60	52	263
2012–13			54	60	46	258	60	60	38	164
2013–14			54	60	60	464	60	60	58	260
2014–15	Summer	Weekend	10	24	24	364	24	24	24	240
		Midweek	10	20	20	100	20	20	20	45
	Winter	Weekend	8	8	7	33	8	8	7	5
		Midweek	8	8	8	19	8	8	8	2
			36	60	59	516	60	60	59	292
2015–16	Summer	Weekend	8	24	28	360	24	24	27	234
		Midweek	9	20	19	101	20	20	16	52
	Winter	Weekend	8	8	8	40	8	8	7	14
		Midweek	8	8	8	10	8	8	8	0
			33	60	63	511	60	60	58	300
2016–17	Summer	Weekend	24	24	25	382	24	24	24	213
		Midweek	20	20	18	92	20	20	19	35
	Winter	Weekend	8	8	8	65	8	8	6	25
		Midweek	8	8	8	28	8	8	8	10
			60	60	59	567	60	60	57	283
2017–18	Summer	Weekend	18	24	25	316	24	24	25	199
		Midweek	15	20	20	124	20	20	20	56
	Winter	Weekend	8	8	8	88	8	8	8	48
		Midweek	8	8	10	58	8	8	10	32
			49	60	63	586	60	60	63	335
2018–19	Summer	Weekend	24	24	21	325	24	24	24	254
		Midweek	20	20	18	117	20	20	20	80
	Winter	Weekend	7	8	7	77	8	8	8	53
		Midweek	7	8	8	28	8	8	8	25
			58	60	54	547	60	60	60	412

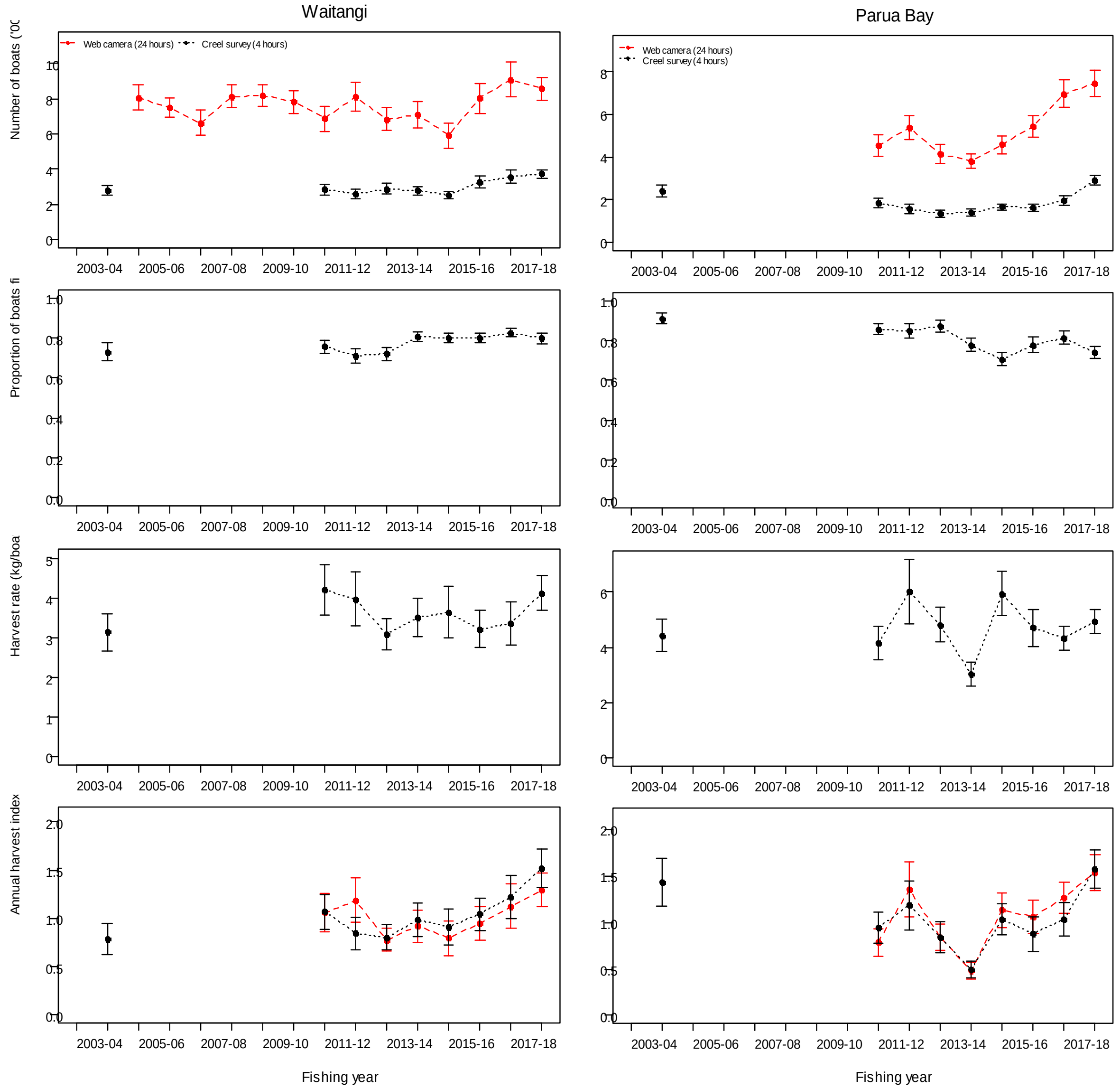

Figure 3: Annual estimates of numbers of boats returning to the boat ramps at Waitangi (left hand panels) and at Parua Bay (right hand panels) in the East Northland region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

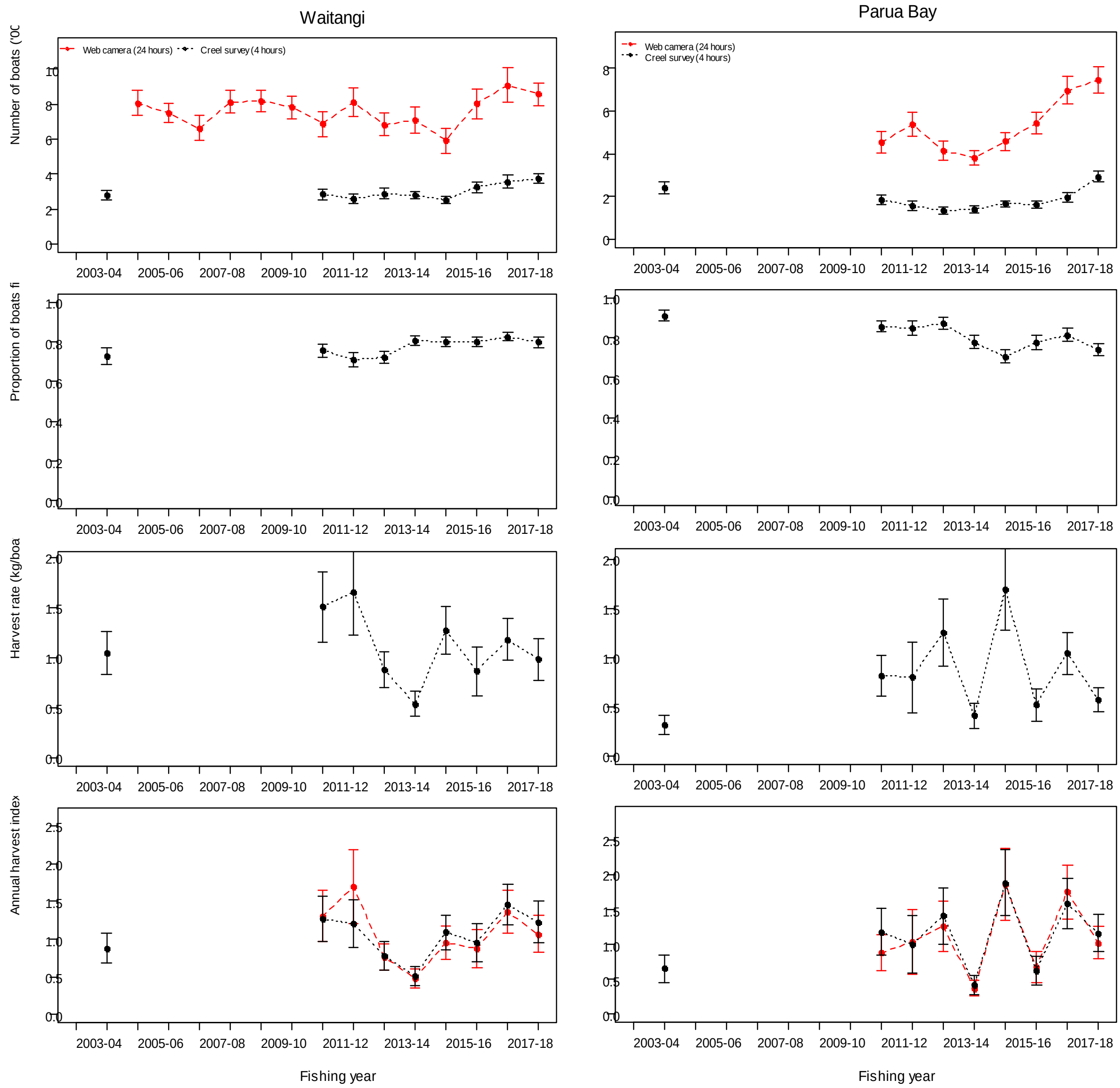

Figure 4: Annual estimates of numbers of boats returning to the boat ramps at Waitangi (left hand panels) and at Parua Bay (right hand panels) in the East Northland region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of kahawai harvested per boat (third panels down), and indices of the annual kahawai harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

Hauraki Gulf

The digital camera systems installed overlooking the Takapuna and Half Moon Bay boat ramps in the Hauraki Gulf have been almost fully operational over the past five fishing years, apart from at Takapuna in 2017–18 (Table 5). Power to the street lighting circuit used to power the camera at this site was lost for two prolonged periods in 2017–18: for a 22-day period in March, and a 45-day period during May–June. GLM modelling was used to predict the number of boats returning to the ramp on the 11 scheduled image interpretation days that occurred during these outage periods, and on a small number of other days when outages occurred in other years.

Boat traffic was also partially interrupted at Half Moon Bay in 2017–18, when a severe storm dislodged the pontoons used to aid boat launching at retrieval at this multi-lane ramp, halting all traffic for a week. These pontoons were not re-established until November 2018, and it is therefore likely that many fishers may have launched their boats elsewhere for the rest of the fishing year. The camera indices of boat traffic generated for both Takapuna and Half Moon Bay show a steady decline in effort since 2010–11, followed by a small increase in effort in 2018–19 (Figure 5).

Creel surveys were also conducted at these sites on most of the scheduled survey days, with 259–427 fishing boat parties interviewed at Takapuna per year, and 424–564 parties interviewed at Half Moon Bay. The trend in boating effort inferred from the creel data follows a similar trend to that seen from the camera counts of boats returning over the full 24-hour period on concurrent days (Table 5).

A slightly higher portion of the boating parties interviewed at Half Moon Bay had been fishing, than at Takapuna, but the trend in boat usage at these two ramps followed a similar pattern over time, with the relative incidence of boats used for fishing peaking around 2011–12 and 2012–13, and then again in recent years (second panel of Figure 5). There is no apparent long-term trend in the average weight of the snapper catch landed by boats at either ramp (third panel of Figure 5), but there was a marked increase in the weight of kahawai landed these ramps between the early-2000s and 2011–12 (third panel of Figure 6). Landings can vary considerably between years, especially for the less commonly caught kahawai.

When the traffic, boat usage, and catch per boat indices are combined to produce landed catch indices for the two ramps, common trends are evident across sites, for both snapper and kahawai. The snapper harvest landed at these two ramps peaked in 2011–12, followed by a decline over the following three years, with a gradual increase evident since 2015–16 (bottom panel of Figure 5). The landed harvest trend for kahawai indicates relatively lower catches at the beginning of the time series, during the mid-2000s, followed by a single year spike in the landed catch after four un-surveyed years, with relatively constant intermediate annual landings since (bottom panel of Figure 6).

Table 5: Availability of digital camera and creel survey data collected at two high-traffic boat ramps in the Hauraki Gulf region of FMA 1. The first year in which creel survey data were intentionally collected in conjunction with digital camera data was 2011–12, although interview data collected for other purposes are also available for some previous years. Annual totals are further broken down by seasonal/day type stratum for the 2014–15 to 2018–19 fishing years, because these were the years during which survey was undertaken as part of this study.

			Takapuna				Half Moon Bay			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2004–05			16	60	36	322	58	60	38	730
2005–06			60	60	–	–	57	60	–	–
2006–07			59	60	35	194	58	60	46	609
2007–08			57	60	–	–	54	60	–	–
2008–09			24	60	–	–	28	60	–	–
2009–10			55	60	–	–	–	60	–	–
2010–11			60	60	–	–	35	60	–	–
2011–12			48	60	51	365	53	60	53	874
2012–13			57	60	56	463	60	60	55	683
2013–14			60	60	58	443	53	60	59	616
2014–15	Summer	Weekend	24	24	23	308	24	24	24	365
		Midweek	20	20	19	88	19	20	20	149
	Winter	Weekend	8	8	8	23	8	8	7	41
		Midweek	8	8	8	8	7	8	7	9
			60	60	58	427	58	60	58	564
2015–16	Summer	Weekend	24	24	29	307	24	24	29	368
		Midweek	20	20	20	46	20	20	20	84
	Winter	Weekend	8	8	8	33	8	8	8	56
		Midweek	8	8	7	7	7	8	8	16
			60	60	64	393	59	60	65	524
2016–17	Summer	Weekend	24	24	26	159	24	24	27	290
		Midweek	19	20	16	44	20	20	20	73
	Winter	Weekend	8	8	7	37	8	8	8	41
		Midweek	8	8	7	23	8	8	8	20
			59	60	56	263	60	60	63	424
2017–18	Summer	Weekend	22	24	20	147	23	24	25	238
		Midweek	17	20	11	34	19	20	19	89
	Winter	Weekend	5	8	7	51	7	8	7	74
		Midweek	5	8	10	27	8	8	9	35
			49	60	48	259	57	60	60	436
2018–19	Summer	Weekend	24	24	23	216	24	24	23	321
		Midweek	20	20	20	73	19	20	18	96
	Winter	Weekend	8	8	8	85	8	8	8	93
		Midweek	8	8	8	28	7	8	7	40
			60	60	59	402	58	60	56	550

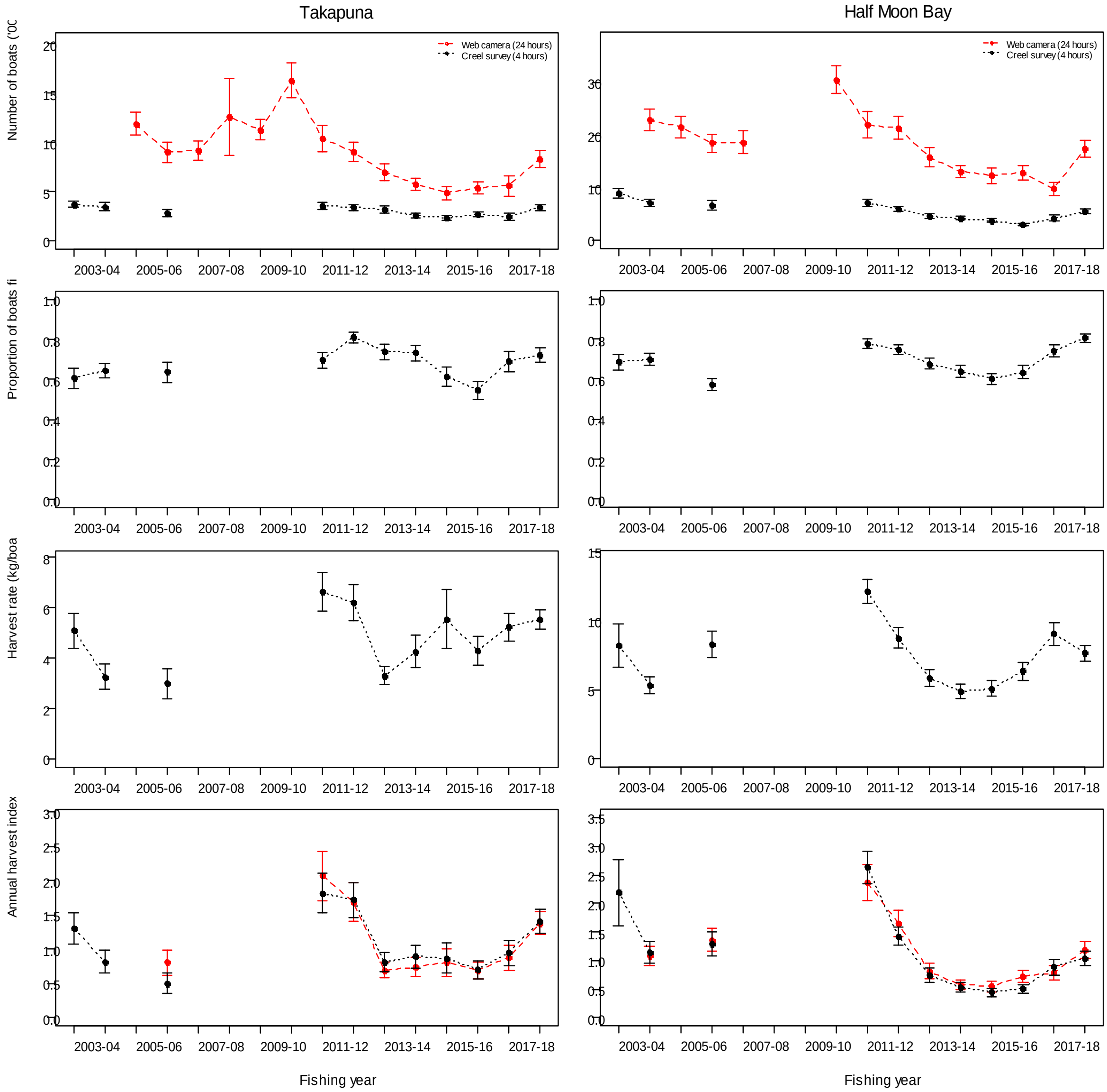

Figure 5: Annual estimates of numbers of boats returning to the boat ramps at Takapuna (left hand panels) and at Half Moon Bay (right hand panels) in the Hauraki Gulf region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

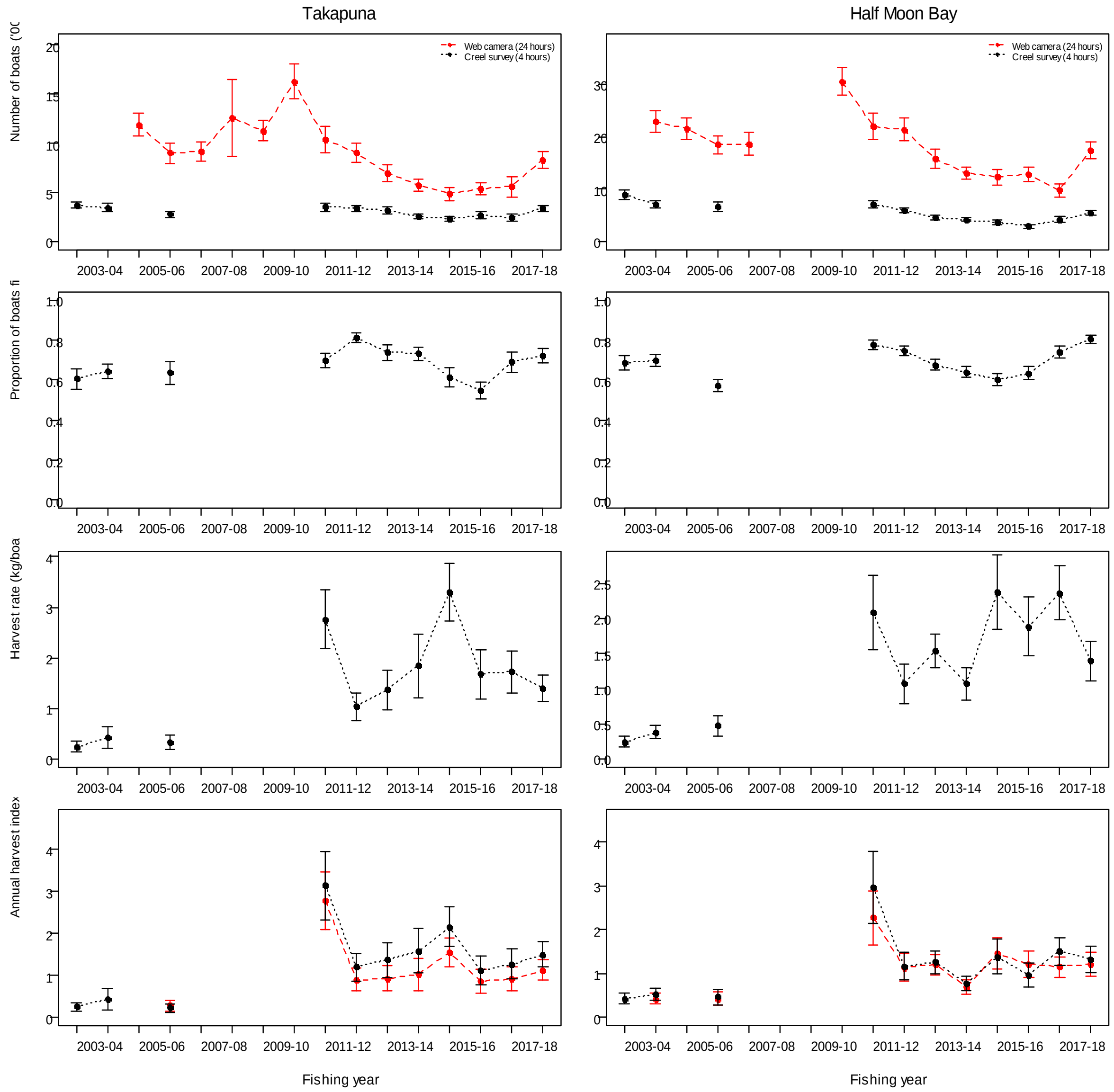

Figure 6: Annual estimates of numbers of boats returning to the boat ramps at Takapuna (left hand panels) and at Half Moon Bay (right hand panels) in the Hauraki Gulf region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of kahawai harvested per boat (third panels down), and indices of the annual kahawai harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

Bay of Plenty

The only location in the Bay of Plenty where a camera system has been used to monitor boat ramp traffic, has been at Sulphur Point in Tauranga, which is the most popular access point for recreational fishers in this region of FMA 1. A second camera was also established to monitor boat ramp traffic at Whakatane in April 2005, but this camera was disestablished and March 2013, when a regression of camera boat traffic counts against concurrent day aerial survey counts of boats fishing in nearby waters suggested that activity at this ramp was a poor indicator of local levels of recreational fishing activity (Hartill 2015). Camera counts of the number of boats returning to the Sulphur Point boat ramp are available for most of the 60 scheduled image interpretation days per fishing year (Table 6). Boat traffic at this ramp trended down between 2004–05 and 2015–16, apart from a marked spike in effort in 2010–11 and has steadily increased since (Figure 7).

A broadly similar trend is evident in the creel survey boat traffic index based on interviews conducted during a 4-hour period on the same 60 pre-selected survey days per fishing year, although the further increase in effort seen in the camera index for 2018–19 is not evident in the creel survey index. There has been an increase in the relative incidence of boats being used for fishing, with over 80% of boats reporting recreational fishing activity during each of the last four fishing years (second panel of Figure 7). The average landed weight per boat of both snapper and kahawai has varied markedly between years, with evidence of a gradual long-term declining trend for snapper (third panel of Figure 7), and no clear long-term trend for kahawai (third panel of Figure 8). When the traffic, boat usage, and catch per boat indices are combined to produce indices of the annual catch of snapper landed at Sulphur Point, the snapper harvest appears to have declined between 2012–13 and 2015–16 (as seen in the Hauraki Gulf), followed by higher landings in recent years (bottom panel of Figure 7). There has been a small but interannually variable increase in annual landings of kahawai at this ramp over the past 4 years (bottom panel of Figure 8).

Table 6: Availability of digital camera and creel survey data collected at Sulphur Point in the Bay of Plenty region of FMA 1. The first year in which creel survey data were intentionally collected in conjunction with digital camera data was in 2011–12, although interview data collected for other purposes are also available for some previous years. Annual totals are further broken down by seasonal/day type stratum for the 2014–15 to 2018–19 fishing years, as these were the years during which survey was undertaken as part of this study.

			Sulphur Point			
			Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed
2004–05			16	60	43	885
2005–06			60	60	–	–
2006–07			60	60	–	–
2007–08			58	60	–	–
2008–09			60	60	–	–
2009–10			60	60	–	–
2010–11			58	60	–	–
2011–12			60	60	47	859
2012–13			59	60	43	367
2013–14			59	60	56	570
2014–15	Summer	Weekend	24	24	20	301
		Midweek	20	20	18	128
	Winter	Weekend	8	8	5	6
		Midweek	8	8	5	14
			60	60	48	449
2015–16	Summer	Weekend	24	24	26	366
		Midweek	20	20	14	80
	Winter	Weekend	5	8	8	55
		Midweek	5	8	8	12
			54	60	56	513
2016–17	Summer	Weekend	24	24	22	369
		Midweek	16	20	20	136
	Winter	Weekend	7	8	8	96
		Midweek	8	8	8	61
			55	60	58	662
2017–18	Summer	Weekend	24	24	25	552
		Midweek	20	20	17	149
	Winter	Weekend	8	8	8	191
		Midweek	8	8	10	141
			60	60	60	1033
2018–19	Summer	Weekend	24	24	19	378
		Midweek	20	20	19	145
	Winter	Weekend	8	8	8	136
		Midweek	8	8	8	74
			60	60	54	733

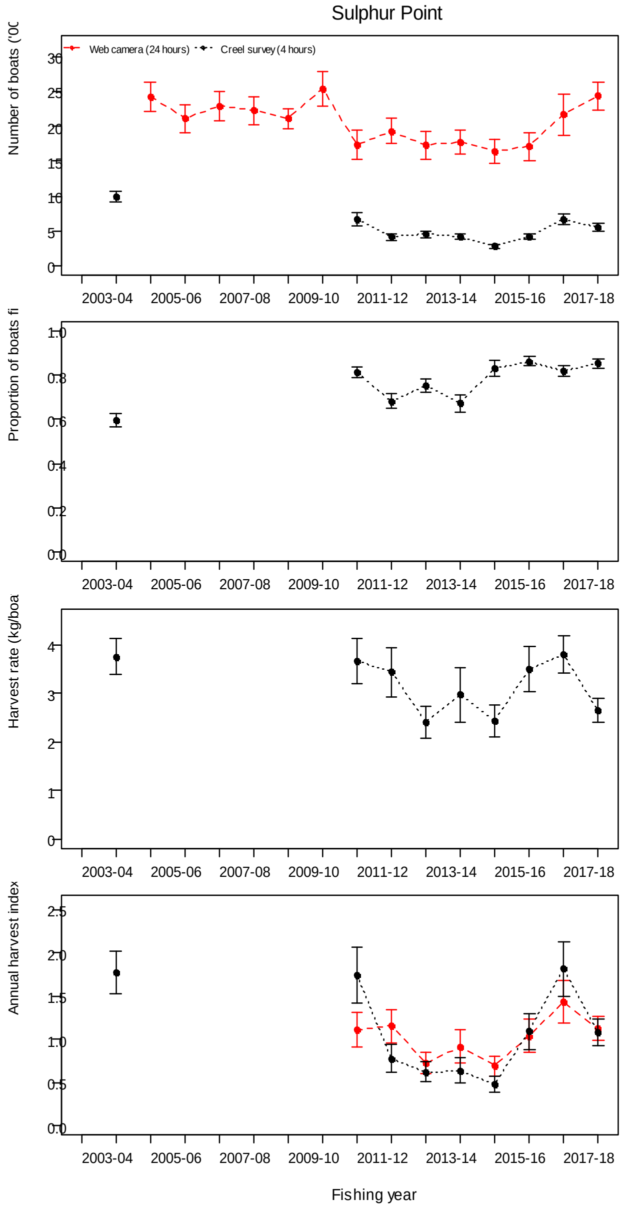

Figure 7: Annual estimates of numbers of boats returning to the boat ramps at Sulphur Point in the Bay of Plenty region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

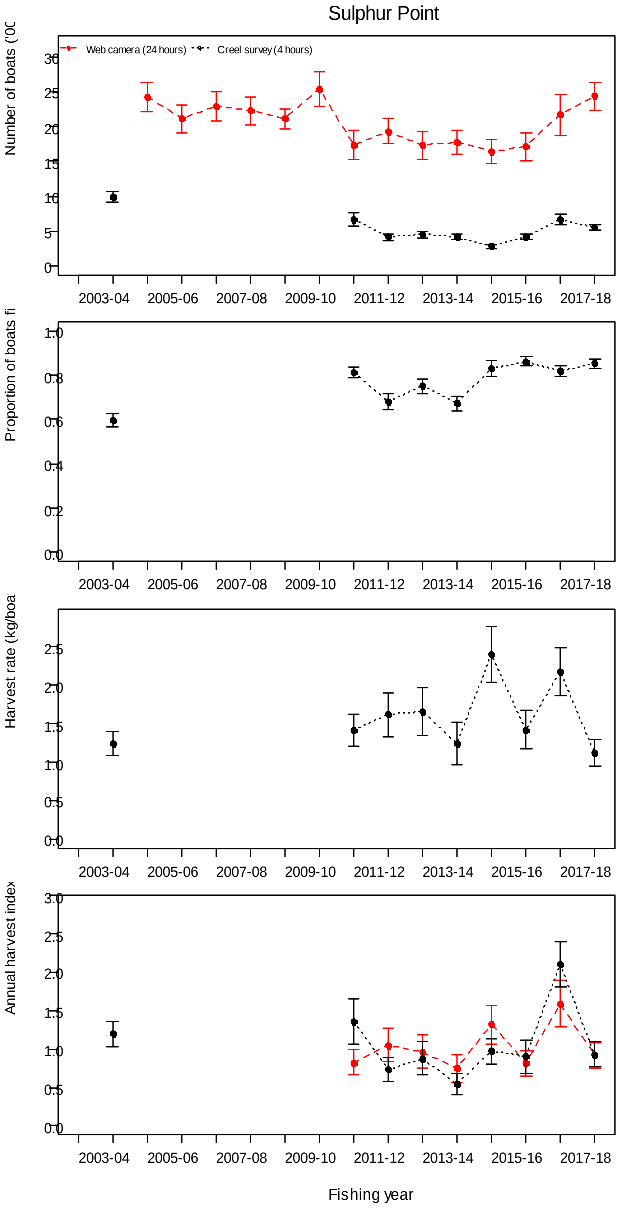

Figure 8: Annual estimates of numbers of boats returning to the boat ramps at Sulphur Point in the Bay of Plenty region of FMA 1 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of kahawai harvested per boat (third panels down), and indices of the annual kahawai harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

Comparison between regional harvest indices and total harvest estimates for FMA 1

When the annual landed snapper and kahawai harvest indices calculated for each monitoring ramp are scaled to, and compared with, concurrent aerial-access and National Panel Survey estimates of the harvest landed throughout each region in 2004–05, 2011–12, and 2017–18, very similar trends in the level of harvest are evident for both snapper and kahawai in East Northland and the Bay of Plenty, but not in the Hauraki Gulf (Figures 9 and 10).

The trends in recreational snapper harvest from East Northland inferred from the scaled indices calculated for each ramp, and for the two ramps combined, are similar and show fluctuating but gradually increasing levels of harvest over time (top panel of Figure 9). The scaled kahawai harvest indices are more variable, both through time and between the two ramps, but a common trend of increasing annual landings is still evident from all data sources (top panel of Figure 10).

The apparent change in levels of recreational harvesting inferred from each ramp and combined ramp harvest indices are more marked in the Hauraki Gulf, showing a significant drop in the annual recreational take of both snapper and kahawai following 2011–12 (middle panels of Figures 9 and 10). Both ramp indices indicate a steady increase in the landed catch of snapper in this region (which is not seen for kahawai), but the increase is not as marked as a comparison of both the aerial-access and NPS estimates for 2011–12 and 2017–18 would suggest. This discrepancy between the degree of change inferred from the ramp harvest indices and the two sets of annual aerial-access and NPS harvest estimates suggests that activity and catch landed by fishers returning to the monitored ramps are not consistently representative of the wider recreational fishery in the Hauraki Gulf.

The reason for this discrepancy becomes clear when the combined ramp index is plotted against aerial-access harvest estimates calculated for four quadrants of the Hauraki Gulf (Figure 11). The two boat ramps that are monitored appear to provide a representative indication of changes in levels of recreational harvesting from the south western corner of the Hauraki Gulf (H1), where they are located. These ramp locations were originally chosen because they were the most popular boat ramps in the Auckland metropolitan area, from which the majority of boating effort occurred at that time. However, in recent years there has been a steady shift in recreational fishing effort to other areas in the Hauraki Gulf, especially in the Firth of Thames (H4) where the rapidly expanding mussel farm now attracts large number of fishing parties who target higher abundances of snapper associated with these structures. Aerial-access survey estimates suggest that the recreational snapper harvest taken from the Firth of Thames has increased more than threefold over a 15-year period, from 170 to 620 tonnes. To address this shift in fishing patterns, camera/creel monitoring should be extended to other areas of the Hauraki Gulf, beyond the Auckland metropolitan area.

The camera/creel monitoring of harvest and effort at Sulphur Point does, however, appear to provide a representative descriptor of changes in recreational harvesting taking place across the wider Bay of Plenty (bottom panels of Figures 9 and 10). Aerial-access survey estimates and, more recently, NPS harvest estimates indicate similar changes in harvest to that seen at Sulphur Point. A comparison of snapper harvest estimates and index values for the 2004–05, 2011–12, and 2017–18 fishing years all suggest little change in snapper harvest over time, but the now-continuous index provided by this camera/creel monitoring programme suggests that the harvest actually dropped substantially during the intervening years between 2011–12 and 2017–18. A similar trend is also evident for kahawai harvesting in this region of FMA 1.

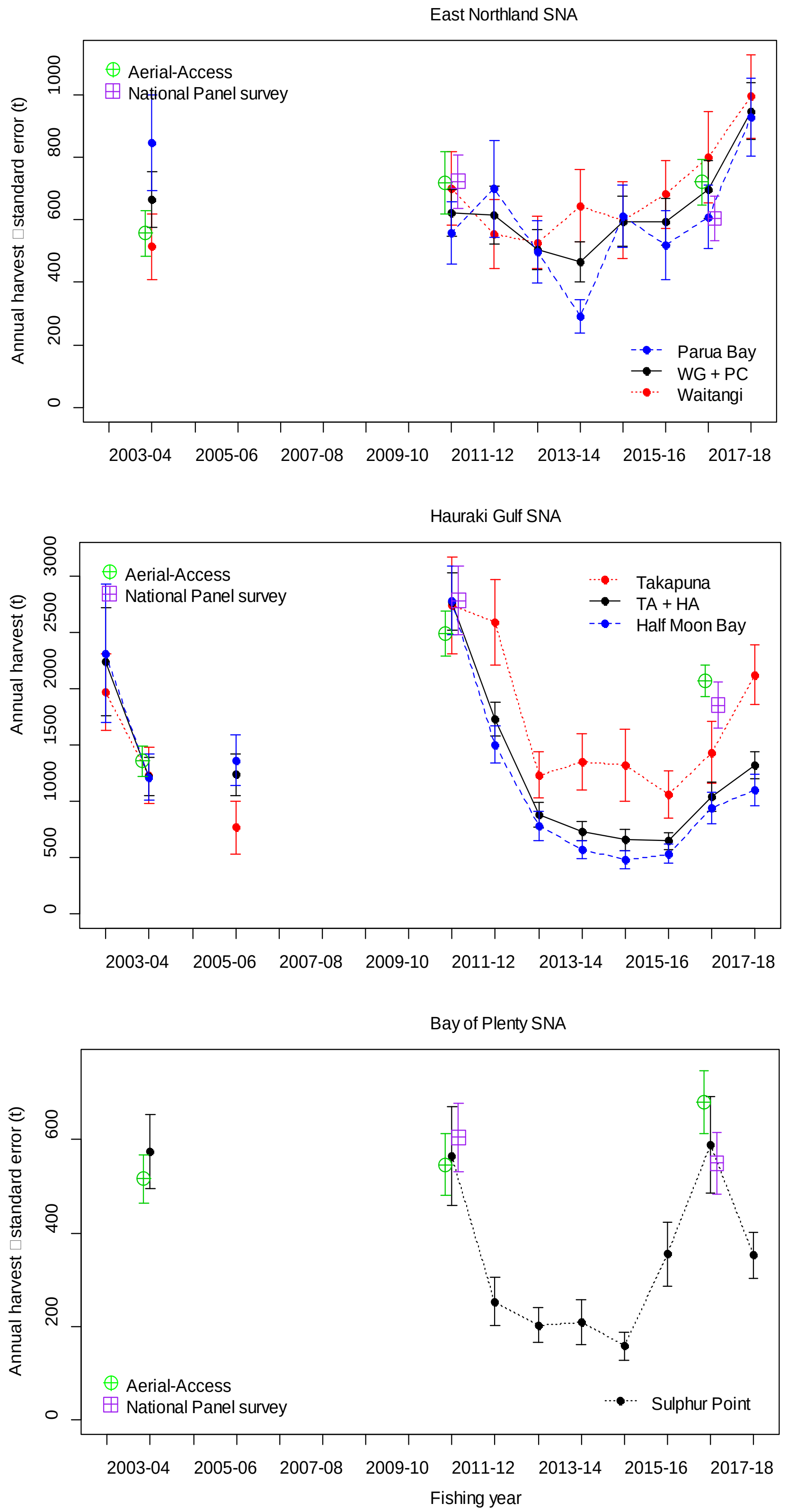

Figure 9: Indices of the snapper harvest snapper harvest landed annually to the ramps monitored in each region of SNA 1 (as seen in the bottom panels of Figures 3, 5, and 7) that have been scaled to the geometric mean of concurrent aerial-access surveys and National Panel Surveys conducted in 2004–05, 2011–12, and 2017–18. Effort-weighted combined landed harvest indices are also shown when the landed harvest was monitored at two ramps within a region, which have also been scaled to the mean of concurrent aerial-access and National Panel Survey harvest estimates.

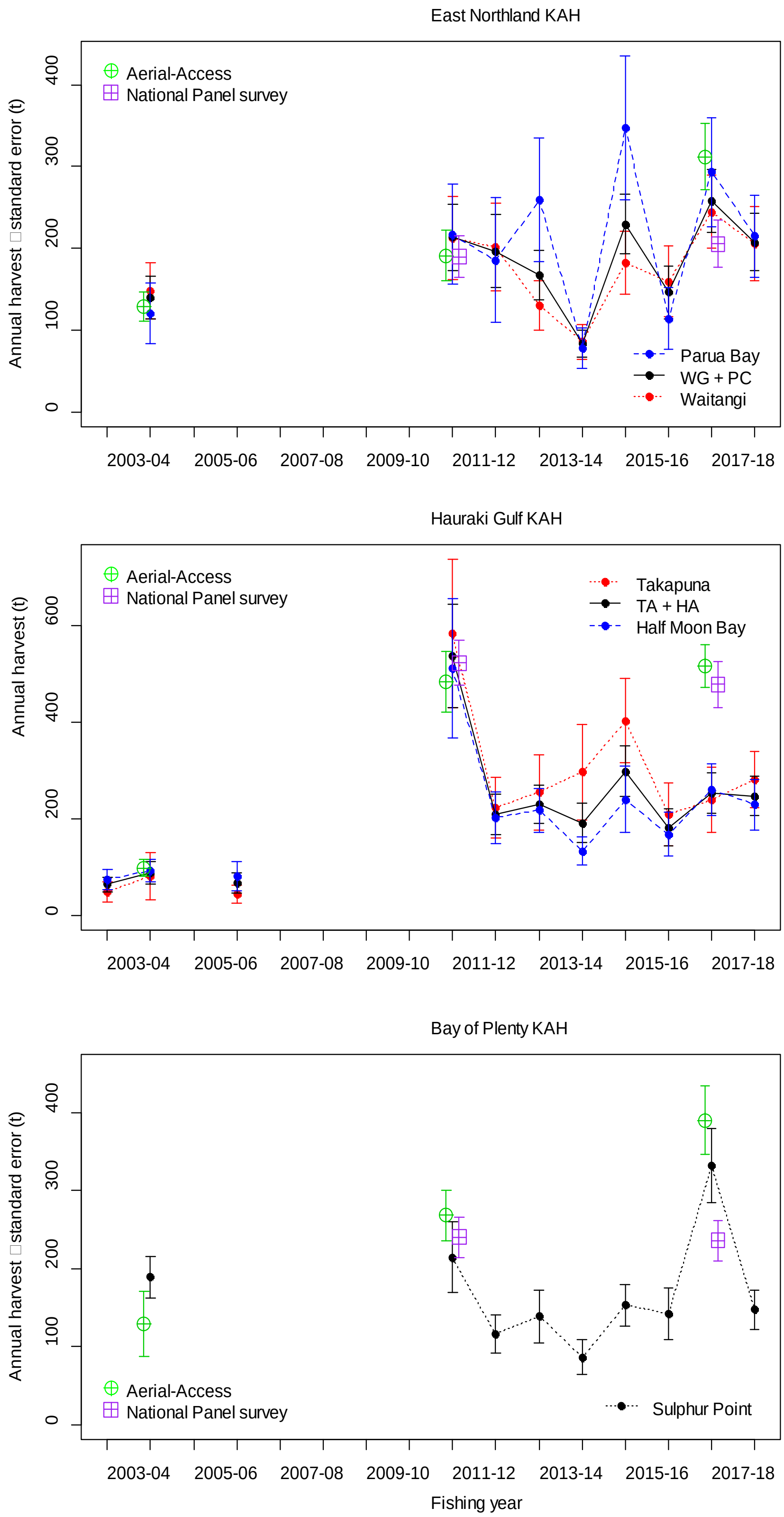

Figure 10: Indices of the kahawai harvest landed annually to the ramps monitored in each region of KAH 1 (as seen in the bottom panels of Figures 4, 6, and 8) that have been scaled to the geometric mean of concurrent aerial-access surveys and National Panel Surveys conducted in 2004–05, 2011–12, and 2017–18.

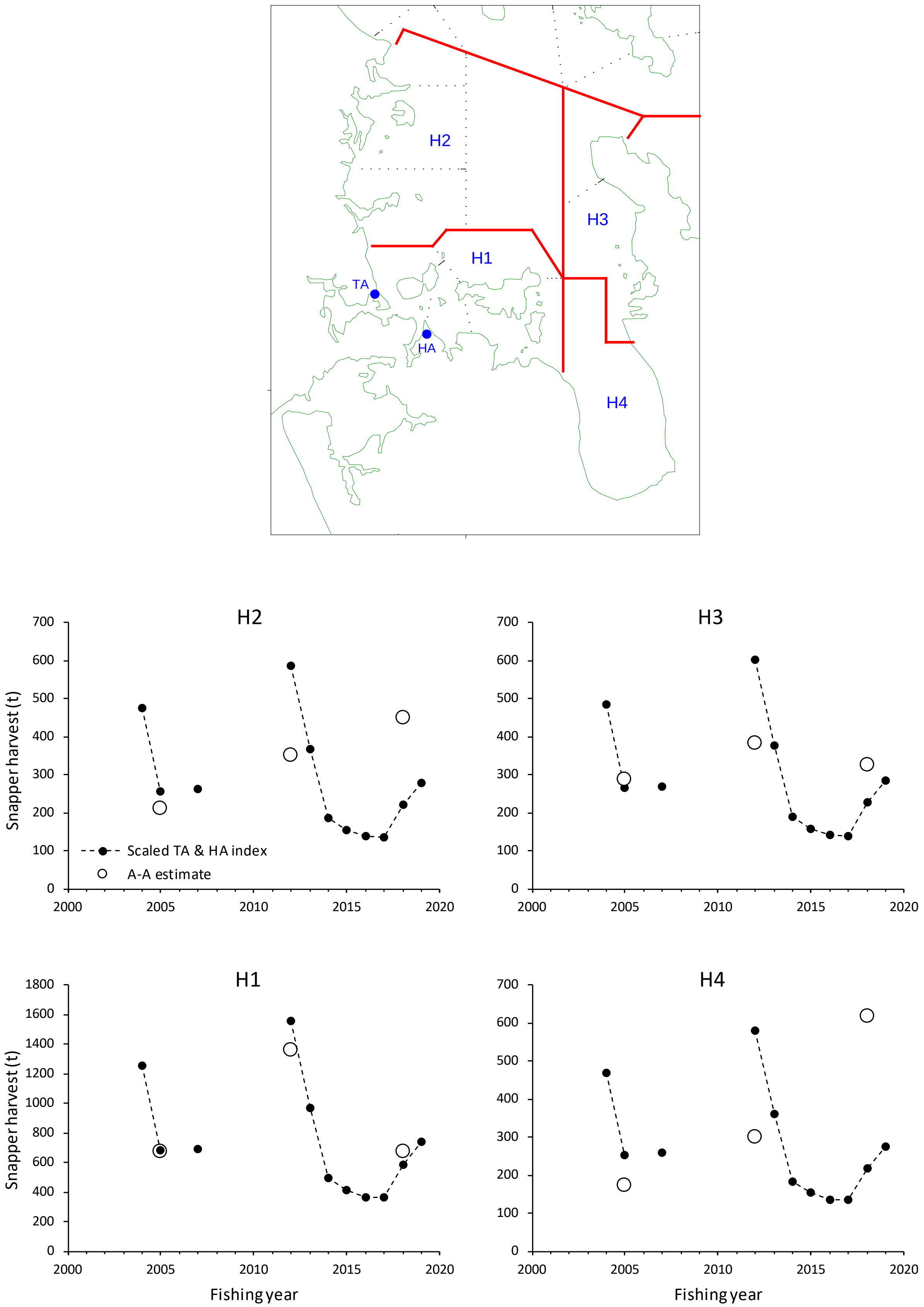

Figure 11: Comparison of aerial-access harvest estimates calculated for each quadrant of the Hauraki Gulf (as defined in the top panel) with the combined Takapuna (TA)/Half Moon Bay (HA) snapper harvest index from Figure 9, which has been scaled to the geometric mean of each quadrant's aerial-access harvest estimates.

3.2 FMA 2

The camera systems overlooking the Hawke's Bay Sport Fishing Club boat ramp in Napier and the ramp adjacent to the port in Gisborne have been fully operational since their installation in 2014 (Table 7), apart from a brief outage in 2015–16 and a more prolonged outage during the summer of 2017–18, which were both due to power being disconnected from the building in which this camera was housed. Interviewers surveyed fishers returning to these ramps on most, but not all the 60 scheduled survey days per fishing year. A small number of scheduled sessions were missed when the interviewer was sick or had resigned at short notice, and a replacement was not able to be found in time before the next scheduled survey day. The Hawke's Bay Sport Fishing Club ramp was taken over by the Napier City Council in 2016; and members of the public who are not club members have also been able to launch their boats from this access point since 2016.

Table 7: Availability of digital camera and creel survey data collected at two high-traffic boat ramps in FMA 2.

			Napier				Gisborne			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2014–15	Summer	Weekend	24	24	24	278	22	24	23	150
		Midweek	20	20	20	39	20	20	20	23
	Winter	Weekend	8	8	8	10	8	8	8	15
		Midweek	8	8	8	2	8	8	8	3
			60	60	60	329	58	60	59	191
2015–16	Summer	Weekend	24	24	24	284	19	24	24	130
		Midweek	20	20	20	30	17	20	20	50
	Winter	Weekend	7	8	8	35	8	8	7	16
		Midweek	8	8	7	5	8	8	7	4
			59	60	59	354	52	60	58	200
2016–17	Summer	Weekend	24	24	24	295	24	24	23	140
		Midweek	20	20	20	26	20	20	19	19
	Winter	Weekend	8	8	8	14	8	8	7	4
		Midweek	8	8	8	6	8	8	7	3
			60	60	60	341	60	60	56	166
2017–18	Summer	Weekend	24	24	23	238	16	24	19	100
		Midweek	20	20	21	44	18	20	19	24
	Winter	Weekend	8	8	7	14	6	8	7	29
		Midweek	8	8	8	5	6	8	7	5
			60	60	59	301	46	60	52	158
2018–19	Summer	Weekend	24	24	24	259	24	24	23	206
		Midweek	20	20	19	62	20	20	18	59
	Winter	Weekend	8	8	8	44	8	8	6	29
		Midweek	8	8	8	9	8	8	8	3
			60	60	59	374	60	60	55	297

The number of boats returning to the boat ramp at Gisborne has increased in all years except 2017–18, and over 60% of the boats interviewed have reported some type of fishing activity (top left panel of Figure 12). The species most commonly landed by recreational fishers returning to Gisborne has been tarakihi, but the catch of this species landed per boat trip has declined in recent years. Declining catch rates of tarakihi have been offset by the increase in effort at this ramp, and there has been little change in the weight of tarakihi landed by recreational fishers at Gisborne over the past five years (bottom left panel of Figure 12). There has been a steady increase in the average weight of the snapper catch landed at this ramp over time, however, which suggests an almost fivefold increase in the annual landed recreational snapper harvest from northern FMA 2 (bottom left panel of Figure 13). The landed catch of gurnard at Gisborne is relatively minor (Figure 14).

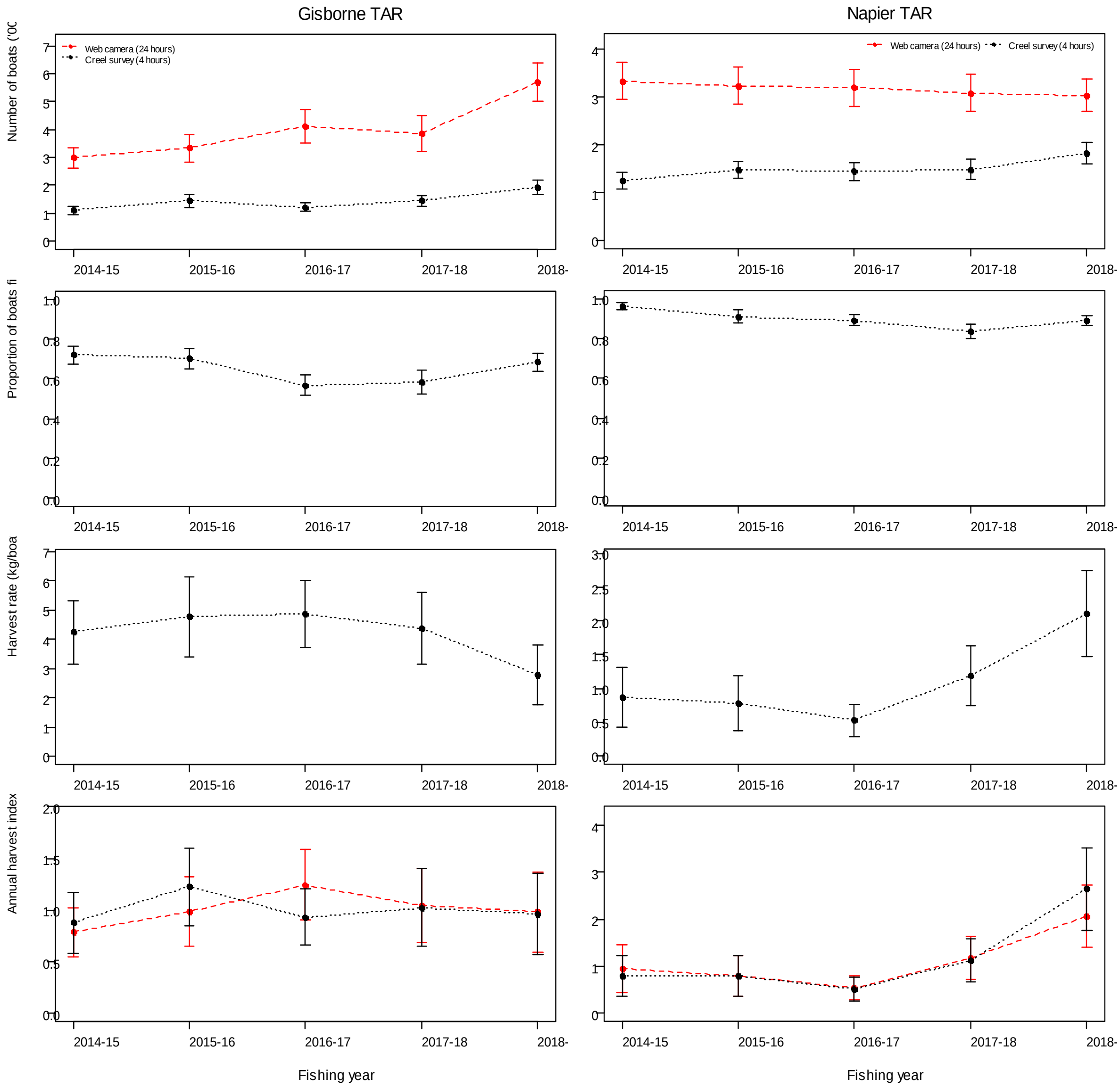

Figure 12: Annual estimates of numbers of boats returning to the boat ramps at Gisborne (left hand panels) and at Napier (right hand panels) in FMA 2 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of tarakihi harvested per boat (third panels down), and indices of the annual tarakihi harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

The image based traffic counts of boats returning to the ramp at Napier indicate a slight reduction in boating effort over the past five years, but the creel survey data collected during a 4-hour period of expected peak activity on the same sample of days, suggests a gradual increase in boating effort over time (top right panel of Figure 13). However, the difference is quite small and most of the change in the catch of each species landed at this boat ramp comes from changes in catch rates over time. The species most commonly landed at this boat ramp has been red gurnard, with catch rates for this species peaking in 2016–17, against an ongoing trend of gradually increasing average catch rates over the past five years (second to bottom right hand panel of Figure 13). The average weight of tarakihi landed per fishing boat has also increased at Napier since 2016–17, as it has for snapper over the last five years (second to bottom right hand panel of Figure 14). The overall trend in the total landed catch of these three species suggests a general improvement in the fishing experience of recreational fishers in Hawke's Bay in recent years.

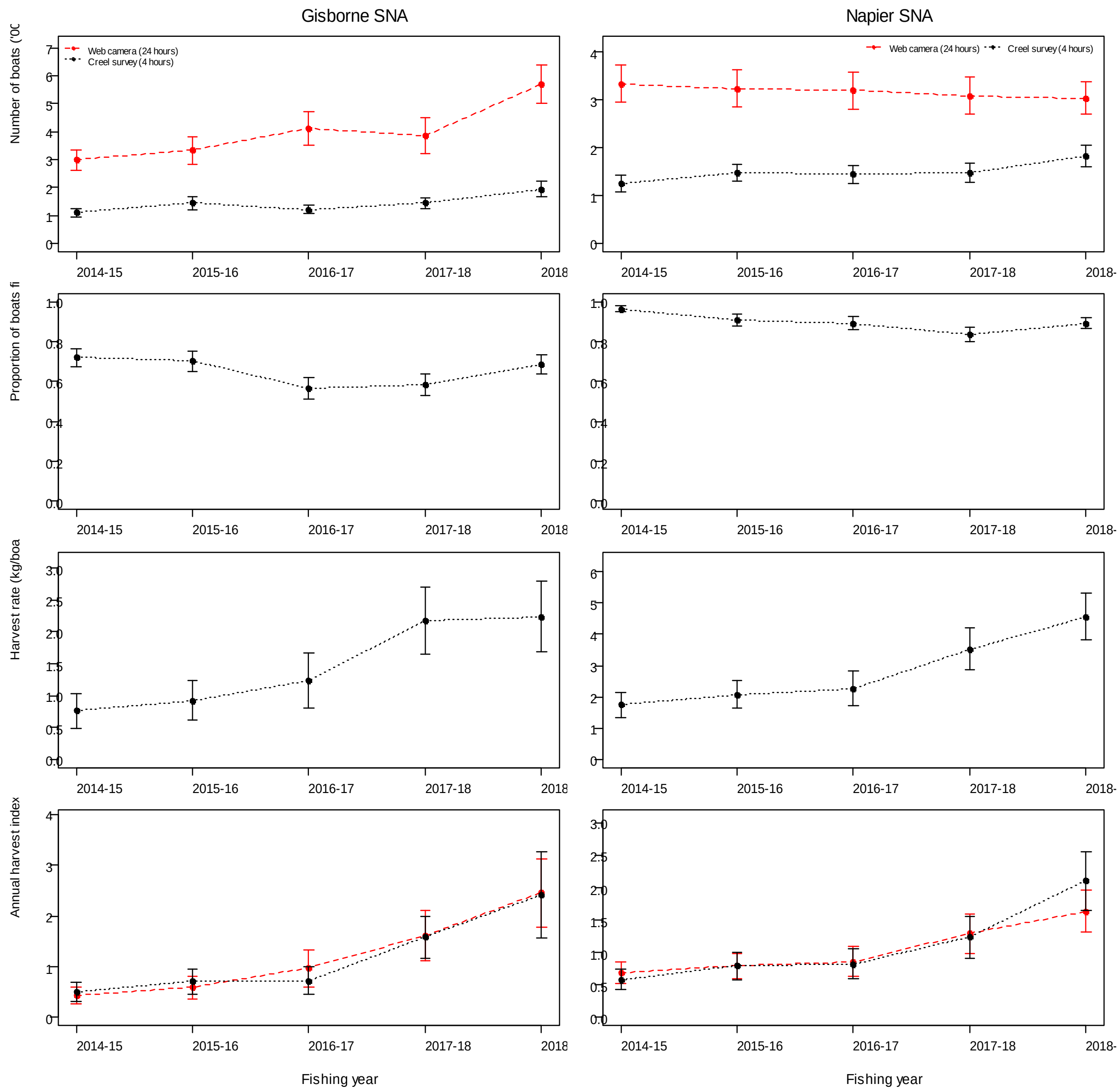

Figure 13: Annual estimates of numbers of boats returning to the boat ramps at Gisborne (left hand panels) and at Napier (right hand panels) in FMA 2 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

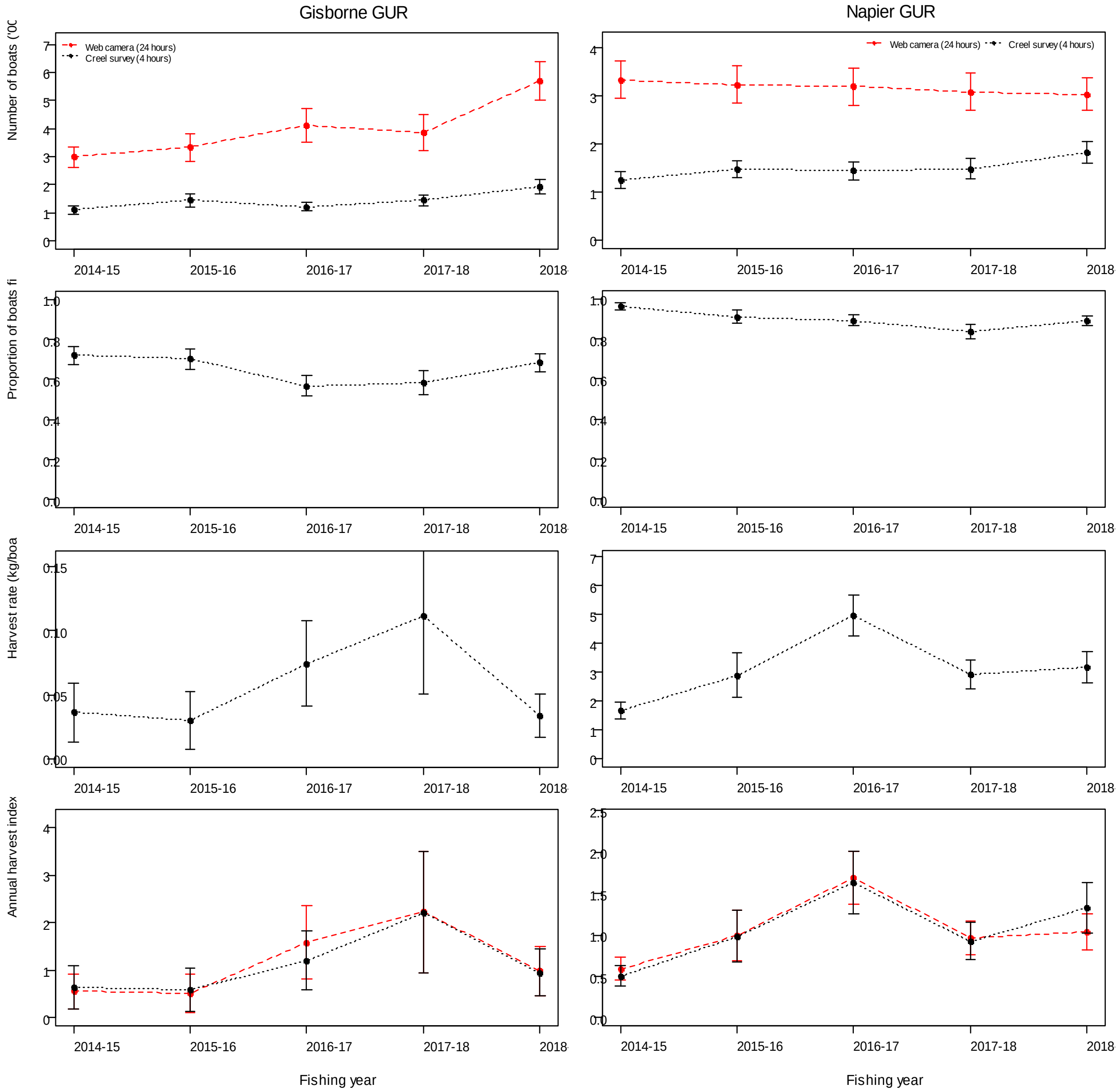

Figure 14: Annual estimates of numbers of boats returning to the boat ramps at Gisborne (left hand panels) and at Napier (right hand panels) in FMA 2 (upper panels – for all hours of the day, based on digital camera imagery; and for the four hours of the day when peak traffic was expected based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of red gurnard harvested per boat (third panels down), and indices of the annual red gurnard harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

3.3 FMA 7

The digital cameras used to monitor recreational boat traffic at the Nelson marina boat ramp (representing the Golden Bay/Tasman Bay fishery) and at the Waikawa Marina boat ramp (representing the fishery in the Marlborough Sounds) have been almost fully operational since they were first installed in late 2015 (Table 8). The only prolonged outage was at Waikawa Marina in late 2016, when there was a 5-week disruption to the street lighting power circuit used to power the camera system at this site. Boat ramp interviewers were present at both of these monitoring sites on almost all of the scheduled survey days in each year.

Both the camera and creel survey boat ramp traffic indices suggest that there has been relatively little change in levels of recreational boating effort in these areas since 2015–16 (upper panels of Figure 15). Only 24–30% of the boats returning to Waikawa had been used for fishing, a lower rate than observed at any other ramp. Catches of snapper were mostly taken from Golden Bay/Tasman Bay, with most of the observed blue cod catch landed from the Marlborough Sounds, with no apparent trend in landing rates evident over the past four years (third panels of Figures 15 and 16); and, consequently, little apparent change in the annual harvest of these species in these areas over that period (lower panels of Figures 15 and 16).

Table 8: Availability of digital camera and creel survey data collected at for two high traffic boat ramps in FMA 7.

			Nelson				Waikawa Marina			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2015–16	Closed summer	Weekend	8	10	10	102	8	10	10	50
		Midweek	10	11	7	12	10	11	7	5
	Open summer	Weekend	17	17	16	252	17	17	15	111
		Midweek	12	12	8	21	12	12	8	19
	Winter	Weekend	6	6	9	65	6	6	9	50
		Midweek	7	7	8	12	6	7	8	13
			60	63	58	464	59	63	57	248
2016–17	Closed summer	Weekend	10	10	9	60	7	10	9	36
		Midweek	11	11	10	10	7	11	10	5
	Open summer	Weekend	17	17	16	160	15	17	17	112
		Midweek	12	12	11	41	10	12	12	17
	Winter	Weekend	6	6	6	19	6	6	6	15
		Midweek	7	7	7	11	7	7	7	9
			63	63	59	301	52	63	61	194
2017–18	Closed summer	Weekend	10	10	9	71	10	10	10	26
		Midweek	11	11	12	21	11	11	12	14
	Open summer	Weekend	15	17	15	180	17	17	16	112
		Midweek	10	12	11	27	12	12	10	19
	Winter	Weekend	6	6	6	33	6	6	6	10
		Midweek	7	7	7	19	7	7	7	12
			59	63	60	351	63	63	61	193
2018–19	Closed summer	Weekend	10	10	13	210	10	10	9	27
		Midweek	11	11	11	24	11	11	9	4
	Open summer	Weekend	17	17	15	176	17	17	14	91
		Midweek	12	12	10	34	12	12	10	14
	Winter	Weekend	6	6	6	23	6	6	6	26
		Midweek	7	7	7	14	7	7	7	5
			63	63	62	481	63	63	55	167

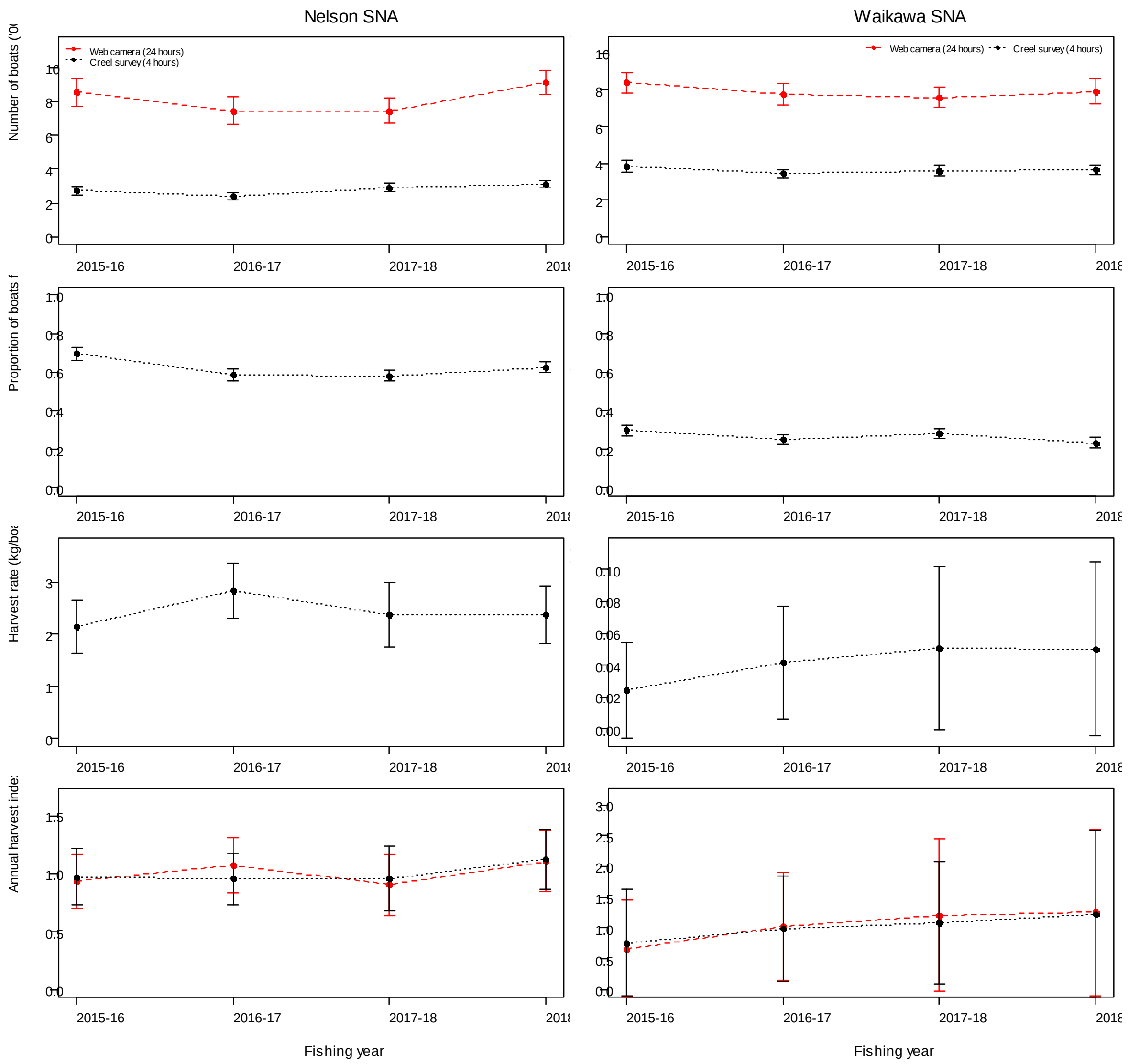

Figure 15: Annual estimates of numbers of boats returning to the boat ramps at Nelson (left hand panels) and at Waikawa (right hand panels) in FMA 7 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

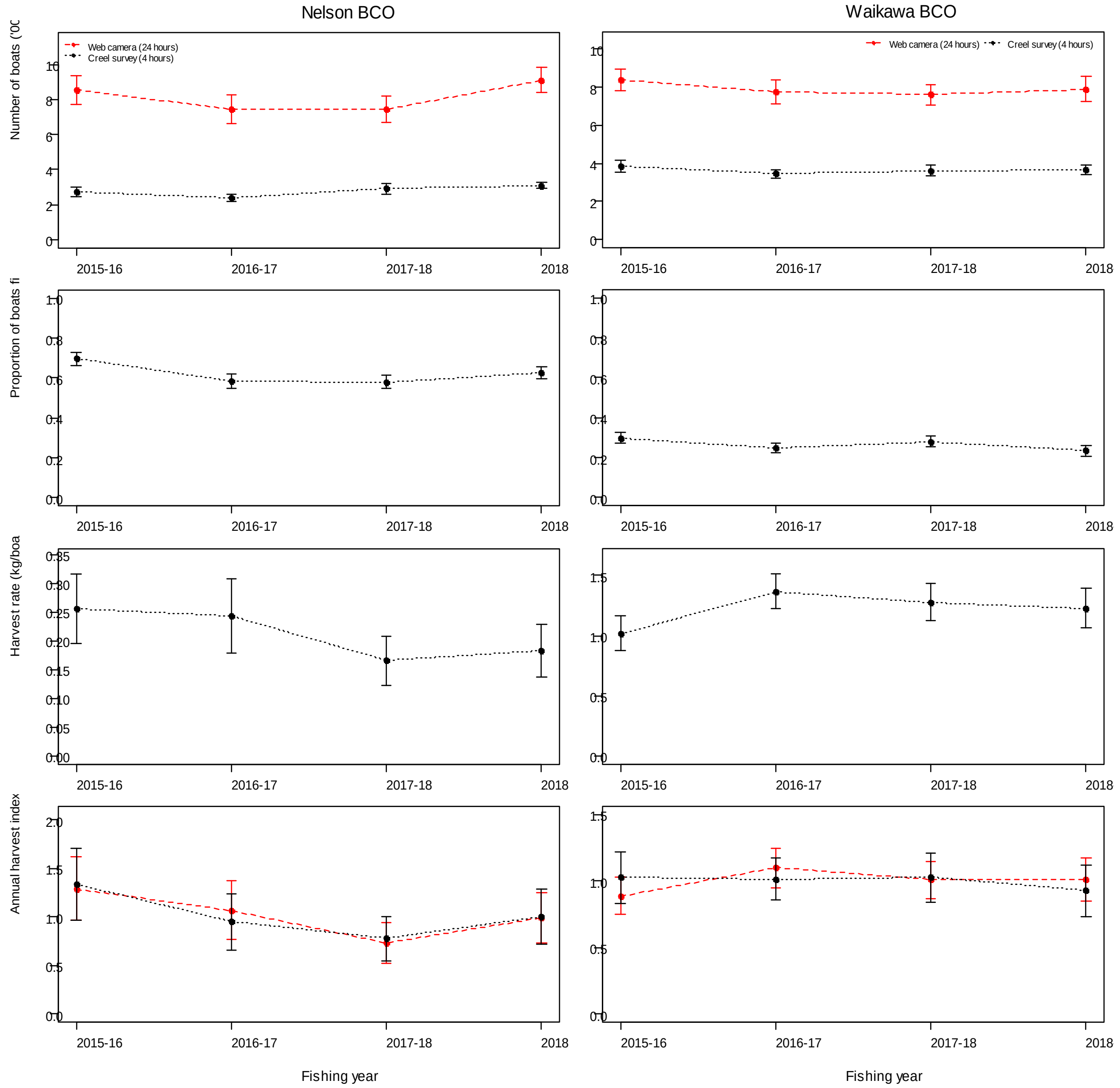

Figure 16: Annual estimates of numbers of boats returning to the boat ramps at Nelson (left hand panels) and at Waikawa (right hand panels) in FMA 7 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of blue cod harvested per boat (third panels down), and indices of the annual blue cod harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

A comparison of the Nelson snapper harvest index with the 2015–16 aerial-access and 2017–18 National Panel Survey harvest estimates for Golden Bay/Tasman Bay suggests that annual recreational harvest levels may have been more variable than this index might suggest (Figure 17). The same applies to blue cod landed at the Waikawa Marina ramp. For snapper in Golden Bay/Tasman Bay, the 2015–16 aerial-access survey harvest estimate (Hartill et al. 2017a) is much lower than that estimated by the National Panel Survey in 2017–18 (calculated here for the first time), with the reverse seen for blue cod in the Marlborough Sounds. These differences may not be that great, given the standard errors of the estimates, but they would be worth exploring if understanding the catch history was considered important for stock assessment purposes.

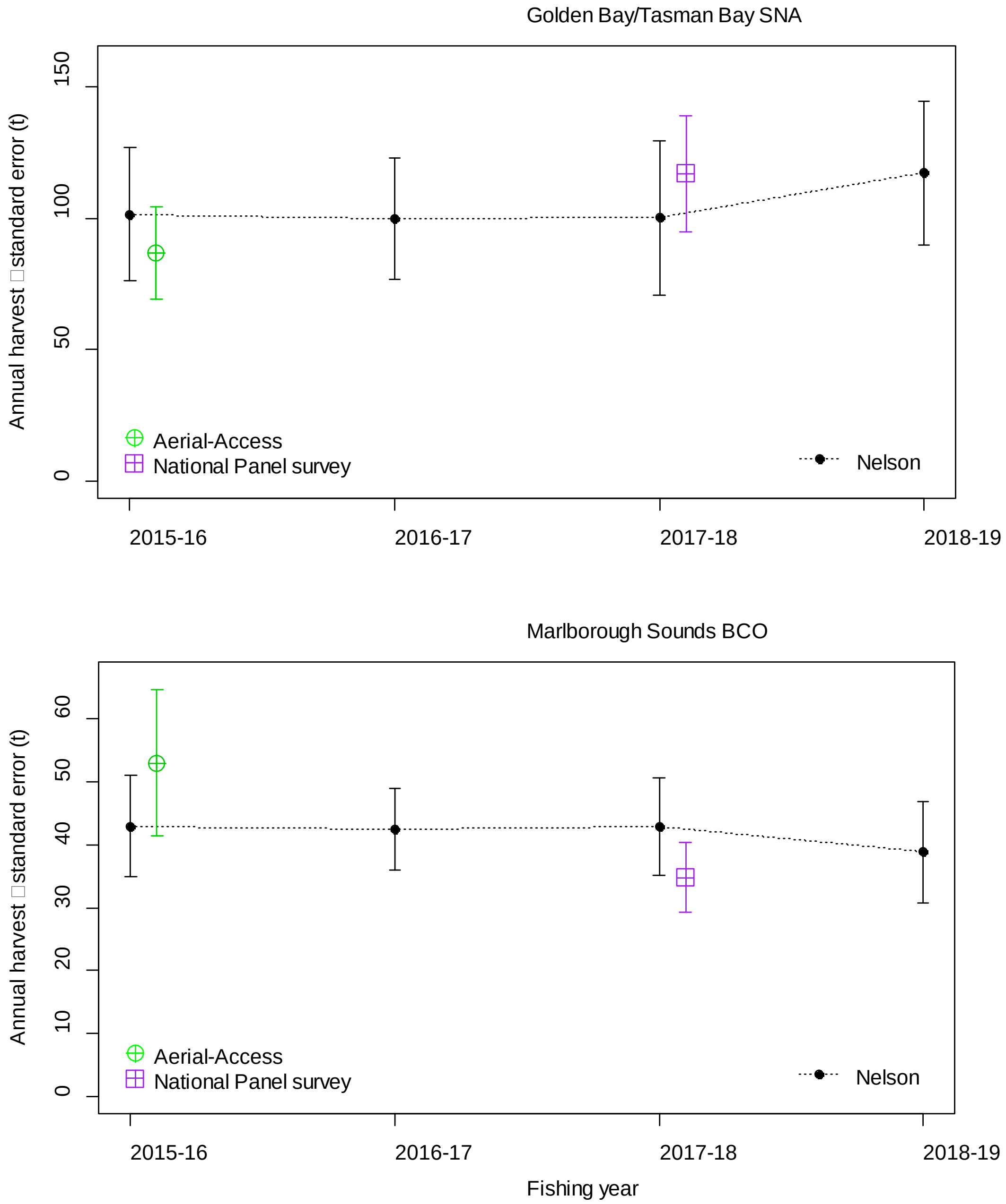

Figure 17: Indices of the snapper harvest landed annually from Golden Bay/Tasman Bay, and of the blue cod harvest landed from the Marlborough Sounds (shown in the bottom left panel of Figure 15 and bottom right panel of Figure 16, respectively) that have been scaled to the geometric mean of concurrent aerial-access and National Panel Surveys conducted in 2015–16 and 2017–18.

3.4 FMAs 8 & 9

Snapper catches account for most of the recreational harvest taken from the west coast of the North Island (FMAs 8 and 9), from the SNA 8 fish stock. Camera monitoring of recreational fishing effort on the west coast has been progressively extended since the first camera systems were installed at Shelly Beach (in the Kaipara Harbour) and at New Plymouth in 2006–07 (Tables 9 and 10). The level of recreational effort and catch can vary considerably along this coast, given localised weather conditions and changes in snapper availability to recreational fishers; cameras were therefore installed at two further sites, to monitor recreational fishing in areas where trends in catch and effort may have differed from areas that were already being monitored. Cameras were installed to monitor boats leaving the Raglan Harbour and from the Manu Bay boat ramp outside Raglan Harbour in late 2009, and another camera was installed overlooking Twin Bridges at Paremata in 2014, to monitor the southern west coast North Island fishery (see Figure 1).

The reliability of these camera systems has progressively improved as they have been re-engineered to address unforeseen problems, and they now provide almost complete temporal coverage of traffic at the ramps they overlook. The only recent prolonged outage occurred at Raglan during the winter of 2018, when several system components failed at different times, possibly due to irregular mains power (Table 9). Most interviewing of boating parties took place as scheduled, but some data collected at Raglan and Twin Bridges in 2017–18 have not been used for the analyses presented here, because the interviewers worked well outside the scheduled time of day, resulting in data which was potentially not consistent with that collected in other years.

The number of boats returning to the Shelly Beach boat ramp (in the Kaipara Harbour) has increased in recent years, but there is no evidence of any long-term trend in effort at the other three monitoring sites on this coast (Figures 18 and 19). A high proportion of the skippers interviewed at each site had been used their boat for fishing, especially at Shelly Beach, where very few of the interviewed boating parties had used their boats solely for another purpose. Reported catch rates from SNA 8 have gradually increased over time, with considerable and correlated interannual fluctuations in snapper landing rates occurring at Raglan and at New Plymouth, which are both on the open coast (third panels down on the left hand side of Figure 18 compared with that on the right hand side of Figure 19).

The annual landed harvest indices calculated for all four monitoring sites (bottom panels of Figures 18 and 19) all bear a marked similarity to the catch rate indices shown in the panels above, which suggests that changes in catch rates explain most of the increase in the recreational harvest taken from SNA 8 in recent years, rather than any change in fishing effort. When the annual landed harvest indices for the busier access points at New Plymouth, Raglan, and Shelly Beach are scaled to the geometric mean of the 2011–12 and 2017–18 National Panel Survey estimates, they all suggest a very similar magnitude of change in recreational harvest between these two fishing years, with a greater degree of variability during the intervening years (Figure 20). The three-ramp combined index that has been scaled to the 2011–12 and 2017–18 NPS harvest tonnage estimates (Figure 20) is potentially the best descriptor of the trend in recreational harvest from SNA 8 since 2011–12; for this the relative weighting for each of the constituent ramps was based on the relative number of boats returning to each ramp during each fishing year. These comparisons do not include the Twin Bridges index, because it does not extend as far back as 2011–12.

Table 9: Availability of digital camera and creel survey data collected at for two high traffic boat ramps in FMA 9.

			Shelly Beach				Raglan			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2006–07			60	60	–	–	–	–	–	–
2007–08			59	60	–	–	–	–	–	–
2008–09			59	60	–	–	–	–	–	–
2009–10			59	60	–	–	13	60	–	–
2010–11			51	60	–	–	57	60	–	–
2011–12			58	60	49	293	57	60	28	156
2012–13			60	60	57	276	60	60	61	351
2013–14			56	60	59	308	54	60	59	319
2014–15	Summer	Weekend	18	24	24	211	21	24	22	162
		Midweek	13	20	20	46	17	20	20	80
	Winter	Weekend	7	8	7	19	8	8	8	8
		Midweek	8	8	8	6	8	8	8	4
			46	60	59	282	54	60	58	254
2015–16	Summer	Weekend	24	24	24	260	23	24	24	218
		Midweek	20	20	16	30	19	20	18	19
	Winter	Weekend	8	8	8	49	5	8	8	21
		Midweek	8	8	8	5	6	8	8	2
			60	60	56	344	53	60	58	260
2016–17	Summer	Weekend	23	24	24	218	21	24	23	172
		Midweek	19	20	20	25	20	20	19	25
	Winter	Weekend	5	8	8	32	7	8	5	7
		Midweek	6	8	8	4	8	8	6	1
			53	60	60	279	56	60	53	205
2017–18	Summer	Weekend	22	24	19	123	23	24	11	70
		Midweek	18	20	19	38	20	20	12	13
	Winter	Weekend	7	8	8	46	2	8	7	21
		Midweek	8	8	8	20	3	8	8	14
			55	60	54	227	48	60	38	118
2018–19	Summer	Weekend	24	24	22	221	21	24	19	144
		Midweek	20	20	19	46	20	20	17	48
	Winter	Weekend	8	8	8	98	7	8	8	30
		Midweek	8	8	4	5	8	8	8	8
			60	60	53	370	56	60	52	230

Table 10: Availability of digital camera and creel survey data collected at for two high traffic boat ramps in FMA 8.

			New Plymouth				Twin Bridges			
			Camera days		Creel survey		Camera days		Creel survey	
Fishing year	Season	Day type	Usable	Target	Days worked	Boats interviewed	Usable	Target	Days worked	Boats interviewed
2006–07			34	60	–	–	–	–	–	–
2007–08			48	60	–	–	–	–	–	–
2008–09			41	60	–	–	–	–	–	–
2009–10			56	60	–	–	–	–	–	–
2010–11			59	60	–	–	–	–	–	–
2011–12			58	60	44	414	–	–	–	–
2012–13			60	60	55	209	–	–	–	–
2013–14			59	60	57	270	–	–	–	–
2014–15	Summer	Weekend	23	24	24	89	11	24	18	118
		Midweek	19	20	20	85	8	20	19	80
	Winter	Weekend	8	8	8	4	8	8	8	12
		Midweek	8	8	8	2	8	8	8	3
			58	60	60	180	35	60	53	213
2015–16	Summer	Weekend	23	24	20	121	24	24	24	204
		Midweek	20	20	15	36	20	20	19	20
	Winter	Weekend	6	8	7	15	8	8	7	10
		Midweek	7	8	6	5	8	8	8	6
			56	60	48	177	60	60	58	240
2016–17	Summer	Weekend	23	24	24	201	24	24	24	201
		Midweek	20	20	20	64	20	20	20	37
	Winter	Weekend	8	8	8	15	8	8	7	1
		Midweek	8	8	8	19	8	8	7	2
			59	60	60	299	60	60	58	241
2017–18	Summer	Weekend	24	24	17	138	24	24	12	78
		Midweek	20	20	18	61	20	20	14	20
	Winter	Weekend	8	8	8	24	8	8	8	11
		Midweek	7	8	8	34	8	8	8	10
			59	60	51	257	60	60	42	119
2018–19	Summer	Weekend	24	24	24	245	24	24	21	148
		Midweek	20	20	19	79	20	20	20	21
	Winter	Weekend	8	8	8	46	8	8	8	9
		Midweek	8	8	8	9	8	8	8	2
			60	60	59	379	60	60	57	180

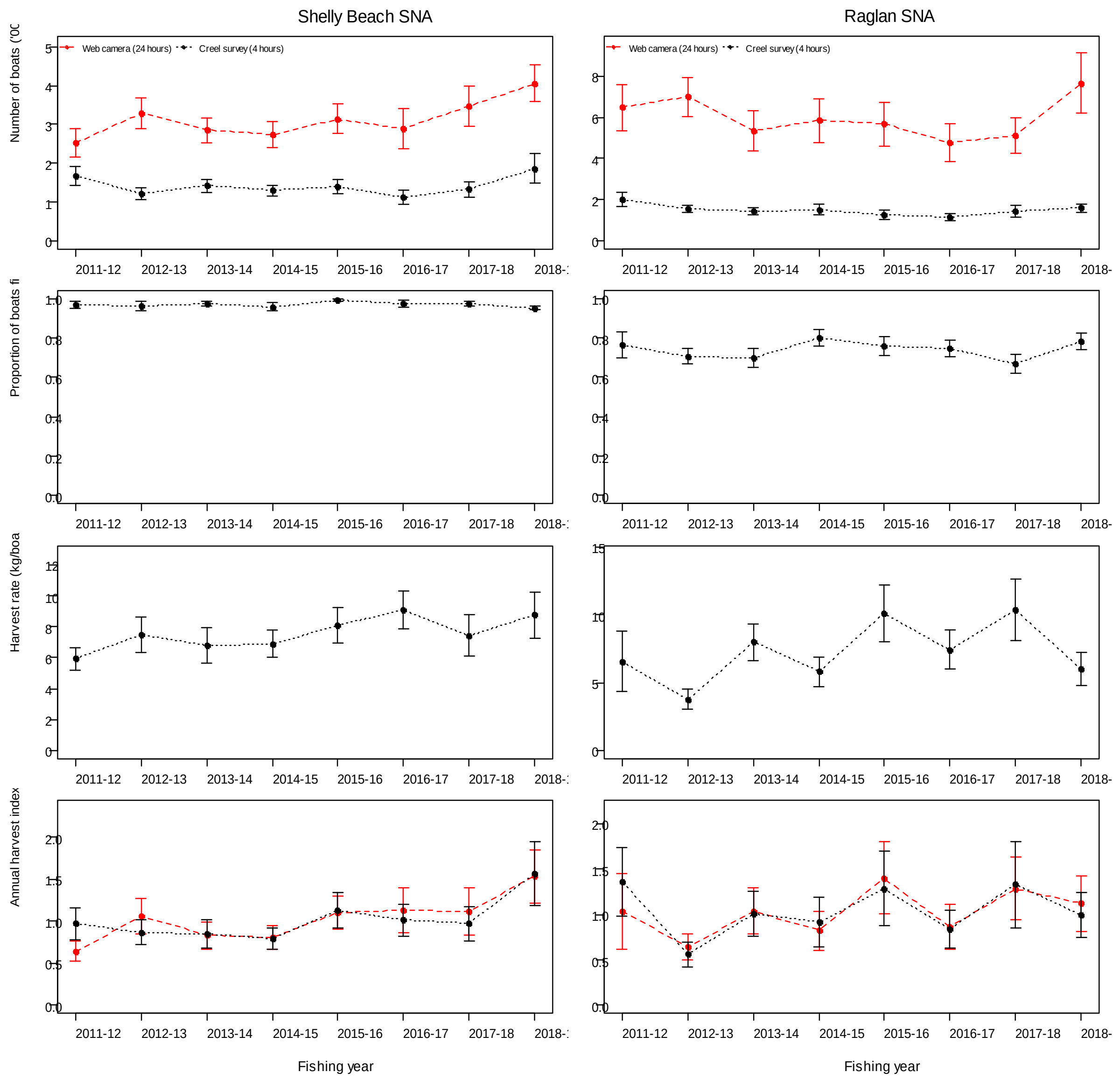

Figure 18: Annual estimates of numbers of boats returning to the boat ramps at Shelly Beach (left hand panels) and at Raglan (right hand panels) in FMA 9 (upper panels – for all hours of the day, based on digital camera imagery, and for the four hours of the day when peak traffic was expected, based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of this indices shown in the top three panels (bottom panels).

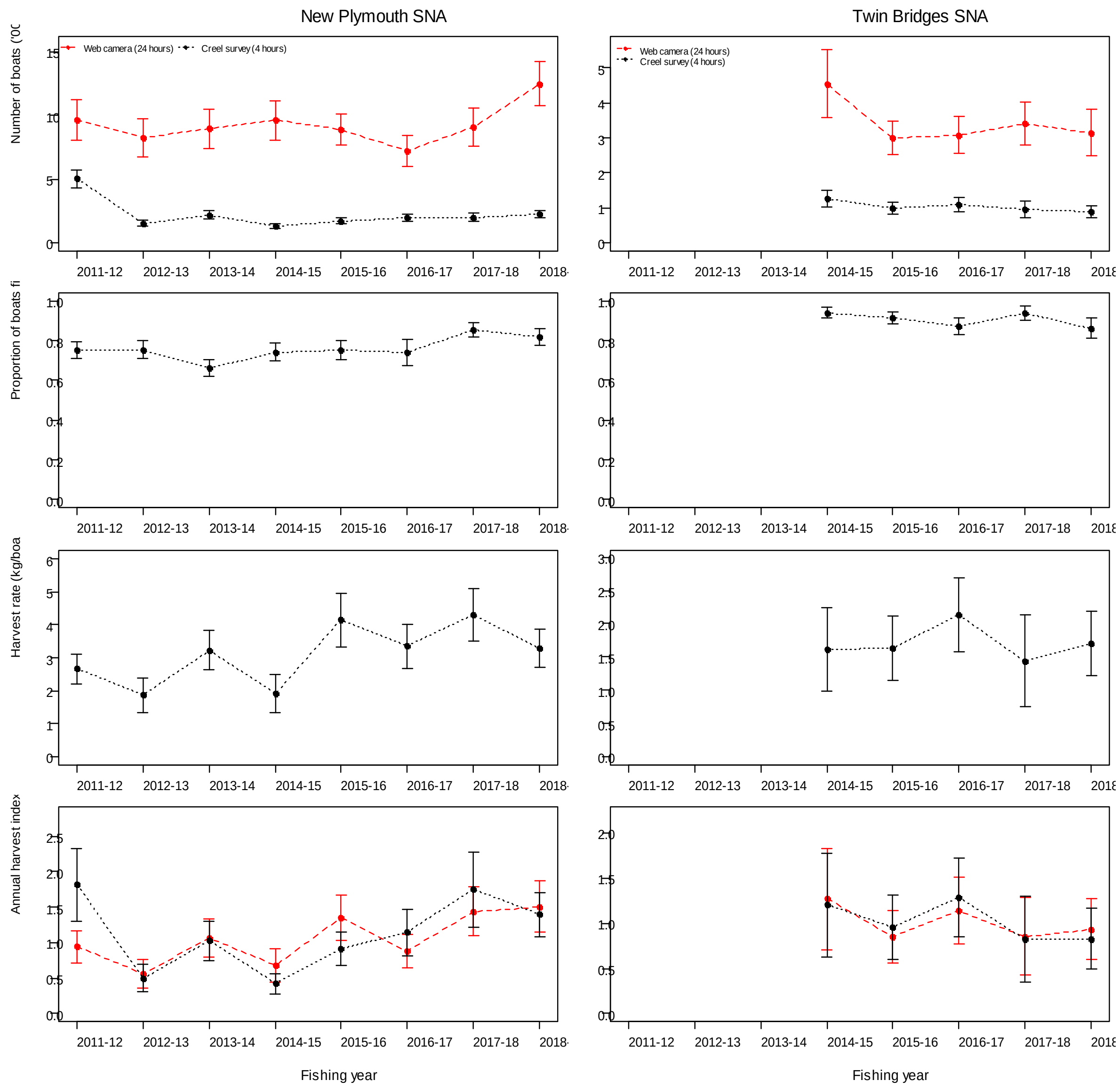

Figure 19: Annual estimates of numbers of boats returning to the boat ramps at New Plymouth (left hand panels) and at Twin Bridges (right hand panels) in FMA 8 (upper panels – for all hours of the day, based on digital camera imagery,; and for the four hours of the day when peak traffic was expected based on creel survey data), the proportion of observed boats that were used for fishing (second panels down), the average weight of snapper harvested per boat (third panels down), and indices of the annual snapper harvest landed at each ramp calculated from the product of the indices shown in the top three panels (bottom panels).

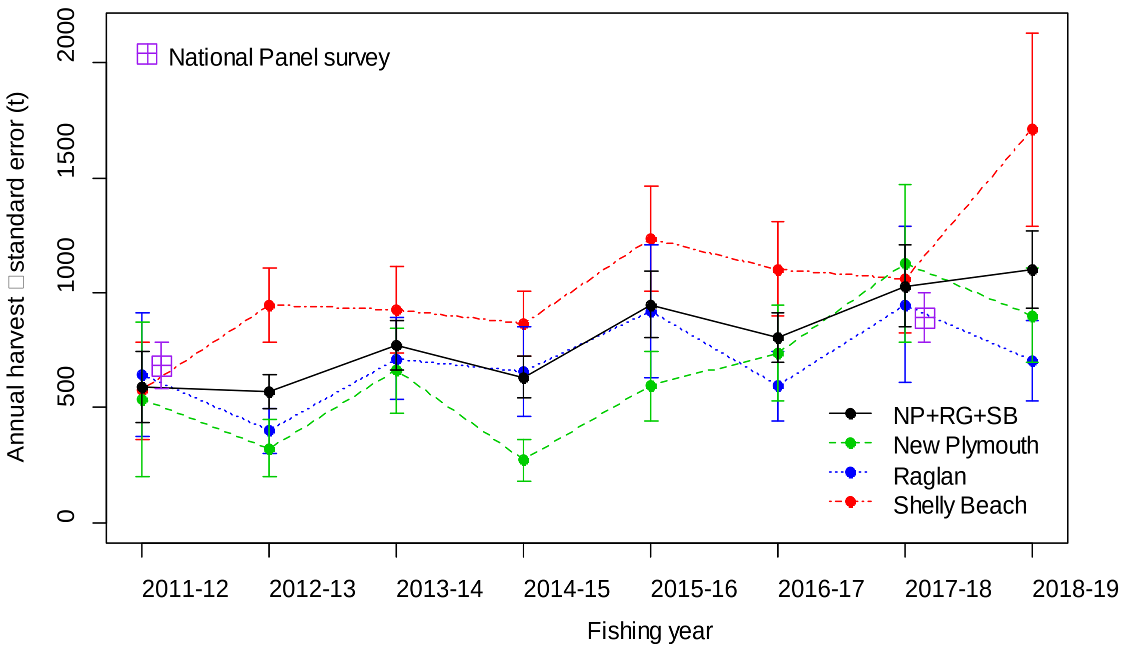

Figure 20: Comparison of annual harvest indices for New Plymouth, Raglan, Shelly Beach (as seen in the bottom panels of Figures 18 and 19) and for all three ramp indices combined, scaled to the 2011–12 and 2017–18 National Panel Survey harvest estimates for SNA 8.

4. DISCUSSION

The digital camera systems that this recreational fishery monitoring programme were initially based on were developed to describe trends in diurnal fishing activity for aerial-access surveys conducted in the Hauraki Gulf in 2003–04, and for all FMA 1 in 2004–05 (Hartill et al. 2007a). These cameras were then retained to monitor longer-term trends in recreational boating effort, to give some indication of levels of recreational harvest that may have occurred during the intervening period between aerial-access surveys (Hartill et al. 2013, 2016, 2019), and more recently, National Panel Surveys (Wynne-Jones et al. 2014, 2019) that are conducted only about every 5 or 6 years. These camera systems have been progressively re-engineered to ensure system reliability and continuity, and to improve the quality of the images they collect (Hartill et al. 2020).

Onsite and offsite surveys over the past 20 years have shown that the recreational harvest can vary considerably over time and, for some fish stocks, recreational landings may often approach or exceed those taken by the commercial sector. It has become increasingly apparent that much of this temporal change in recreational harvesting levels cannot be explained solely by the trends in recreational boating effort. It is also necessary to monitor changes in boat usage and catch rates, which cannot not be inferred from camera imagery (Hartill et al. 2016). A concurrent creel survey was therefore initiated at each of the camera monitoring sites in 2012–13, to collect data on these other metrics of recreational catch. The relative harvest indices provided by this camera/creel monitoring programme broadly correspond to the degree of change seen in the periodic aerial-access and NPS harvest estimates in most, but not all, areas.

A key assumption with the resulting camera/creel survey monitoring programme is that the trends in effort and catch observed at a small number of monitoring sites are broadly representative of the wider recreational fishery taking place in surrounding waters. This no longer appears to be so in the Hauraki Gulf where camera and creel harvest indices for snapper and kahawai both showed more interannual variability over the past 6 years than a comparison of the 2011–12 and 2017–18 aerial-access or NPS estimates for this region would suggest.

The reason for this discrepancy became apparent when spatially disaggregated aerial-access estimates were calculated for four quadrants of Hauraki Gulf for 2004–05, 2011–12, and 2017–18, for comparison with the camera/creel harvest index which initially appeared to describe the trend in recreational harvesting for the entire Gulf. Although the two monitoring sites located in urban Auckland provide a reasonable indication of the harvest taken from the south-western Hauraki Gulf (which until recently had accounted for over half of the recreational fishing taking place in Hauraki Gulf), this is not so for other sites. There has been a significant shift in both effort and catch to other areas of Hauraki Gulf in recent years, resulting in a more than threefold increase in effort the Firth of Thames (associated with rapidly expanding mussel farms) and a doubling in the north-western Hauraki Gulf since 2004–05. Only a very small proportion of the effort in these two areas would have originated from the two monitored boat ramps. Additional effort and catch monitoring is therefore clearly needed outside the Auckland urban area, to more representatively monitor the wider Hauraki Gulf fishery. Non-representative coverage is less likely to be an issue in most other areas, given the location and level of traffic at existing monitoring sites, but these should also be reviewed on a regular basis.

Any expansion of the monitoring network comes at a cost, however, which could undermine the long-term cost-effectiveness and viability of this approach. Much of this cost is associated with the operation and maintenance of the camera systems, and the interpretation of the images they collect. The pairwise comparisons of the ramp traffic indices generated from camera boat counts over 24-hour periods, with those based on creel survey data collected during a 4-hour period on the same day suggests that creel survey data can be used to generate traffic indices, and camera monitoring might therefore be unnecessary at all sites. Fisheries New Zealand has therefore decided to remove the camera systems from some sites and use the savings to initiate creel surveys at additional sites, without any associated camera monitoring. These new sites are: at Waikawau to monitor the burgeoning fishery in and around the expanding mussel farms in the Firth of Thames; at Gulf Harbour in the north-western Hauraki Gulf; and at Whitianga and Whakatane to cover the northern and eastern Bay of Plenty, respectively. Monitoring has also been discontinued at Takapuna in Auckland, where boat trailer parking has become limited; and at Twin Bridges in southern FMA 8, where the incidence of snapper landings is low relative to the other three sites that are also used to monitor the recreational catch taken from the SNA 8 stock.

These changes maintain the cost-effectiveness of the monitoring approach while extending its spatial coverage and representativeness. Some camera systems have been retained to provide continuous temporal coverage of activity at a reduced number of sites. Although previous analyses of counts of boats returning to some FMA 1 ramps during all 365 days in 2004–05, 2011–12, and 2017–18 suggested that the interpretation of images collected on a temporally stratified subsample of 60 days per fishing year should give a reasonably precise estimate of the number of boats returning to a ramp each fishing year, the ongoing collection of image data could be used to reassess this assumption at a later date. The development of computer vision methods to automate the interpretation of the images would be a significant step forward, because it could be used to continuously and cost-effectively monitor recreational fishing effort in real time. Early attempts to develop computer vision methods to automate the interpretation of images of the Waitangi boat ramp appeared promising; a concerted effort would still be required to operationalise this approach.

Regardless of how recreational harvests are monitored, there is probably a need to do so regularly given the magnitude of the harvest taken and the extent to which recreational effort and catch varies over time and between costly national surveys. Many of the boat ramp traffic indices derived from this study fluctuate considerably from year to year; reasons for this relate to the timing and nature of prevailing weather conditions, intentions to fish given perceived likely fishing success and availability of fish like snapper close inshore, and other societal factors such as conflicting demands on a fisher’s time and fuel prices. It is usually assumed that recreational catches will increase with human population growth, but there has been no apparent long-term increase in traffic at most of the sites monitored by this study. Participation rates in many recreational fisheries outside New Zealand are in fact declining, and this has been attributed to a variety of factors (Arlinghaus et al. 2014). Instead, most of the change in the harvest landed at the sites monitored by this study appears to have been due to changes in catch rates, rather than fishing effort. Much of the interannual variation in the catch rate indices derived from this study has probably been due to changes in the localised availability of fish to anglers fishing in shallower depths or changes in recruiting year class strength, rather than rapid substantial increases or decreases in stock wide abundance. The increase in the minimum legal size limit and the decrease in the daily bag limit for SNA 1 in 2013 will also have resulted in some, but not all, of the decline in snapper catch rates reported for the Hauraki Gulf at this time.

The results of this study give a better understanding of not only the factors that influence recreational harvesting levels, but also show how unpredictable these factors can be and how variable the recreational harvest can be. This programme has been extended for a further 5-year period by Fisheries New Zealand as part of MAF2019-01. This should provide further insight into the temporal dynamics of the recreational fisheries that have been monitored so far.

5. ACKNOWLEDGMENTS

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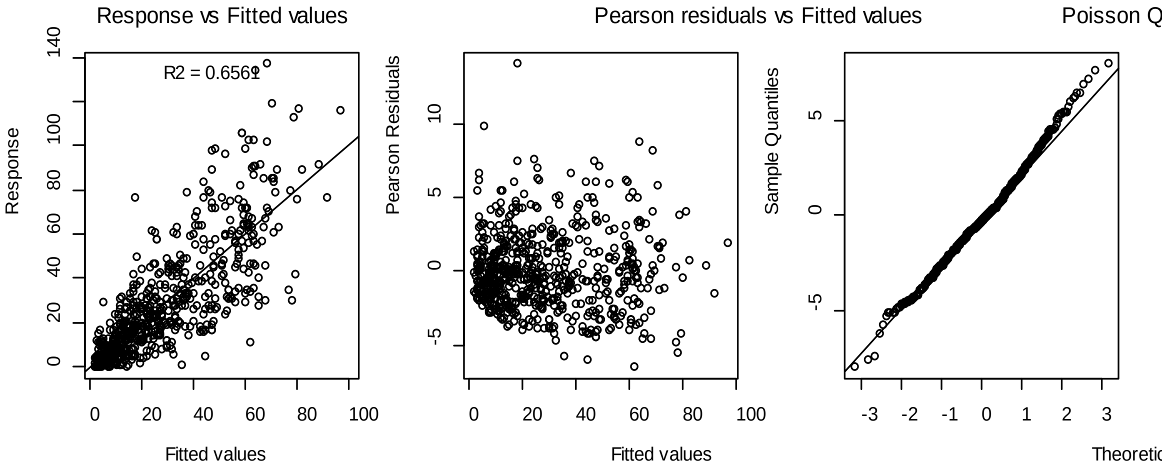
APPENDIX 1: Diagnostics for GLMs of FMA 1 daily traffic count data

Appendix 1a: Order in which explanatory variables are fitted to a model of daily boat traffic volumes at the Waitangi boat ramp in East Northland. The additional deviance explained by the sequential addition of each variable and the probability that the addition of that variable improves the explanatory power of the model is also given. TA denotes concurrent daily traffic counts at Takapuna in the Hauraki Gulf and SU denotes concurrent daily traffic counts at Sulphur Point in the Bay of Plenty.

WAITANGI

Variable	% Deviance explained	P(>|Chi|)
poly(sqrt(SU),	50.5%	<2.2e-16
poly(sqrt(TA),	7.6%	<2.2e-16
Fyear	4.7%	<2.2e-16
Daytype	1.9%	<2.2e-16
Season	2.9%	<2.2e-16
Fyear:sqrt(SU)	1.1%	<2.2e-16
Fyear:sqrt(TA)	0.9%	<2.2e-16

Diagnostic plots of the relationship between daily counts of boats returning to the Waitangi boat ramp relative to daily counts predicted from a model based on the variables given above [left panel]; residuals plotted against the daily counts predicted by the model [middle panel]; a Q–Q plot of these residuals.



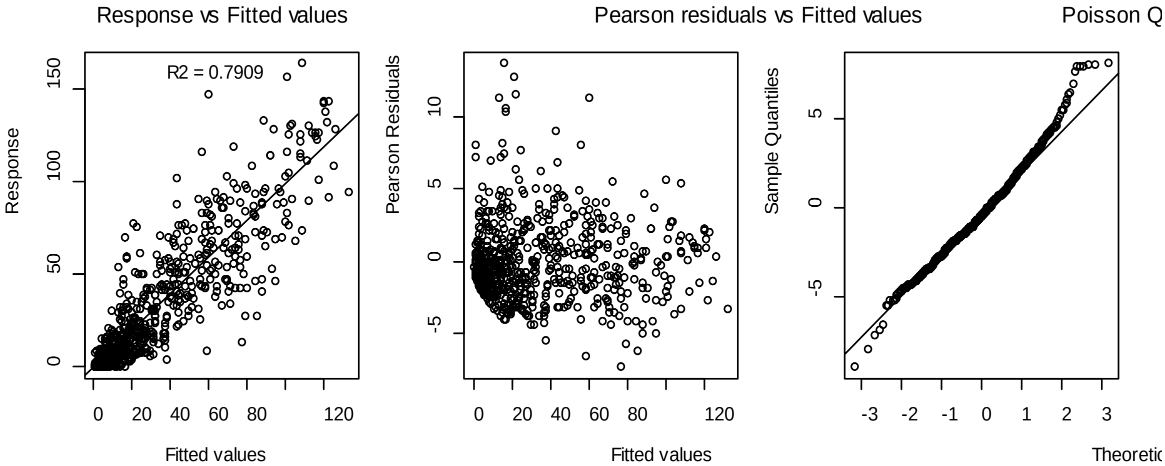
APPENDIX 1: *continued*

Appendix 1b: Order in which explanatory variables are fitted to a model of daily boat traffic volumes at the Takapuna boat ramp in the Hauraki Gulf. The additional deviance explained by the sequential addition of each variable and the probability that the addition of that variable improves the explanatory power of the model is also given. SU denotes concurrent daily traffic counts at Sulphur Point in the Bay of Plenty and WG denotes concurrent daily traffic counts at Waitangi in East Northland.

TAKAPUNA

Variable	% Deviance explained	P(>|Chi|)
poly(sqrt(SU),	66.4%	<2.2e-16
poly(sqrt(WG),	6.8%	<2.2e-16
Fyear	6.0%	<2.2e-16
Daytype	0.0%	0.0009178
Season	0.0%	0.0040138
Fyear:sqrt(SU)	0.6%	<2.2e-16
Fyear:sqrt(WG)	0.6%	<2.2e-16

Diagnostic plots of the relationship between daily counts of boats returning to the Takapuna boat ramp relative to daily counts predicted from a model based on the variables given above [left panel]; residuals plotted against the daily counts predicted by the model [middle panel]; a Q–Q plot of these residuals.



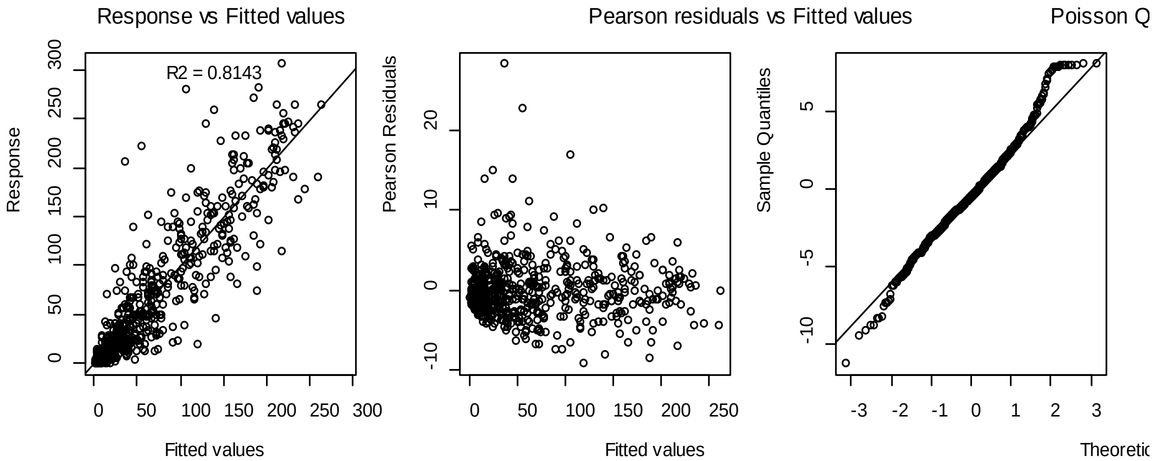
APPENDIX 1: *continued*

Appendix 1c: Order in which explanatory variables are fitted to a model of daily boat traffic volumes at the Half Moon Bay boat ramp in the Hauraki Gulf. The additional deviance explained by the sequential addition of each variable and the probability that the addition of that variable improves the explanatory power of the model is also given. SU denotes concurrent daily traffic counts at Sulphur Point in the Bay of Plenty and WG denotes concurrent daily traffic counts at Waitangi in East Northland.

HALF MOON BAY

Variable	% Deviance explained	P(>|Chi|)
poly(sqrt(SU),	72.8%	<2.2e-16
poly(sqrt(WG),	3.4%	<2.2e-16
Fyear	4.5%	<2.2e-16
Daytype	0.6%	<2.2e-16
Season	0.4%	<2.2e-16
Fyear:sqrt(SU)	0.6%	<2.2e-16
Fyear:sqrt(WG)	0.8%	<2.2e-16

Diagnostic plots of the relationship between daily counts of boats returning to the Half Moon Bay boat ramp relative to daily counts predicted from a model based on the variables given above [left panel]; residuals plotted against the daily counts predicted by the model [middle panel]; a Q–Q plot of these residuals.

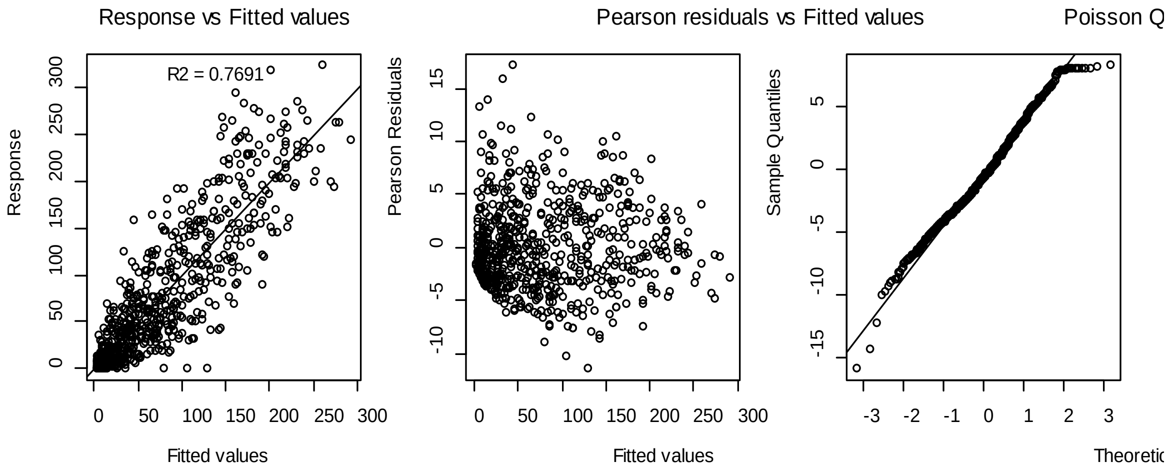


Appendix 1d: Order in which explanatory variables are fitted to a model of daily boat traffic volumes at the Sulphur Point boat ramp in the Bay of Plenty. The additional deviance explained by the sequential addition of each variable and the probability that the addition of that variable improves the explanatory power of the model is also given. WG denotes concurrent daily traffic counts at Waitangi in East Northland and TA denotes concurrent daily traffic counts at Takapuna in the Hauraki Gulf.

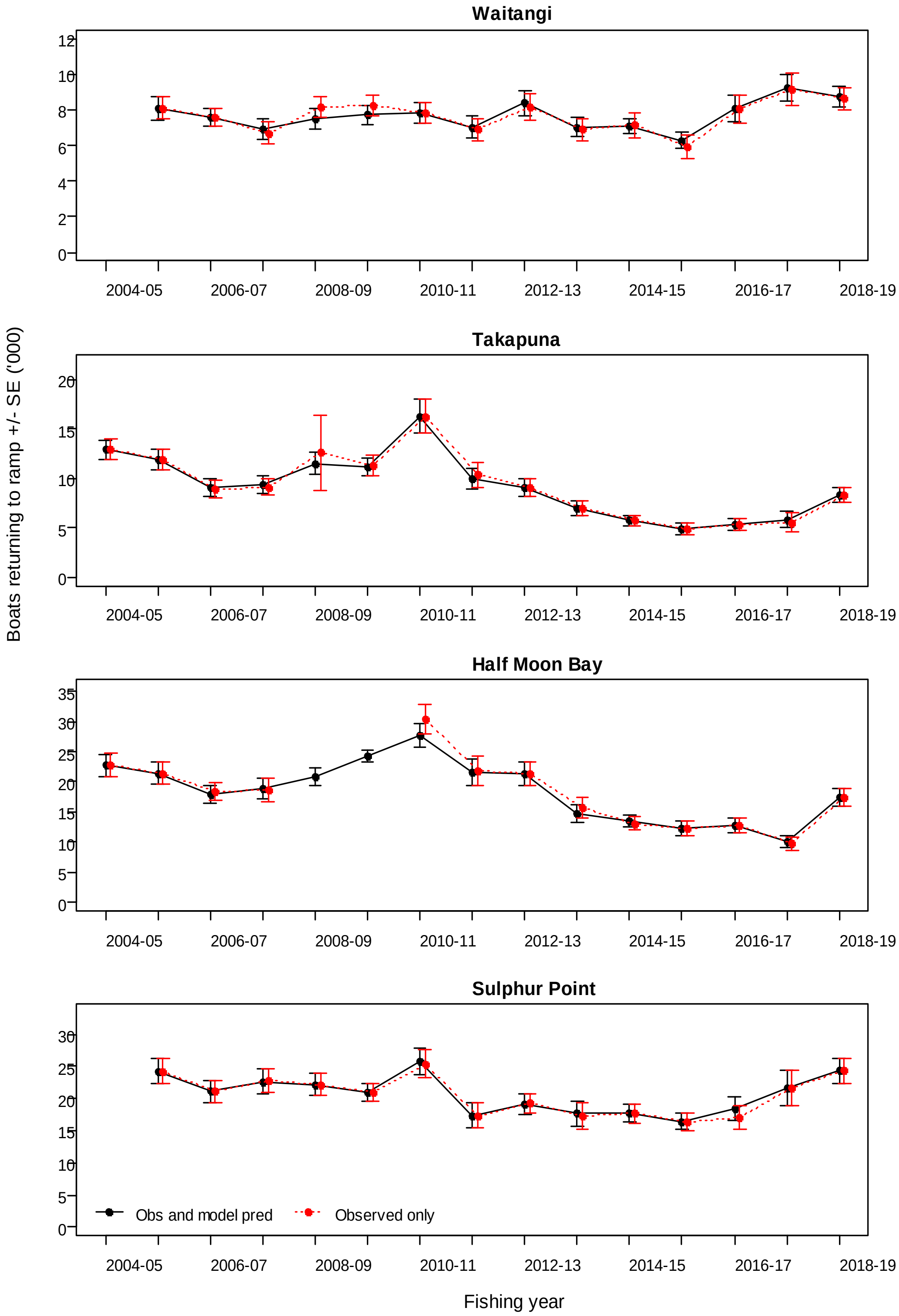
SULPHUR POINT

Variable	% Deviance explained	P(>|Chi|)
poly(sqrt(WG),	51.4%	<2.2e-16
poly(sqrt(TA),	19.7%	<2.2e-16
Fyear	1.8%	<2.2e-16
Daytype	2.2%	<2.2e-16
Season	0.5%	<2.2e-16
Fyear:sqrt(WG)	0.6%	<2.2e-16
Fyear:sqrt(TA)	0.9%	<2.2e-16

Diagnostic plots of the relationship between daily counts of boats returning to the Sulphur Point boat ramp relative to daily counts predicted from a model based on the variables given above [left panel]; residuals plotted against the daily counts predicted by the model [middle panel]; a Q–Q plot of these residuals.



APPENDIX 2: Traffic indices for FMA 1 ramps with and without GLM predictions for missing counts



APPENDIX 3: Recreational harvest tonnage estimates for FMA 1

Harvest tonnage estimates calculated by scaling the indices of relative catch by the geometric mean of the aerial-access estimates in concurrent years (with CVs in brackets) for SNA 1, as shown in Figure 9. Estimates for East Northland and the Hauraki Gulf are those calculated for the combined ramp index.

Fishing year	East Northland	Hauraki Gulf	Bay of Plenty	SNA 1
2004–05	730 (0.14)	1 216 (0.13)	605 (0.15)	2 551 (0.08)
2005–06	–	–	–	–
2006–07	–	1 224 (0.16)	–	–
2007–08	–	–	–	–
2008–09	–	–	–	–
2009–10	–	–	–	–
2010–11	–	–	–	–
2011–12	689 (0.13)	2 772 (0.09)	596 (0.18)	4 057 (0.07)
2012–13	679 (0.15)	1 718 (0.09)	273 (0.21)	2 671 (0.07)
2013–14	540 (0.12)	876 (0.13)	216 (0.19)	1 632 (0.08)
2014–15	511 (0.14)	735 (0.11)	223 (0.25)	1 469 (0.08)
2015–16	647 (0.13)	657 (0.15)	171 (0.19)	1 475 (0.09)
2016–17	649 (0.13)	649 (0.12)	385 (0.19)	1 683 (0.08)
2017–18	751 (0.13)	1 037 (0.11)	623 (0.16)	2 410 (0.08)
2018–19	1 030 (0.09)	1 312 (0.09)	376 (0.13)	2 718 (0.06)

Harvest tonnage estimates calculated by scaling the indices of relative catch by the geometric mean of the aerial-access estimates in concurrent years (with CVs in brackets) for KAH 1, as shown in Figure 10. Estimates for East Northland and the Hauraki Gulf are those calculated for the combined ramp index.

Fishing year	East Northland	Hauraki Gulf	Bay of Plenty	KAH 1
2004–05	149 (0.20)	88 (0.26)	229 (0.15)	465 (0.11)
2005–06	–	–	–	–
2006–07	–	69 (0.30)	–	–
2007–08	–	–	–	–
2008–09	–	–	–	–
2009–10	–	–	–	–
2010–11	–	–	–	–
2011–12	217 (0.18)	541 (0.19)	259 (0.21)	1 017 (0.12)
2012–13	207 (0.22)	212 (0.20)	139 (0.21)	558 (0.12)
2013–14	175 (0.19)	229 (0.18)	167 (0.24)	571 (0.12)
2014–15	86 (0.20)	191 (0.19)	107 (0.26)	384 (0.13)
2015–16	241 (0.17)	298 (0.18)	184 (0.17)	723 (0.10)
2016–17	158 (0.22)	181 (0.19)	170 (0.24)	509 (0.13)
2017–18	275 (0.15)	260 (0.16)	404 (0.15)	938 (0.09)
2018–19	227 (0.16)	245 (0.17)	174 (0.16)	646 (0.10)

APPENDIX 4: Recreational harvest tonnage estimates for FMA 7

Harvest tonnage estimates calculated by scaling the indices of relative catch by the geometric mean of the aerial-access estimates in concurrent years (with CVs in brackets) for the Golden Bay/Tasman Bay region of SNA 7, as shown in Figure 17.

Fishing year	SNA 7
2015–16	101 (0.26)
2016–17	103 (0.30)
2017–18	101 (0.31)
2018–19	114 (0.24)

Harvest tonnage estimates calculated by scaling the indices of relative catch by the geometric mean of the aerial-access estimates in concurrent years (with CVs in brackets) for the Marlborough Sounds region of BCO 7, as shown in Figure 17.

Fishing year	BCO 7
2015–16	43 (0.19)
2016–17	42 (0.15)
2017–18	43 (0.18)
2018–19	39 (0.21)

APPENDIX 5: Recreational harvest tonnage estimates for SNA 8

Fishing year	SNA 8
2011–12	593 (0.26)
2012–13	571 (0.13)
2013–14	773 (0.14)
2014–15	633 (0.15)
2015–16	947 (0.15)
2016–17	807 (0.13)
2017–18	1 029 (0.17)
2018–19	1 102 (0.15)