New Zealand Fisheries
Assessment Report
2007/25
August 2007
ISSN 1175-1584

Recreational marine harvest estimates of snapper and kahawai in the Hauraki Gulf in 2003–04

B. Hartill
T. Watson
M. Cryer
H. Armiger

Recreational marine harvest estimates of snapper and kahawai in the Hauraki Gulf in 2003–04

B. Hartill
T. Watson
M. Cryer
H. Armiger

NIWA
P O Box 109695
Auckland

New Zealand Fisheries Assessment Report 2007/25
August 2007

Published by Ministry of Fisheries
Wellington
2007

ISSN 1175-1584

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

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Hartill, B.; Watson, T.; Cryer, M.; Armiger, H. (2007). Recreational marine harvest estimates of snapper and kahawai in the Hauraki Gulf in 2003–04.

***New Zealand Fisheries Assessment Report 2007/25.* 55 p.**

This report provides preliminary harvest estimates for snapper and kahawai caught by recreational fishers in the Hauraki Gulf during the summer of 2003–04 (1 December 2003 to 30 April 2004) and winter of 2004 (1 May 2004 to 30 November 2004). We used an adaptation of the aerial overflight methodology to estimate that summer and winter harvests of snapper were 1088.7 and 172.0 tonnes respectively. Kahawai harvest estimates were 26.3 tonnes for summer and 11.5 tonnes for winter.

However, these are estimates of the harvest from stationary fishing vessels, which account for most, but not all, of the recreational harvest of these species. Estimates of the harvest caught by other methods, such as trolling, longlines, set nets and shore-based techniques, must also be considered. Harvests taken by minor, vessel-related methods such as trolling, set netting and longlining are estimated from boat ramp data. Shore-based harvests taken by surf casting, beach seining and kite fishing are estimated using the proportion of the snapper and kahawai catch taken by diarists by these methods in 2000.

Our survey estimates do not fully consider the harvest from the Lion Red Furuno Fishing Tournament. Over a three day period, 2608 kg of snapper (roughly half the weight of previous years) and 865 kg of kahawai were weighed in at Kawau Island. We treated these days as typical midweek and weekend days, but recognised that additional harvesting would have arisen as a result of the Tournament. We have adopted the simple expedient of adding the tournament harvest to our estimates. This is likely to result in a slight overestimation of the total summer harvest, as aerial observations strongly suggested that much of the Lion Red Furuno fishing effort, and hence catch, took place outside the Hauraki Gulf. Further, it is likely that some fishers would not have been fishing on those days if there was no competition on. Regardless, the weight of snapper landed during the Lion Red Furuno is small relative to that taken over the entire summer, although the associated catch of kahawai is perhaps higher than expected.

When these additional sources of harvest are considered, our estimate of the 2003–04 snapper harvest increases from 1260.8 to 1334.2 tonnes, and that for kahawai from 37.8 to 55.8 tonnes.

Some potential sources of bias are also investigated. These are: non-random selection of survey days given prevailing weather conditions; inaccurately derived scalars, which are used to combine aerial counts with profiles derived from boat ramp interviews; and failure to account for catches landed before or after interviewers were present at the ramp.

Survey days were selected at random according to a temporally stratified design, without any prior knowledge of fishing conditions on the days chosen. Subsequent examination of daily wind speed data suggests that, for three out of four temporal strata, a greater proportion of survey days fell on low wind speed days than actually occurred. This suggests that we may have overestimated harvests by over-sampling of days when fishing effort, and hence catch, was most likely.

The ratio of the number of fishers interviewed, who claimed to be fishing at midday, and the number of fishers observed from the air at that time, is a key component of our analysis. We compared eight of these daily ratios with those derived concurrently from an independent on-the-water survey, and found that there was a consistent difference between our two sets of estimates, of as much as 25%. Explanations are given for this, but we suspect that once quieter days are taken account, it is possible that we have overestimated the harvest by as much as 10–15%.

Our methodology is also based on diurnal profiles of catch and effort, which are derived from boat ramp interviews. Researchers in Australia found that significant catches are often landed after dark.

We used web camera data to estimate the proportion of fishers who may have been missed, and found that on average 14% of boating parties may have been unobserved. If all these parties had been fishing, we would have underestimated the harvest by about 15%.

Collectively these biases suggest that we may have marginally overestimated harvests of snapper and kahawai in the Hauraki Gulf between 1 December 2003 and 30 November 2004, but there is no evidence to suggest that our estimates are substantially biased.

The feasibility of using web camera based indices of boat ramp traffic as a proxy for an index of fishing effort is also examined. Significantly correlated relationships between camera based traffic counts and measures of daily fishing effort and snapper harvest derived from the aerial overflight survey suggest that this approach could be used to provide an ongoing index of fishing effort, and perhaps in the short term, if there is little change in catch rates, daily harvest.

1. INTRODUCTION

Reliable estimates of recreational harvest are a fundamental requirement for inshore stock assessments and management, yet are currently unavailable. Initial attempts to estimate harvests focused on indirect telephone survey/diary methodologies, but these are now considered unreliable, at least in an absolute sense.

This report describes an adaptation of the aerial overflight methodology (sensu Pollock et al. 1993) which has been used to estimate an annual recreational harvest of snapper in a manner which is more direct than one based on diarist selection and recall. The methodology combines aerial counts of recreational fishing vessels at midday, with boat ramp interview data, which are used to describe how fishing effort and associated catch levels change throughout the day. Survey days were selected a priori, according to a random stratified design. During the survey, the Ministry of Fisheries requested concurrent harvests estimates for kahawai, which are also given.

Seasonal, species-specific harvest estimates are provided for four spatial divisions of the Hauraki Gulf, which are combined to provide annual estimates for the Gulf. The methodology focuses on stationary, boat based fishing methods, which account for most, but not all, of the snapper harvest. Other harvest sources, such as those resulting from indirectly assessed shore-based methods, such as surfcasting and kite fishing, and vessel-based methods such as trolling and longlining, are also considered indirectly. Some sources of bias are also explored, insofar as this is possible.

Web camera systems were developed and installed at two of the busiest boat ramps in the Auckland metropolitan area. Images from these cameras can be used to monitor boat ramp traffic continuously, on a minute-by-minute basis, and we examine the feasibility of using these data to develop an ongoing index of fishing effort in the Hauraki Gulf.

Objective

To provide estimates of the recreational harvest of snapper in the Hauraki Gulf.

Specific objectives

1. To develop one or more independent methodologies for estimating the recreational harvest of snapper in the Hauraki Gulf.

2. To test the methodologies developed in Objective 1 for estimating the level of recreational harvest of snapper in the Hauraki Gulf over the period 1 November 2003 to 30 April 2005.

3. To test the feasibility of adapting the aerial-access method to other areas outside the Hauraki Gulf (north and south) and to include the additional species of kahawai and kingfish.

4. To develop an ongoing index of fishing effort for estimating the recreational harvest of snapper in the Hauraki Gulf.

The Ministry of Fisheries subsequently requested a kahawai harvest estimate for the summer of 2003–04, which is provided in this report along with an additional estimate of the harvest of kahawai during the winter of 2004.

2. METHODS AND RESULTS

2.1 Aerial-access methodology overview

Daily harvest estimates, collected according to a temporally stratified random design, were weighted together appropriately to give both seasonal and annual harvest estimates. Each daily harvest estimate was derived from an estimate of the level of instantaneous fishing effort near midday, which was then used to scale up diurnal profiles of effort and related harvest.

Daily estimates of the level of instantaneous fishing effort near midday, for a given area, were derived from counts of recreational fishing boats made by observers flying at 500 feet. On the same day, fishers were interviewed at key boat ramps between approximately dawn and dusk, from which diurnal profiles of relative fishing effort (as boats or people fishing) and harvest (as weight or number of fish) were generated. The ratio of the number of boats fishing (i.e., fishing parties) as observed from the air at a given time, relative to the number of interviewed fishing parties claiming to be fishing at that time, was used to scale up the profiles mentioned above. These scaled profiles were integrated (i.e., the area under the "curve" was calculated") and the resulting daily estimates of effort and harvest were combined to produce larger scale temporal harvest estimates based on the original random stratified sample design.

The method used here is, therefore, based on that described by Pollock et al. (1993) as used for the Lake Taupo trout fishery (Department of Conservation 1991) and for the western Hauraki Gulf snapper fishery in 1994 by (T. Sylvester, MAF Fisheries, unpublished results). These studies used multiple flights during the day to provide estimates of fishing effort and catch at different periods of the day, whereas we use counts from a single midday flight which is used to scale up profiles derived from boat ramp interviews.

The analytical approach used is discussed in the next few sections to provide a framework for the survey results. A more succinct description of the analytical approach is given in Appendix 5, which includes mathematical formulae.

2.2 Temporal stratification

The highly variable nature of recreational fishing effort was accommodated in a stratified sampling design based on fisher behaviour relative to the conventional working week (weekend/public holiday vs midweek day-types) and season (summer vs winter).

Recreational fishing effort generally peaks during the "summer" (1 December to 30 April) and is, therefore, likely to be most variable at this time of year. A theoretically optimal allocation of summer sampling effort between week days and weekend/public holiday days was derived from parametric simulations using data collected during the only previous aerial-access survey in the Hauraki Gulf, in 1994. Only data collected between 1 January 1994 and 30 April 1994 were used in these simulations (no data being available from December 1993).

Within the simulations, fishing effort profiles were derived from hourly vessel counts made by ferry skippers. These profiles were scaled up by mid-day vessel counts from 8 midweek and 10 weekend overflights to provide daily estimates of the total number of hours fished. These effort estimates were then multiplied by the average landed catch of snapper per vessel hour, obtained from the boat ramp surveys, to provide daily harvest estimates. Distributions were found to be approximately normal. The mean and variance of these estimates were used in parametric bootstraps to estimate the variance associated with different levels of sampling intensity during both midweek and weekend/holiday temporal strata (Figure 1).

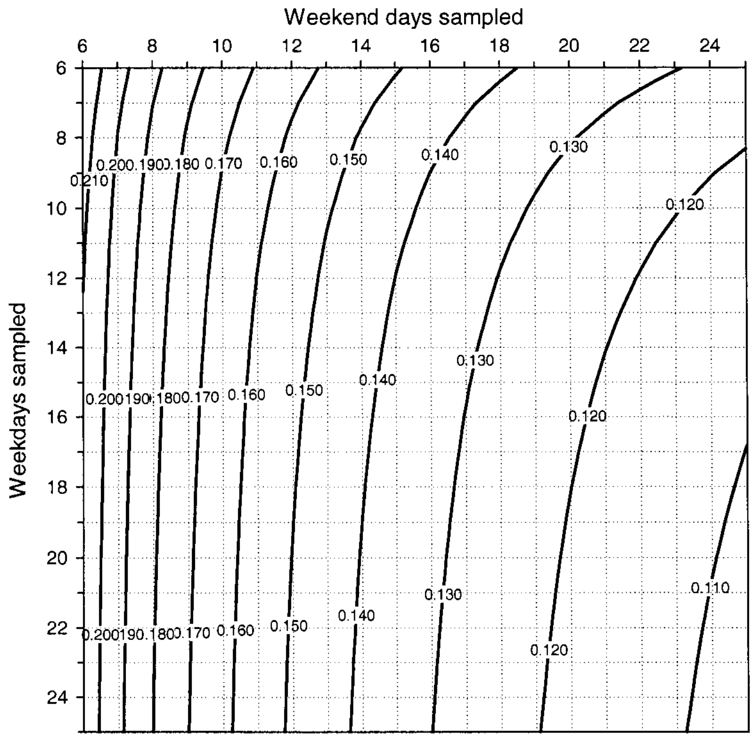


Figure 1: Estimates the variance (coefficients of variation) for snapper harvest estimates based on parametric simulations of different levels of midweek and weekend sampling effort.

These simulations suggested that most daily variation in snapper harvest levels occurred during the weekend/holiday strata, when fishing effort is generally greatest. Most sampling effort was, therefore, allocated to the summer weekend/holiday stratum, with eight days assigned to each of the remaining seasonal/day-type strata (Table 1).

Table 1: Aerial-access sample design for the summer (1 December 2003 to 30 April 2004) and winter (1 May to 30 November 2004) seasons.

Season	Temporal strata	Number of days available	Days flown	Sampling intensity
Summer	Midweek days	98	8	0.08
	Weekends/holidays	51	21	0.41
	Lion Red Furuno Fishing Tournament	3	3	1.00
Winter	Midweek days	150	8	0.05
	Weekends/holidays	64	8	0.13

Many local fishing competitions take place in the Hauraki Gulf in the summer. Because of their numerous and localised nature, these were generally treated as random occurrences and their harvest was not considered separately. One competition was specifically considered however, the Lion Red Furuno Fishing Tournament, which is by far the largest on the region's fishing calendar. The tournament was based on Kawau Island, where no boat ramp interviewers were usually based. This competition was initially treated as a separate, independent temporal stratum, with aerial counts of fishing boats taking place on all three days (Thursday, 18 March to Saturday, 20 March 2004).

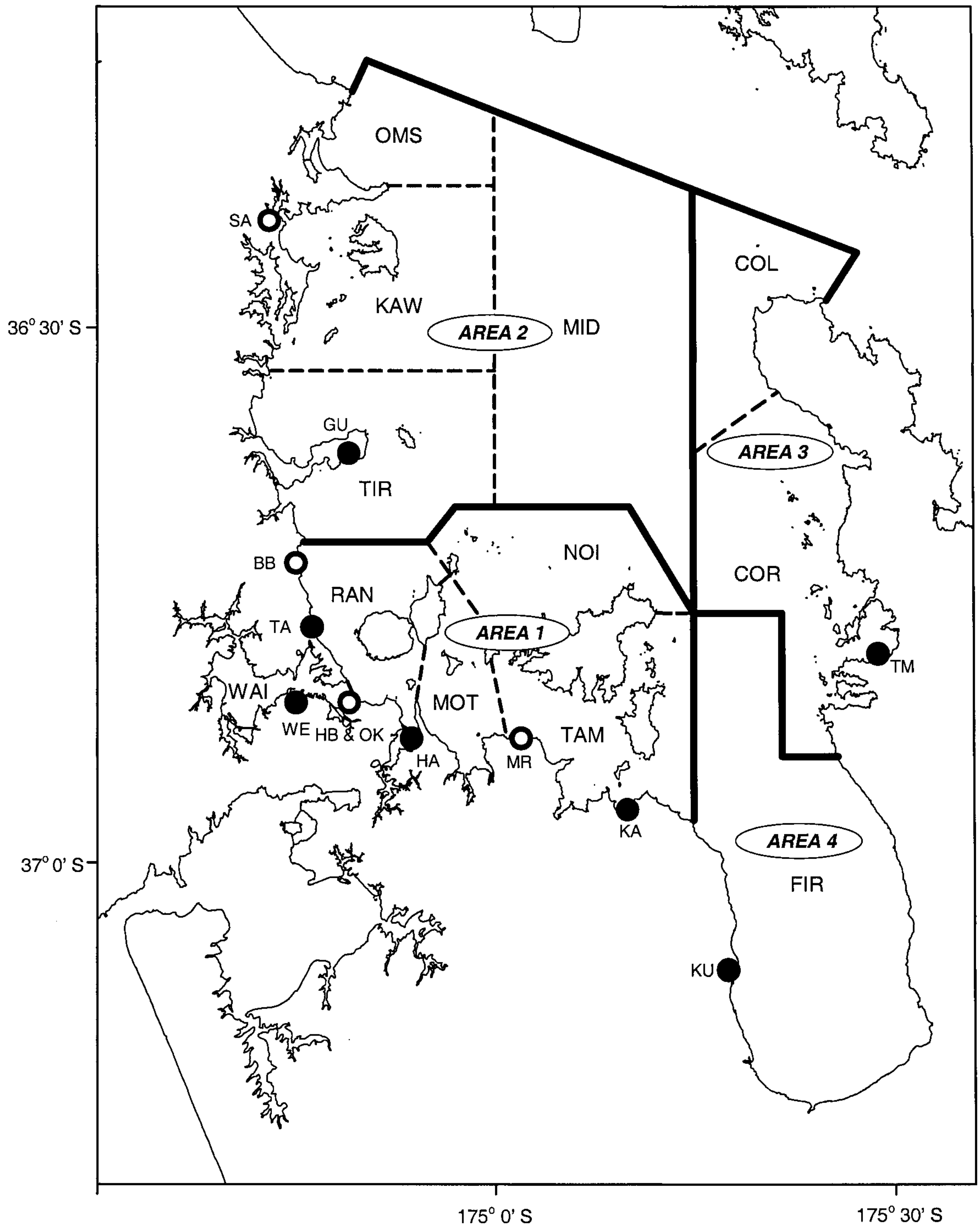
2.3 Spatial stratification

Most recreational fishing occurs close to major population centres, and the intensity of effort is therefore spatially heterogeneous. This, combined with the wide range of snapper habitats in the Hauraki Gulf, necessitated some form of spatial stratification. Maps delineating coastal areas of most of the North Island have been used since the first marine recreational fishing survey was conducted in 1990–91. We used the same spatial definitions in this survey, as they broadly described different areas of differing fishing intensity, and consistency with previous boat ramp surveys was considered desirable (Figure 2). These spatial stratifications were used in all aspects of this programme, although for analysis, some areas were coalesced into four larger subdivisions of the Hauraki Gulf (as defined by bold lines in Figure 2). This was necessary because very little fishing occurs in some parts of the Gulf, and the amount of information on the diurnal profile of fishing effort and catch rates was considered too limited to derive sensibly precise harvest estimates over smaller spatial scales. A further consideration when defining these areas was the proximity of boat ramps in neighbouring areas, and the likely range of boats on daily fishing trips.

2.4 Aerial overflights – estimating instantaneous fishing effort

Late morning aerial overflights were conducted on each randomly predetermined survey day, weather permitting. Two planes were used to count boats throughout the Hauraki Gulf over a 2–2.5 hour period starting at about 10:00 a.m. This period was considered apriori to correspond to the time of peak fishing activity (boat ramp interview data suggest that this was the case on most days). Flights followed roughly the same route each time, with one plane flying the western gulf, and another flying the eastern gulf. Flight routes were based upon the need to cover the survey area as efficiently as possible, and, given the geography of the Hauraki Gulf, only limited variation in routes was possible. Initially there was some experimentation with varying flight routes, and with repeat counts in areas already flown by the other plane, but cursory inspection of the results of these flights suggested that, at this time of day, there was very little change in the number of boats counted in an area over a half hour period. The busiest area of the gulf, the Motuihe Channel (MOT), was surveyed at the beginning and end of each flight of the western gulf, and there was usually very little difference between the two counts.

Aerial observers used standard laminated maps to record the approximate positions of all boats thought to be involved in stationary recreational fishing activity, and noted the time at which their plane passed from one area to another. Pilots acted as secondary observers, counting all boats on their side of the plane. This necessitated clear communication between the two parties, as to who was counting which boats in which areas, with overall responsibility resting with the primary observer. Route navigation was left to the pilot, although intervention by the observer was sometimes necessary when they felt that the area was not being covered to their satisfaction, or when the pilot was not affording the observer the best possible view of most of the boats. Only a limited pool of pilots was used, and they soon became very proficient at optimising the routes flown, and spotting vessels. A pool of five observers was trained and used throughout the first 12 months, and the choice of observer for a given day and route was randomised to minimise any observer bias.



BB	Browns Bay	GU	Gulf Harbour	HA	Halfmoon Bay
HB	Hobson Bay	KA	Kawakawa	KU	Kaiaua
MR	Maretai	OK	Okahu Bay	SA	Sandspit
TA	Takapuna	TM	Te Kouma	WE	Westhaven

Figure 2: Spatial stratification of recreational fishing in the Hauraki Gulf. Areas of water defined by bold lines, with labels surrounded by ellipses, are those for which harvest estimates were calculated. Dashed lines denote smaller sub areas, with three letter labels, which were commonly used by aerial observers, boat ramp and on-the-water interviewers. Two intensities of boat ramp interviewing took place. At the most frequently used ramps, denoted by closed circles, interviewing took place from approximately dawn to dusk. At the less frequently used ramps, denoted by open circles, interviewing took place for 6 hours only. Two letter codes are used to label all ramps.

Boats were classified as: trailer boats (T, usually with outboards and of trailerable size), launches (L), yachts (Y), charter boats (C, usually based on the number of visable fishers and the general appearance of the boat), or kayaks (K). Boats which were under way were ignored, as were stationary boats obviously involved in non-line fishing activity, such as diving or picnicking close inshore. Observers and pilots were instructed to count boats as fishing when there was any doubt. Daily environmental conditions were recorded by each observer.

Predictably, fishing effort is generally highest in the summer months, and, within a season, higher on weekends and public holidays (Figure 3). Within any temporal stratum, however, fishing effort was highly variable from day to day, and this is thought to be largely due to weather conditions (as suggested by Watson & Hartill (2005)). Fishing effort during the Lion Red Furuno Fishing Tournament was comparatively high, especially during the two midweek days, but not as high as previous events would have suggested. Only 2440 fishers registered for the 3000 places available, and they landed only 2608 kg of snapper (about half the weight landed in previous years) and 865 kg of kahawai.

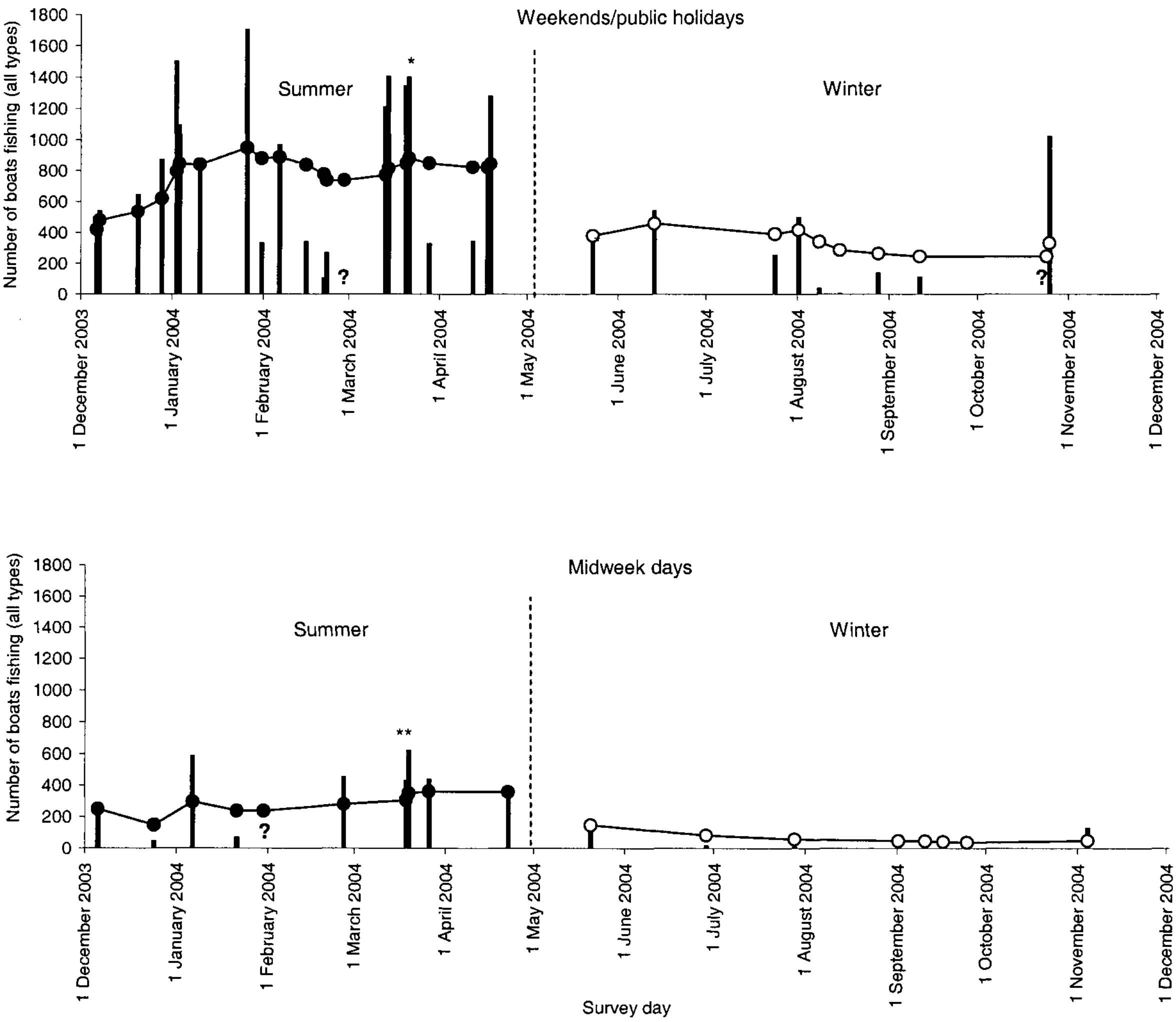


Figure 3: Counts of recreational fishing boats (all vessel types combined) in the Hauraki Gulf made by airborne observers on late morning flights during weekends/public holidays (top panel) and midweek days (bottom panel). Running averages are given for each season, denoted by closed circles for summer and open circles for winter. Asterisks denote the three days of the Lion Red Furuno Fishing Tournament, which are considered atypical fishing days. Question marks denote days on which low cloud prevented aerial counts of recreational fishing vessels (in the case of the two unflown summer days, flying effort was shifted to the winter weekend temporal stratum).

The intensity of fishing effort was also spatially variable, both between and within areas. Most fishing occurs in sheltered waters close to population centres, although fishing effort was low in the upper Waitemata Harbour, where fishing is very localised (Figure 4). Comparatively few fishers were found in the outer and central Gulf, and effort was very dispersed in the Firth of Thames, except at mussel farms where fishers tend to concentrate.

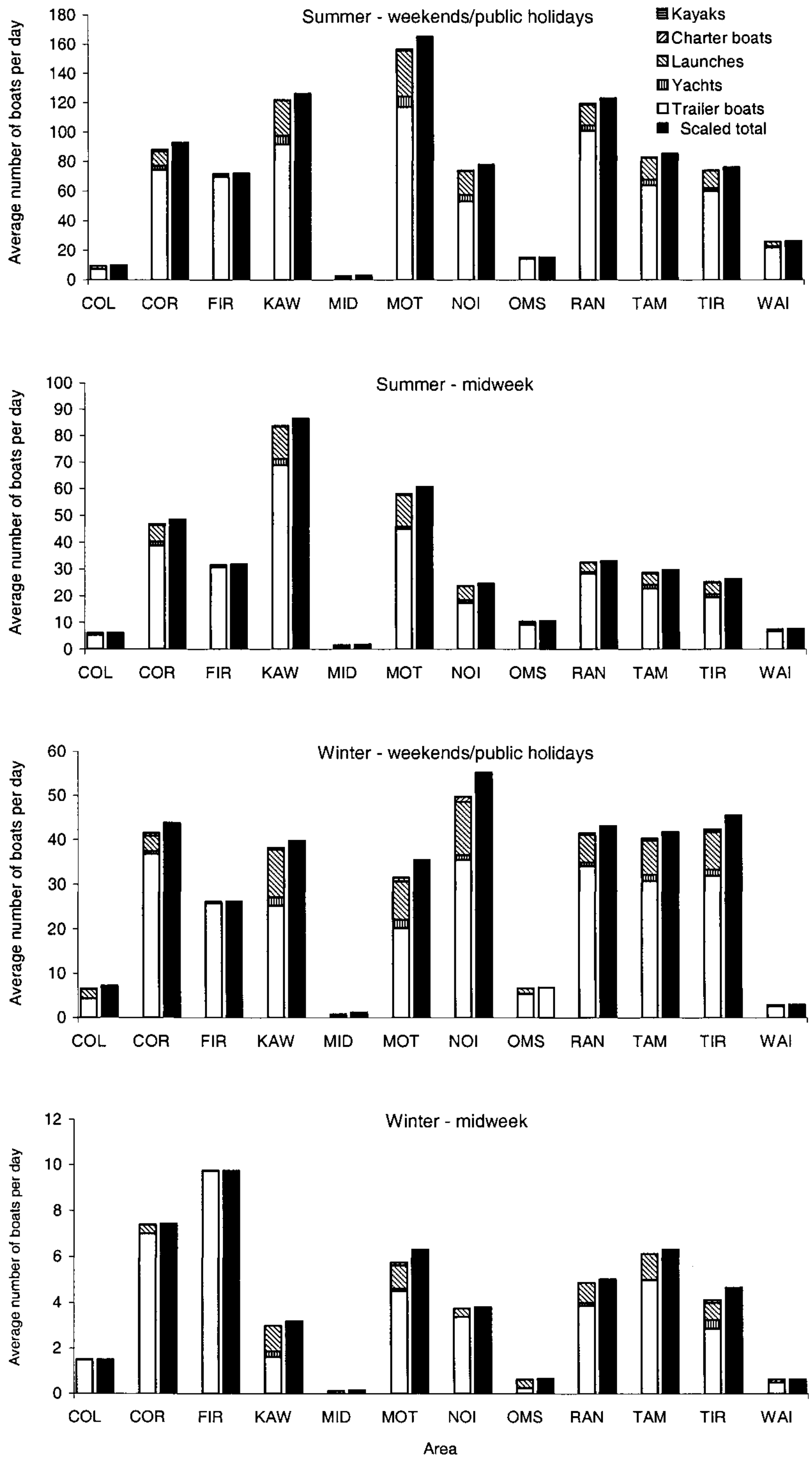


Figure 4: Average count of boat types by airborne observers during late morning flights on randomly chosen days by survey area (as defined in Figure 1). Solid black columns denote a scaled total of all boat types in a given area based on the average number of fishers in each boat type as shown in Figure 5.

Trailer boats consistently accounted for about 80% of the recreational fishing fleet, with most of the remainder being launches. Very few fishers appear to fish from yachts and kayaks, although the former are more likely to employ trolling methods to catch pelagic species such as kahawai, possibly because of their suitable cruising speed. Counts of charter boats used here are probably underestimates, as only boats with at least 6 to 8 fishers which appeared to be equipped for large numbers of fishers were so classified by airborne observers. Charter boats with fewer occupants would have been classified as either trailer boats of launches.

For the most part, only trailer boats patronise boat ramps, and we therefore used information on the relative number of fishers in other types of boats to rescale aerial counts of non-trailer-borne boat types. If, for example, charter boats have on average four times the number of fishers on board trailer boats, we multiplied all charter boat counts by a factor of four. Data on boat type occupancy was collected as part of a series of eight on-the-water surveys (four midweek days and four weekend days) conducted in the inner Hauraki Gulf in early 2004 (Figure 5). Aerial counts of recreational fishing vessels, re-expressed in terms of "trailer boat" fishing parties, are given in Figure 4 as solid black columns. In doing this we have assumed that vessel type has no influence on either catch rates or fishing duration.

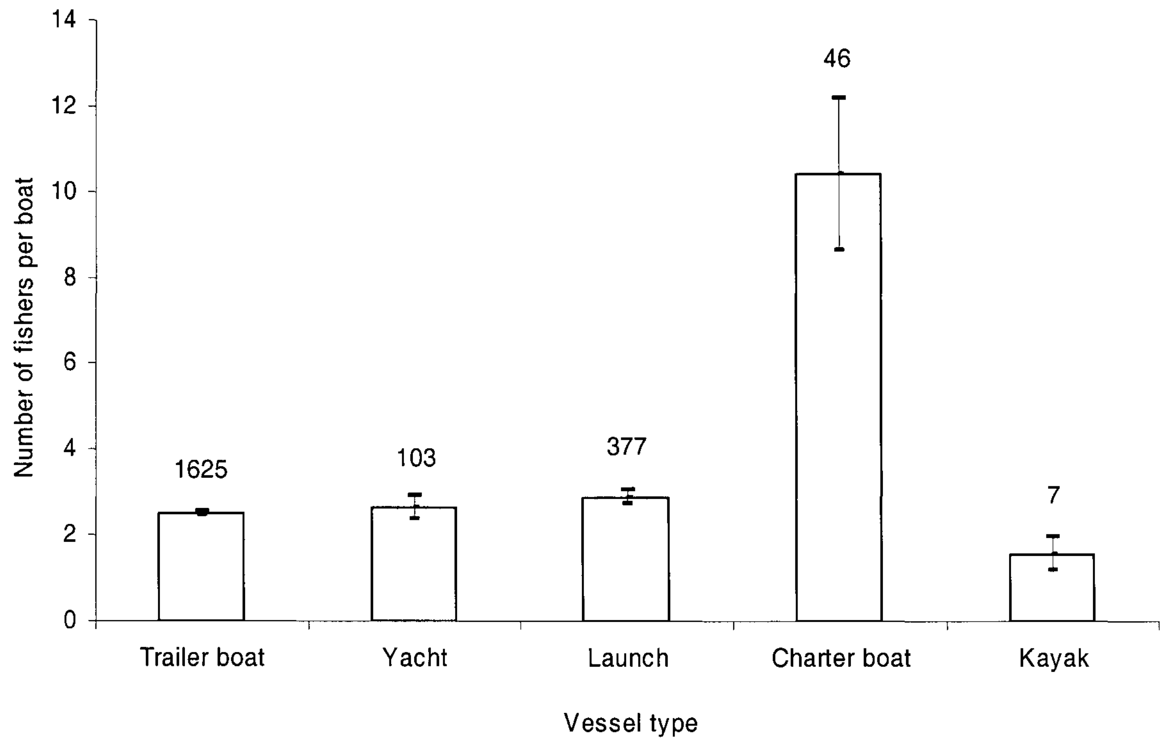


Figure 5: Average number of fishers per vessel type determined from on-the-water interviews in the inner Hauraki Gulf. Error bars represent 95% confidence intervals and numbers above each column denote the sample size.

Aerial observation of fishing activity was sometimes precluded by low cloud. All flights were cancelled on three summer days (30/01/04, 28/02/04, and 04/04/04) and localised conditions in the western Firth of Thames prevented flying in this area on 17/04/04. All flights were also cancelled during one winter day (24/10/05). Estimates of the number of boats fishing at midday on all days are required, however, as cancellation was weather dependent and not random. These estimates were, therefore, based on the relationship between known aerial counts and the number of vessels fishing concurrently, as predicted for those vessels which returned to surveyed ramps on that day (Figure 6). Estimates of the number of boats fishing at the time of the overflight were based on profiles of fishing effort which are discussed in the next section.

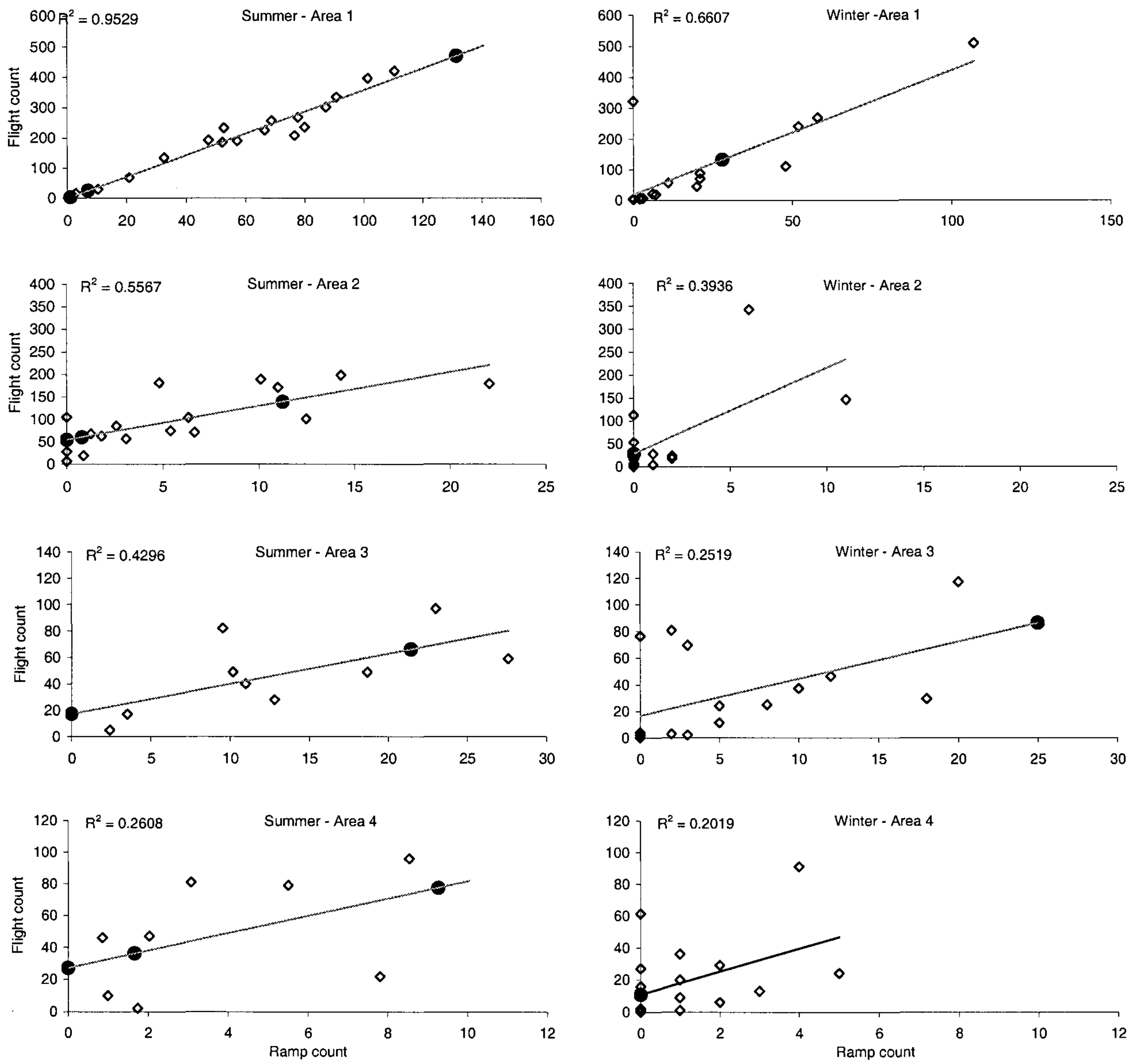


Figure 6: Season/area specific relationships between daily counts of the number of boats observed from the air and those estimated from boat ramp data at the time at which the flight took place. These relationships are used to predict the number of vessels that would have been counted on those days when flights were cancelled due to weather conditions. Dots denote estimated aerial counts for unflown days.

2.5 Boat ramp interviews – estimation of diurnal fishing profiles

Three sources of information on the diurnal profile of fishing effort were initially considered. The first was based on counts of fishing vessels made by ferry skippers as they passed through the Motuihe Channel. This was the method used by Sylvester in 1994, who pooled all data collected within a day-type to generate a single global diurnal profile of fishing effort. Between 1 December 2003 and 31 March 2004 we asked skippers to repeat this exercise, but despite much urging, the data were collected in a patchy and ad hoc fashion unsuited to our purposes. We also felt that such an approach was inadequate because it related to only part of the Hauraki Gulf, and that it did not take into account between-day variation in fisher behaviour.

The second approach was the use of web camera images from two ramps, which could be used to build a relative profile of the number of boats on the water over any period. We were concerned, however, that there was no way of accounting for time spent on the water which did not involve fishing, both for those boats travelling to and from fishing grounds, and for those boats which were used for other purposes, such as water skiing. Technical delays also meant that the two cameras were not installed until several months into the survey. These data were collected primarily for other reasons and will be discussed later.

The most direct and widespread source of data on the relative intensity of fishing throughout the day is that collected by boat ramp interviewers each day. Interviewers at quieter ramps were instructed to conduct interviews over a 6 hour period, and to make the timing of this session variable from day to day. On the busier ramps, two consecutive 6.5 hour shifts were worked, with at least one interviewer present at all times (two pairs of interviewers were present at Half Moon Bay because of heavy traffic levels). The timing of this 13 hour survey period varied with the time of year, but always ended at dusk (very few fishers return to boat ramps in the early morning, before the first interviewer would normally arrive).

The original sampling design was closely adhered to at most boat ramps, with occasional sessions missed at a few ramps due to staffing issues (which were not weather related, Table 2). In early February, interviewing at Browns Bay ceased due to low fisher encounter rates, and sampling effort was shifted to Te Kouma, which was subsequently staffed for 13 hours a day.

Interviewers were instructed to note the time at which each boat returned to the ramp, and classify them as: interviewed, charter boat, interviewed but not fishing, refused but fishing, refused (activity unknown), or not interviewed. From these data it is possible to establish how many boats approached the ramp over any period, and to estimate how many had been fishing, given the proportion of those that had been spoken to that claimed to have been fishing. At busy ramps, or at busy times of day, the interviewer may have been unable to interview all fishing parties approaching the ramp. In such instances, the interviewer was instructed to select boats at random.

Interviews of recreational fishers followed the format of those undertaken in all previous boat ramp surveys conducted by MAF Fisheries and NIWA, ensuring that data were collected in a consistent and rigorously tested manner. Data collected as part of these interviews can be used to determine where fishing took place, at what time, which methods were used, and which fish were caught by each fisher, for any given combination of method, area, and time. Usually, the interviewer was able to measure the catch, but when this was not possible, a count or estimate of the number of fish of each species was made and the nature of that count recorded.

Profiles of fishing effort and catch (relative to the time of overflight) were described by combining interview data collected from those fishers fishing in each area on each survey day. Each survey day was divided up into 15 minute bins, and effort profiles were generated by counting up the number of fishers (or boats) who reported fishing activity within each 15 minute period.

The shape of an effort profile will be distorted when a boat returned to the ramp but was unable to be interviewed to determine whether, and for how long, the party had been fishing. When no information was available on a returning boat, we substituted the uninterviewed boat's data with that of the next boat for which data was available. This should not introduce any bias in terms of the number, or nature, of boats fishing (or otherwise) if the boats were originally selected at random.

Catch profiles were also generated by apportioning each fisher's catch (numbers and weight of fish) across the period fished, and summing these apportioned values within each 15 minute bin. Daily fishing, or harvest estimates, are derived by summing up the area underneath a profile, and scaling up this number by the ratio of the aerial count in an area by the number of interviewed boats which claimed to be fishing in that area at the time of the overflight.

Ultimately, only data collected at boat ramps from approximately early morning to dusk (termed "all day" ramps) were used to generate profiles of fishing effort, and, hence, harvest estimates. Data from the lesser ramps, which were only covered for 6 hours a day, were not used for profiling as there was no means of building a profile of activity for the entire day based on such short periods. Regardless, interviews at "all day" ramps accounted for 81% of the boats interviewed and 84% and 82% of the snapper and kahawai respectively encountered by all interviewers. Further, when rod and reel fisher catch rate (Figure 7) and trip duration (Figure 8) data collected from "six hour" and "all day" ramps are compared, no significant systematic differences are evident.

Table 2: Summary statistics, by boat ramp, of the number of days surveyed, total hours of interviewing, numbers of boats interviewed, interview rates, snapper measured, and all snapper encountered by interviewers between 1 December 2003 and 30 April 2004.

Ramp	Interview period	Season	Days sampled	Hours worked	Parties interviewed	Fishers interviewed	Boats per hour	Snapper harvested	Kahawai harvested
Sandspit	6 hours	Summer	26	160	185	514	1.2	678	62
		Winter	16	99	56	143	0.6	118	17
Browns Bay	6 hours	Summer	16	96	93	233	1.0	266	17
		Winter	–	–	–	–	–	–	–
Gulf Harbour	All day	Summer	29	345	617	1 602	1.8	2 440	141
		Winter	17	127	55	128	0.4	133	7
Takapuna	All day	Summer	29	367	1 042	2 670	2.8	6 370	337
		Winter	14	148	118	303	0.8	348	70
Westhaven	All day	Summer	29	353	883	2 406	2.5	6 352	174
		Winter	16	175	193	504	1.1	388	30
Hobson Bay	6 hours	Summer	27	163	415	1 042	2.5	2 442	66
		Winter	15	90	76	193	0.8	144	27
Okahu Bay	6 hours	Summer	22	132	369	984	2.8	2 344	68
		Winter	17	102	78	202	0.8	174	43
Halfmoon Bay	All day	Summer [1]	29	660	2 032	5 873	3.1	19 108	489
		Winter	17	159	276	715	1.7	725	74
Maretai	6 hours	Summer	29	176	390	905	2.2	3 206	71
		Winter	16	96	68	173	0.7	325	74
Kawakawa Bay	All day	Summer	29	350	1 097	2 884	3.1	8 190	435
		Winter	17	182	280	711	1.5	916	169
Kaiaua	All day (tidal)	Summer	29	171	219	546	1.3	1 006	14
		Winter	16	96	18	40	0.2	87	–
Te Kouma	All day	Summer	25	242	487	1 682	2.0	4 788	56
		Winter	17	178	199	651	1.1	1 323	46
Total		Summer		3 215	7 829	21 341	2.4	57 190	1 930
		Winter		1 451	1 417	3 763	1.0	4 681	557
		Year		4 666	9 246	25 104	2.0	61 871	2 487

1 – Two interviewers were based at this ramp due to high traffic rates.

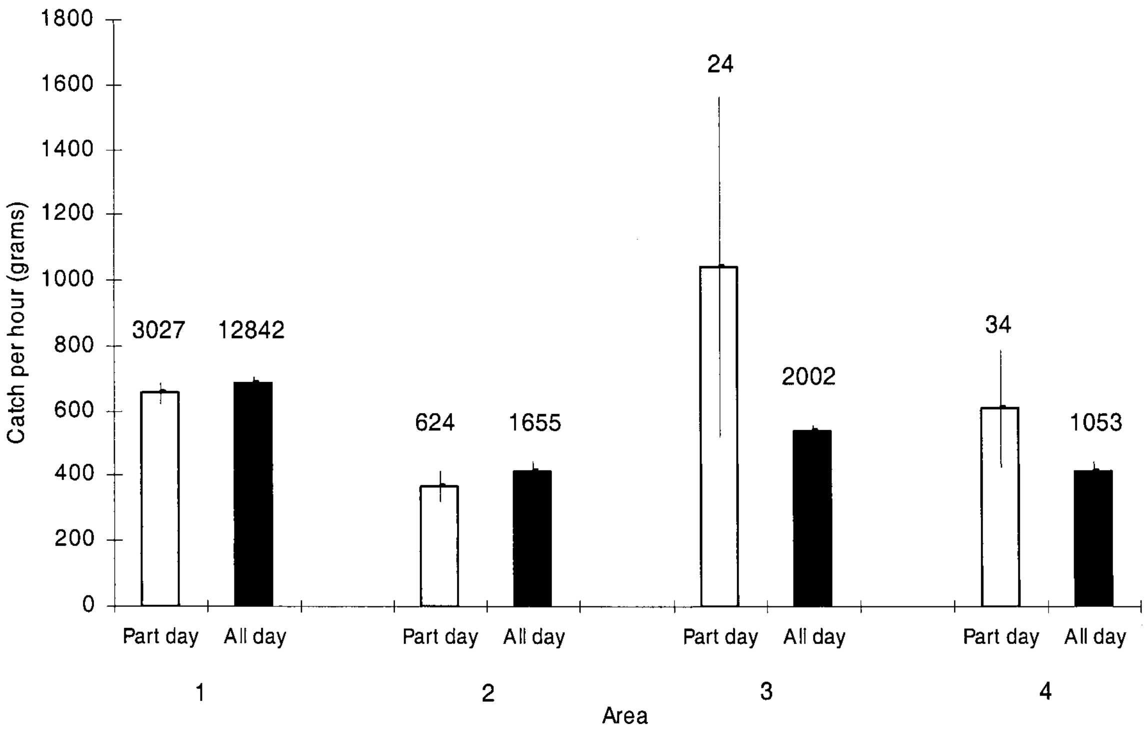


Figure 7: Comparison of snapper catch rates (rod and reel) reported by summertime fishers returning to ramps surveyed for just 6 hours a day, and to ramps surveyed from early morning to dusk. Error bars represent 95% confidence intervals. The four areas used are those used to derive harvest estimates for the Hauraki Gulf, as shown in Figure 1.

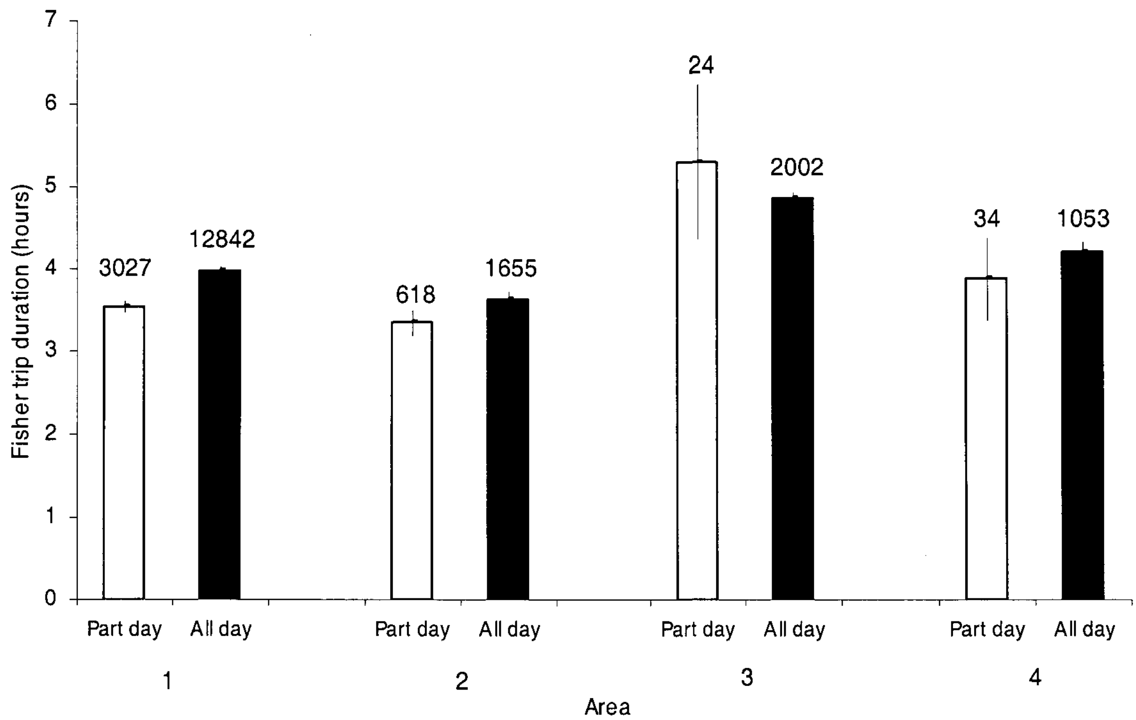


Figure 8: Comparison of hours fished as reported by summertime rod and reel fishers returning to ramps surveyed for just 6 hours a day, and to ramps surveyed from early morning to dusk. Error bars represent 95% confidence intervals. The four areas used are those used to derive harvest estimates for the Hauraki Gulf, as shown in Figure 1.

Although interview rates at "all day ramps" mostly resulted in sufficient data to yield meaningful diurnal profiles of fishing effort for most areas, this was not always the case. First, very little fishing activity took place in some weather conditions. Second, "all day" coverage of parties fishing in Areas 3 and 4 was very limited until interviewing at Te Kouma was extended from 6 to 13 hours a day in early February. Insufficient data were more common for week days, when less fishing took place. The criteria for deciding whether or not meaningful profiles of fishing effort and catch rates could be derived are as follows:

1) Ignore all interview data relating to fishing areas 3 and 4 collected prior to 01/02/04, as all day interviewing was not conducted at Te Kouma before this date.

2) Ignore a day's data if no fishers who had fished in a given area were encountered by boat ramp interviewers.

3) Ignore all boat ramp interview data on those days when the number of boats observed from the air in a given area was thirty or more times greater than the number of boats interviewed at boat ramps which reported fishing activity at the time of the overflight.

4) Ignore interview data on those days when aerial counts suggested that one or more boats fished a given area, but none of the fishers encountered by boat ramp interviewers reported any fishing activity in that area at the time of the overflight.

Combinations of days and areas where these criteria were met, and profiles were subsequently generated from boat ramp interview data, are given in Table 3. Profiles were generated for all survey days in Area 1, as this area is the most heavily fished and the number of fishers interviewed was always sufficient for profiling purposes. Coverage in the other three areas is patchy however, partly because fewer fishers were encountered at ramps in these areas, and partially because of a lack of interviewing initially in Areas 3 and 4, as discussed above. In Area 2 there was only one winter weekend day on which there was sufficient data to generate profiles which is of some concern, but aerial counts of fishing vessels suggests that very little fishing occurred in this area, on most days, at this time of year (Figure 6).

On days when there was insufficient interview data to build meaningful profiles, profiles were still required to describe changes in catch and effort throughout the day. These were derived by creating an average profile from those days when there was enough data for profiling purposes, from the relevant seasonal/day type/area strata. For most of the days when average profiles were required, their use will create very little bias in the final harvest estimate, as aerial counts suggest that very little catch was taken on these days. In some instances, however (such as those relating to Criteria 1 of Table 3), the use of average profiles may result in biased harvest estimates, as they may poorly describe fishing activity on days when large numbers of boats were observed from the air. One solution to this is to combine data from two areas together.

As a sensitivity, we combined Areas 1 & 4 and 2 & 3, together, which yielded enough interview data to build usable profiles for almost every survey day. The snapper harvest estimate derived from these two combined areas was only 2.5% higher than that derived from the four separate areas. In combining areas, however, flight counts became less instantaneous, and differences between localised catch rates and length frequency distributions were ignored. Estimates based on a greater number of spatial strata are, therefore, considered preferable.

Table 3: Days where there was sufficient boat ramp data available in a given area to satisfy the criteria given in Table 3. Data meeting these criteria were used to generate diurnal profiles of fishing effort and catch, which were scaled by aerial counts of fishing.

			Analysis area			
Season	Day type	Date	1	2	3	4
Summer	Weekend/ Public holiday	06/12/03	Y	Y	–	–
		07/12/03	Y	Y	–	–
		20/12/03	Y	Y	–	–
		28/12/03	Y	Y	–	–
		02/01/04	Y	Y	–	–
		03/01/04	Y	Y	–	–
		10/01/04	Y	–	–	–
		26/01/04	Y	Y	–	–
		31/01/04	Y	Y	–	–
		06/02/04	Y	Y	Y	–
		15/02/04	Y	–	Y	Y
		21/02/04	Y	–	Y	Y
		22/02/04	Y	Y	Y	Y
		28/02/04	Y	Y	–	–
		13/03/04	Y	–	Y	Y
		14/03/04	Y	Y	Y	Y
		21/03/04	Y	–	Y	Y
		04/04/04	Y	Y	Y	Y
		12/04/04	Y	–	Y	–
		17/04/04	Y	Y	Y	Y
		18/04/04	Y	Y	Y	Y
	Weekday	05/12/03	Y	Y	–	–
		24/12/03	Y	Y	–	–
		06/01/04	Y	Y	–	–
		21/01/04	Y	–	–	–
		30/01/04	Y	Y	–	–
		26/02/04	Y	–	Y	Y
		26/03/04	Y	–	Y	Y
		22/04/04	Y	–	Y	–
Winter	Weekend/ Public holiday	23/05/04	Y	–	Y	Y
		24/07/04	Y	–	–	Y
		01/08/04	Y	Y	Y	–
		08/08/04	Y	–	Y	–
		28/08/04	Y	–	Y	Y
		11/09/04	Y	–	Y	–
		24/10/04	Y	–	Y	–
		25/10/04	Y	–	Y	Y
	Weekday	20/05/04	Y	Y	Y	–
		28/06/04	Y	–	Y	–
		16/08/04	Y	–	–	–
		01/09/04	Y	–	–	–
		10/09/04	Y	Y	Y	Y
		16/09/04	Y	–	–	–
		24/09/04	Y	–	–	–
		04/11/04	Y	Y	Y	Y

2.6 Estimates of effort catch and catch per unit effort

Because interview data were collected in a format which allows us to identify a fisher's catch (if any) and the time spent fishing, we were able to estimate a variety of profiles other than for the number of boats fishing a given area on a given day. These include profiles of the number of vessel-borne fishers (i.e., not boats), the catch of a given species (weight or numbers of fish), and associated catch rates (derived by dividing a day's catch profile by its associated fisher effort profile). Because these profiles were based on data collected at a subsample of the available access points in the Hauraki Gulf, it was then necessary to scale them up to reflect all fishing activity. This was done by calculating the ratio of the number of boats observed from the air to that estimated by the boat ramp data profile at the time at which the aerial flight took place. Separate daily estimates were derived for each analysis area. When a profile was not available for a survey day for a given area (see Table 3), an averaged profile was derived from those days (in the same temporal stratum) for which there were sufficient data.

Stratum-specific variance estimates were generated by a bootstrapping procedure. Survey days from each seasonal/day-type/area stratum were selected with replacement. In turn, data from fishing parties interviewed on that day were selected with replacement, and used to construct profiles of fishing effort, catch, and catch rate. Each of these profiles were then scaled up by the aerial count on that day. When there was insufficient interview data for profiling on the selected day, profile data was selected at random from one of the stratum days which meet the criteria given on p 17.

Bootstraps were performed 1000 times, from which mean, median, and 5% and 95% percentile profiles were generated. Stratum-specific profiles and (associated bootstrap distributions) of effort (numbers of boats and fishers), catch (numbers of fish and weight caught), and catch rates are given in Appendix 1 (summer) and Appendix 2 (winter).

Predictably, fishing effort is highest during the summer months, and within any given season and area, generally higher on weekends and public holidays. Summer profiles tend to be broader, reflecting longer daylight hours, with fishing effort on weekends and public holidays generally peaking in the late morning. The diurnal distribution of midweek fishing tends to be broader, however, as a greater proportion of evening fishing takes place on work days. About half of the effort observed in the Hauraki Gulf took place in Area 1, which is adjacent to Auckland.

In strata with higher levels of fishing effort, increased encounter rates at surveyed ramps resulted in smoother dome-shaped effort profiles, with mean and median bootstrap distributions closely matching those derived from the original data. Profiles in the less heavily fished strata tend to be irregular, with asymmetrical confidence intervals and less similarity between the mean and median bootstrap profiles and those derived from the original data.

The shapes of stratum specific profiles of snapper harvesting throughout the day broadly reflect those associated with effort, with most fish caught midday. The confidence intervals associated with harvest profiles, however, are generally broader than those associated with effort.

Snapper catch rates appear to change during the day, with CPUE peaking at around dawn and dusk, and troughing in the early afternoon in most areas. Recreational fishers generally expect this to be the case, although it is possible that these trends also partially reflect the relative abilities of fishers at different times of days, with keen, experienced (and presumably more successful) fishers preferring to fish in the early mornings and late evenings. The wide bootstrap intervals at either end of the day are indicative of low levels of fishing effort, and hence numbers of interviews, at these times.

The pattern of kahawai harvesting throughout the day roughly follows that for snapper, but the relatively few fish encountered by boat ramp interviewers is reflected in the width of the confidence intervals and spikes associated with a few large catches. No kahawai were landed by interviewed fishers fishing in Area 4 during midweek days in the summer, and in Areas 2 and 4 during winter weekdays. It is highly unlikely that no kahawai were landed midweek from this area, however, although the data suggest that such landings may be uncommon. The low incidence of kahawai landings is also reflected in the highly variable profiles of catch rates. In some strata, catch rates appear to peak at dawn and dusk.

2.7 Snapper and kahawai harvest estimates

Harvest estimates are derived by summing up the area under each area/day-type specific catch profile, and weighting these estimates together on the basis of the number of days in each day-type stratum (Tables 4 and 5). Harvest estimates for both species are estimated with reasonable precision, with skewed bootstrap values for some lightly fished area/day-type strata. The aggregated bootstrap estimates themselves are normally distributed, regardless of season and species (Appendices 3 and 4)

Aerial counts made during the Lion Red Furuno Fishing Tournament were not ultimately used, as there was very little interview data available from contestants, and their fishing is considered atypical. The number of days used to scale up average daily harvests from the summer midweek and weekend/public holiday strata were, therefore, increased by two and one accordingly. Nonetheless, additional harvesting would have taken place as a result of the Tournament and we adopted the simple expedient of adding the weighed in tournament harvest to our estimates. Over a three day period, 2608 kg of snapper (roughly half the weight of previous years) and 865 kg of kahawai were weighed in at Kawau Island. This is likely to result in a small overestimation of total summer harvest, as aerial observations strongly suggested that much of the Lion Red Furuno Fishing Tournament fishing effort, and hence catches, took place outside the Gulf. Further, it is likely that some fishers would not have been fishing on those days if there was no competition on. Regardless, the total landed catch from the Lion Red Furuno Fishing Tournament is small relative to that taken over the entire summer. The kahawai catch from the Lion Red Furuno Fishing Tournament was larger than expected, however, but this may reflect catches in deeper waters north of the Hauraki Gulf, which we would not normally include in our estimate for this area.

The aerial overflight method does not account for vessel-based harvests from trolling, longlining, and set netting. We used boat ramp interview data on the number of snapper and kahawai landed by these methods to estimate appropriate scalars which were then applied to overflight estimates. Other recreational harvests, which were not considered in our survey, were those associated with shore-based fishing methods such as surf casting, beach seining, and kite fishing. We used data on the method-specific catch of snapper and kahawai from the 2000 telephone diary survey (R. Boyd et al; Kingett Mitchell, unpublished results) to estimate appropriate scalars to account for shore-based fishing.

When these other sources of recreational harvest are considered, the annual snapper harvest estimate increases from 1260.8 t to 1334.2 t. For kahawai, these additional harvest sources have a greater effect, increasing our initial estimate from 37.8 t to 55.8 t. This low tonnage reflects a marked decline in kahawai landings that summer, compared to the three previous years (Hartill et al. 2007).

Estimates from this programme relate only to the Hauraki Gulf, which is part of both SNA 1 and KAH 1. For these estimates to be used in a management context, therefore, an understanding of the scale of the Hauraki Gulf fishery relative to that fishing the wider stock is required. Results from the most recent telephone diary survey in 2000 suggest that about 50% of the recreational snapper harvest in SNA 1 is taken from the Hauraki Gulf (although some earlier survey estimates have been about 40%). The Hauraki Gulf fishery is therefore probably home to the largest recreational fishery in New Zealand given its area. The 2000 telephone diary data also suggests that about 17% of the kahawai harvest from KAH 1 is taken in the Hauraki Gulf. The poor kahawai catch in 2002–03, relative to that experienced in East Northland and the Bay of Plenty, would suggest that a smaller proportion of the catch was taken from the Gulf in the summer of 2004.

Table 4: Estimates of the 2003–04 recreational harvest of snapper in the Hauraki Gulf for each stratum in summer (1 December 2003 to 30 April 2004) and winter (1 May 2004 to 30 November 2004) with associated bootstrap statistics. Days from the Lion Red Furuno Tournament strata given in Table 1 have been reallocated to the appropriate day-type strata (two midweek days and one weekend day). Aerial survey estimates are adjusted in the second half of the table to account for harvests by vessel-based fishing methods which were not estimated by the overflight approach, harvests by shore-based fishers, and the landed catch of fishers participating in the 2004 Lion Red Furuno Fishing Tournament.

Area	Season	Day-type	Number of days	Estimate	Mean of bootstraps	Median of bootstraps	5th percentile	95th percentile	c.v.
1	Summer	Weekend/PH	52	7.021	7.054	7.004	5.361	8.787	
		Midweek	100	2.735	2.813	2.749	1.720	4.011	
	Winter	Weekend/PH	64	0.766	0.779	0.739	0.227	1.619	
		Midweek	150	0.217	0.224	0.215	0.058	0.415	
2	Summer	Weekend/PH	52	2.022	2.088	2.075	1.526	2.681	
		Midweek	100	0.880	0.927	0.911	0.545	1.381	
	Winter	Weekend/PH	64	0.260	0.286	0.252	0.104	0.560	
		Midweek	150	0.016	0.012	0.009	0.000	0.038	
3	Summer	Weekend/PH	52	1.724	2.168	2.068	1.433	3.242	
		Midweek	100	1.070	1.297	1.245	0.656	2.133	
	Winter	Weekend/PH	64	0.434	0.437	0.427	0.212	0.701	
		Midweek	150	0.088	0.092	0.087	0.022	0.178	
4	Summer	Weekend/PH	52	0.601	0.803	0.752	0.487	1.294	
		Midweek	100	0.291	0.348	0.334	0.180	0.567	
	Winter	Weekend/PH	64	0.336	0.383	0.340	0.077	0.821	
		Midweek	150	0.059	0.034	0.024	0.000	0.117	
Weighted summer total				1 088.7	1 168.4	1 168.1	993.	1 350.5	0.09
Weighted winter total				172.	174.9	172.2	115.1	246.6	0.23
Weighted annual total				1 260.8	1 343.3	1 340.1	1 151.	1 532.3	0.09
				1 094.7					
Scaled to account for 05 % of catch				173.					
by unassessed vessel based methods[1]				1 267.7	1 350.7	1 347.5	1 157.7	1 539.7	0.09
				1 149.9					
Scaled to account for 4.8 % of catch[2]				181.7					
by shore based methods				1 331.6	1 422.7	1 418.7	1 220.1	1 624.8	0.09
				1 152.5					
Including weighed in catch from				181.7					
Lion Red Furuno Fishing Tournament (2 608 kg)				1 334.2	1 425.3	1 421.3	1 222.7	1 627.4	0.09

1 - Derived from concurrent boat ramp interview data.

2 - Derived from telephone diary survey data collected for the Hauraki Gulf in 2000.

Table 5: Estimates of the 2003–04 recreational harvest of kahawai in the Hauraki Gulf for each stratum in summer (1 December 2003 to 30 April 2004) and winter (1 May 2004 to 30 November 2004) with associated bootstrap statistics. Days from the Lion Red Furuno Tournament strata given in Table 1 have been reallocated to the appropriate day-type strata (two midweek days and one weekend day). Aerial survey estimates are adjusted in the second half of the table to account for harvests by vessel-based fishing methods which were not estimated by the overflight approach, harvests by shore-based fishers, and the landed catch of fishers participating in the 2004 Lion Red Furuno Fishing Tournament.

Area	Season	Day-type	Number of days	Estimate	Mean of bootstraps	Median of bootstraps	5th percentile	95th percentile	c.v.
1	Summer	Weekend/PH	52	0.158	0.159	0.158	0.118	0.201	
		Midweek	100	0.072	0.070	0.070	0.043	0.098	
	Winter	Weekend/PH	64	0.067	0.069	0.065	0.024	0.132	
		Midweek	150	0.014	0.015	0.013	0.002	0.035	
2	Summer	Weekend/PH	52	0.055	0.052	0.049	0.025	0.086	
		Midweek	100	0.025	0.034	0.029	0.001	0.081	
	Winter	Weekend/PH	64	0.031	0.024	0.019	0.004	0.058	
		Midweek	150	0.000	0.000	0.000	0.000	0.000	
3	Summer	Weekend/PH	52	0.008	0.006	0.006	0.003	0.011	
		Midweek	100	0.039	0.037	0.032	0.009	0.078	
	Winter	Weekend/PH	64	0.018	0.016	0.015	0.002	0.034	
		Midweek	150	0.000	0.000	0.000	0.000	0.001	
4	Summer	Weekend/PH	52	0.025	0.022	0.021	0.009	0.039	
		Midweek	100	0.000	0.000	0.000	0.000	0.000	
	Winter	Weekend/PH	64	0.028	0.041	0.032	0.006	0.107	
		Midweek	150	0.000	0.000	0.000	0.000	0.000	
Weighted summer total				26.3	26.5	26.1	20.4	33.6	0.16
Weighted winter total				11.5	11.9	11.5	6.5	18.2	0.30
Weighted annual total				37.8	38.4	38.2	29.6	47.3	0.14
				29.6					
Scaled to account for 11.2 % of catch				12.9					
by unassessed vessel based methods[1]				42.6	43.1	42.8	33.4	53.6	0.15
				38.3					
Scaled to account for 22.5 % of catch[2]				16.7					
by shore based methods				54.9	55.7	55.6	42.9	69.3	0.15
				39.1					
Including weighed in catch from				16.7					
Lion Red Furuno Fishing Tournament (865 kg)				55.8	56.6	56.5	43.8	70.1	0.15

1 - Derived from concurrent boat ramp interview data.

2 - Derived from telephone diary survey data collected for the Hauraki Gulf in 2000.

2.8 Potential sources of bias

2.8.1 Non-representative selection of survey days – a positive bias

Prior random selection of survey days can lead to biased sampling when environmental conditions on sampled days are atypical. Watson & Hartill (2005) explored the relationship between boat ramp traffic and a range of environmental variables, and found that wind speed was a key determinant of traffic rates. Cumulative comparison of wind speeds occurring on survey days, relative to that for an entire season, suggests that the prior random selection of survey days may have been marginally biased (Figure 9). In three out of the four seasonal/day-type strata, a greater proportion of survey days fell on low wind days than actually occurred. Fishing effort declines markedly as wind speeds approach, and exceed, 15 knots. Any resultant harvest estimates may therefore be positively biased due to the over-sampling of fishable days

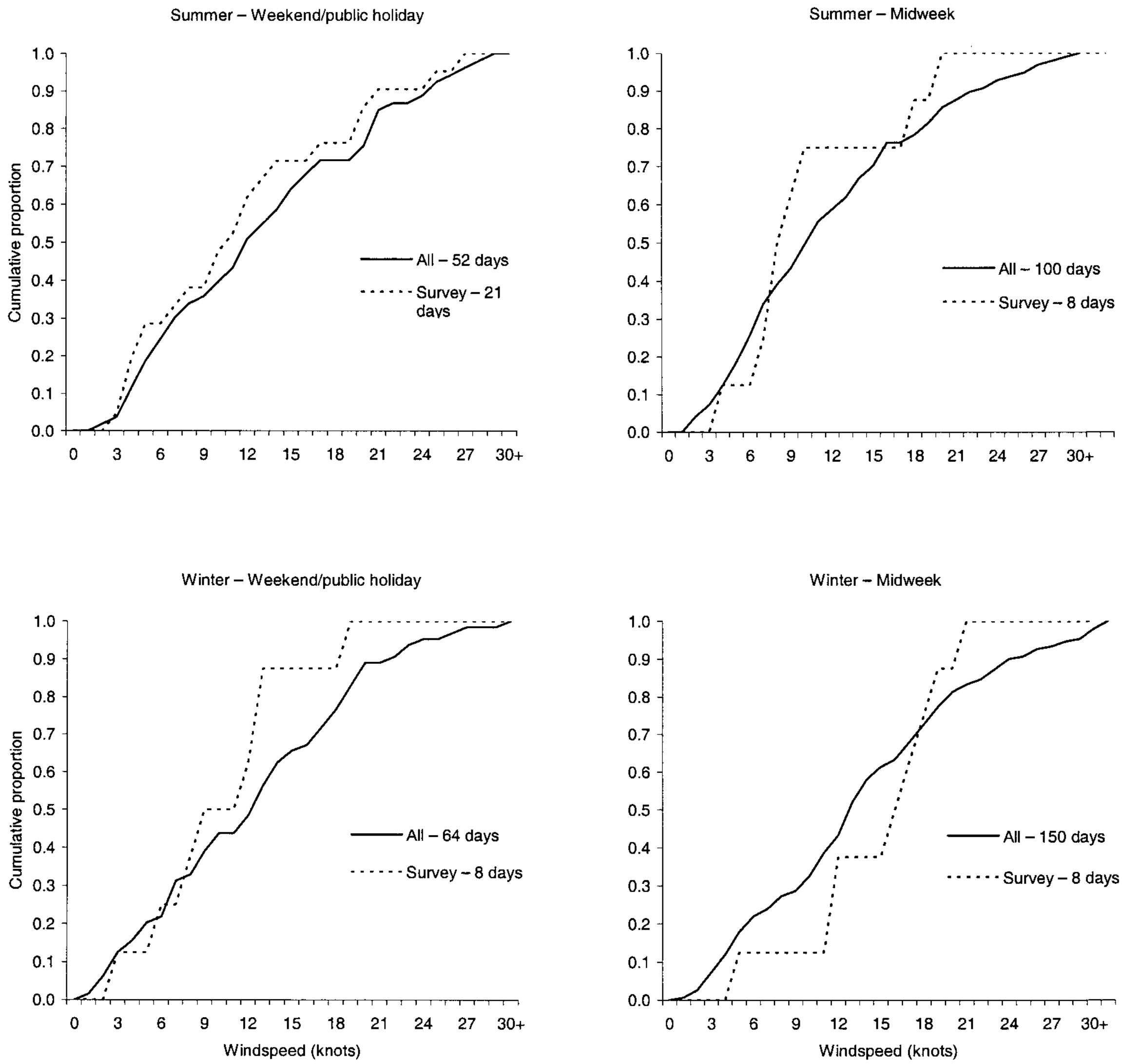


Figure 9: Comparison of wind speeds encountered on randomly selected survey days relative to those encountered on all days within seasonal/day-type strata. The number of days is expressed cumulatively in terms of increasing wind speed.

2.8.2 Ramp-census vs aerial counts – a positive bias

In the first four months of 2004 an independent on-the-water survey (referred to as the ramp-census approach) was conducted in the inner Hauraki Gulf (Area 1) which was to provide harvest estimates concurrent with those collected as part of the aerial-access survey. Ultimately, however, we have adapted our aerial-access method to an extent where it relies on some data sources which are identical to those required for the ramp-census approach. Direct statistical comparison of harvest estimates derived from two independent sources is, therefore, no longer possible. Regardless, some of the information collected as part of the ramp-census survey can be used to corroborate a key component of the main aerial-access survey: the relationship between aerial counts conducted at midday and levels of fishing effort originating from surveyed ramps.

As part of the ramp-census approach, on-the-water surveys were conducted on four midweek and four weekend days when weather conditions permitted reasonable levels of fishing effort and flying was scheduled. Two boats were used to approach parties fishing throughout Area 1, who were asked which ramp their trip originated from. Interviewers also noted the number of fishers on the vessel, and the vessel's position and type (trailer, launch, yacht, charter boat, or kayak). From these data it is possible to determine, on a given day, the proportion of fishers which should be encountered at those ramps which were surveyed between dawn and dusk (Table 6).

Table 6: Numbers of fishers encountered on surveyed days on the water, by vessel type and proportions of fishers whose trips originated from boat ramps were interviewers were present from dawn to dusk.

	Number of fishers by vessel type						Proportion using
Date	Trailer boat	Launch	Yacht	Charter boat	Kayak	Total	surveyed ramps
03/01/04	481	98	20	41	2	642	0.35
06/01/04	379	131	37	39	2	588	0.36
06/02/04	758	181	69	20	2	1 030	0.31
26/02/04	329	85	27	120	0	561	0.33
14/03/04	796	299	45	66	2	1 208	0.30
26/03/04	328	88	28	39	3	486	0.39
17/04/04	652	161	40	126	0	979	0.35
22/04/04	328	44	6	17	0	395	0.31
Total	4 051	1 087	272	468	11	5 889	0.33

Of the vessels encountered, about 80% were classified as trailer boats, which were potentially able to use boat ramps. On average, there were 2.5 fishers per trailer boat, with slightly greater numbers fishing from yachts and launches, and significantly more fishing from charter boats (see Figure 5). The proportion of fishers reporting destinations which coincided with ramps where interviewers were stationed between dawn and dusk ranged from 0.30 to 0.39.

These are, therefore, estimates of the proportion of a day's fishing effort which we observed at selected ramps, which should equate to an analogous estimate of sampling effort derived from the concurrent aerial survey: the ratio of the number of interviewed fishers reporting fishing activity at midday relative to the number of fishers counted from the air at that time. A comparison of these two estimates of sampling effort is given in Figure 10.

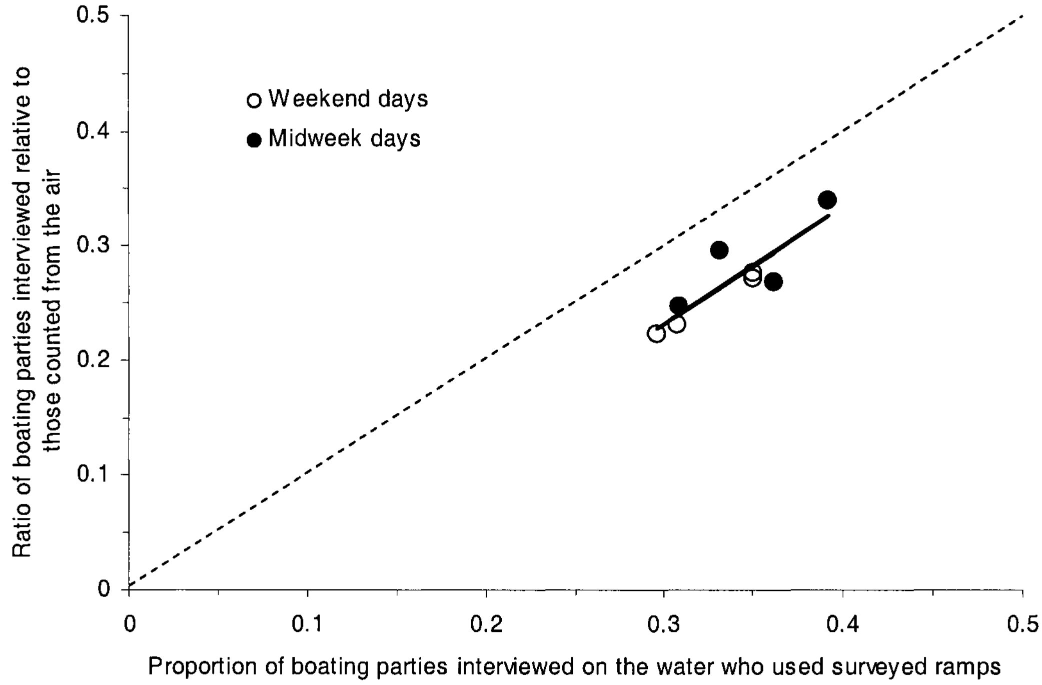


Figure 10: Comparison of eight daily estimates of the proportion of inner Hauraki Gulf fishing parties using ramps surveyed from dawn to dusk derived from two separate sources: an on-the-water survey of vessel-borne fishers, and the ratio of the number of fishing parties recorded by boat ramp interviews relative to those estimated from aerial counts of fishing vessels. The solid line denotes a regression fitted to all estimates, and the dashed line denotes a line of equivalence between both survey estimates.

These estimates should be similar, but those derived from the flights are 25% higher than those derived from the on-the water survey. If we assume that the on-the-water survey gives accurate estimates of the proportion of fishers using surveyed ramps, it suggests that our harvest estimates are positively biased by either inflated aerial counts of fishing vessels, or by underestimates of fishing effort derived from boat ramp interviews.

Several possible explanations exist for this discrepancy, three of which suggest that the flight survey has overestimated the harvest, perhaps by as much as 25%. There are three possible sources of bias:

- Aerial observers have counted boats which were not fishing at the time of observation.
- When fishers were interviewed, they denied fishing and claimed to have been involved in other activity such as picnicking. This is a form of soft refusal, as detected in the most recent telephone diary surveys.
- On busy ramps, at busy times, ramp interviewers were overwhelmed by traffic volumes, and failed to note down the presence of some of the vessels which passed uninterviewed.

The third explanation is strongly supported by comparisons of daily web camera counts of boats returning to the Takapuna and Half Moon Bay ramps with counts made by interviewers stationed at the ramps on the same day (Table 7). On average, across both ramps, the number of boats recorded daily by the interviewers was 29% less than that counted from web camera images. Once early morning and night time arrivals are taken into account, it appears that the interviewers missed about 15% of the boats returning to these ramps during survey hours. The potential for bias appears to be greatest on days when fishing effort was highest, and is always positive (Figure 11). On-the-water surveys were deliberately conducted on busier than average days (to maximise the number of interviews) and non-regressive averaging will therefore overestimate the likely level of bias.

Boats missed during a survey session would reduce the area under a catch profile, but increase the ratio used to scale up this profile, as the difference between the aerial counts and associated ramp boat count would be increased. These two artefacts therefore compensate for each other, to an unknown extent. These estimates of bias are, therefore, probably high.

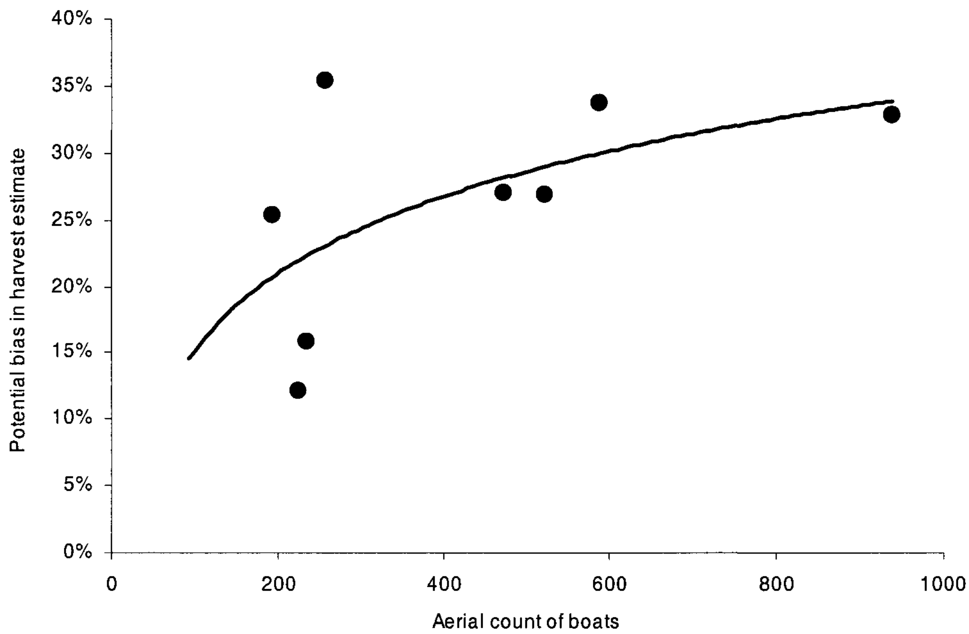


Figure 11: Relationship between day-specific levels of bias, and the number of vessels observed from the air on those days. The four days with more than 400 boats observed from the air were the weekend days.

Another possible explanation for the discrepancy between the two surveys no implications of bias in harvest estimates. This is that fishers tend to overestimate the time spent fishing. This tendency will not affect catch estimates, as it is cancelled out by a concomitant decrease in catch rates, as the observed landed catch remains unaffected.

It is highly likely that more than one of these sources of bias has occurred, although the extent of their combined influence is uncertain. At least one explanation will manifest itself only at busy times and will therefore be most prevalent on weekends, during the summer. If on-the-water surveys provide unbiased estimates of the proportion of fishers using particular ramps, this analysis suggests that the may be some positive bias in our aerial-access estimates of fishing effort. This bias could be as high as 30% on some busy days, but the effect on an annual harvest estimate is likely to be less, perhaps in the order of 10–15%. We consider this analysis indicative rather than conclusive.

2.8.3 Boats returning to ramps outside of session hours – a negative bias

A key assumption of this survey is that the profiles generated from boat ramp interviews describe diurnal changes in the intensity of effort and catch of all fishers in an unbiased manner. Boat ramp interviewers were continuously stationed at boat ramps over a 13 hour period (which was shortened when daylight hours lessened in the winter months) which ended at dusk. Some fishers, however, returned to ramps outside these hours, and their effort and catch is not included in the harvest estimate. Omission of these data results in truncated profiles which consequently underestimate dawn, and to a much greater extent, dusk harvests. Web camera data were used to assess the potential magnitude of this bias. Time stamped images of the Takapuna and Halfmoon Bay boat ramps were used to estimate the number of trailer boats returning outside the hours surveyed at these ramps (Table 7).

Only a few boats returned to Halfmoon Bay before interviewers arrived at the ramp in the morning, and none at Takapuna. Late arrivals were far more common at both ramps, and their incidence was highly variable on a day-to-day basis. On average, 17% of the boats using the Takapuna boat ramp on survey days (when web camera data were available) returned to the ramp outside of the survey period, compared with 13% at Halfmoon Bay.

Interviewers were instructed to record the time at which all boats returned to their boat ramp, regardless of whether the vessel was approached. A comparison of web camera counts with interviewer counts suggests that some boats were missed during the survey session. When daily interviewer counts are compared with camera counts for a whole 24 hour period, it is evident that, on average, 34% percent of the boats returning to the Takapuna ramp, and 28% of boats returning to the Half Moon Bay ramp, were missed by interviewers. Usually, a greater percentage of boats was missed on busier than average days. Not all the missed boats will have been involved in fishing effort, but most probably were.

The overall percentage of boats missed, both during and outside the daily survey session, is 29%. As discussed previously, boats missed by interviewers during the survey session (about 15%) may lead to an overestimation of the harvest. Conversely, however, when boats return to a ramp outside survey hours (about 15%) early in the morning or after dark, their catch is not observed, leading to a an underestimation of the harvest. It is, therefore, possible that any negative bias arising from boats returning outside interview hours might counterbalance any positive bias, as discussed in the previous section.

Table 7: Daily percentage of the number of fishers returning to the Takapuna and Halfmoon Bay boat ramps before (Early boats) and after (Late boats) interviewers are present.

Ramp	Season	Day-type	Date	Total boat count	Early boat count	Late boat count	% Early or late	Interviewer count	Overall % missed
Takapuna	Summer	Midweek	26/02/04	60	0	1	2	43	28
	Summer	Midweek	21/03/04	170	0	16	9	108	36
	Summer	Midweek	26/03/04	76	0	23	30	37	51
	Summer	Midweek	22/04/04	37	0	17	46	33	11
	Winter	Weekend	08/08/04	3	0	1	33	3	0
	Winter	Midweek	28/08/04	22	0	5	23	19	14
	Winter	Midweek	01/09/04	3	0	0	0	3	0
	Winter	Midweek	10/09/04	4	0	0	0	3	25
	Winter	Midweek	11/09/04	2	0	0	0	2	0
	Winter	Midweek	16/09/04	2	0	1	50	1	50
	Winter	Midweek	24/09/04	5	0	0	0	3	40
	Total			384	0	64	17	255	34
Halfmoon Bay	Summer	Weekend	12/04/04	54	0	4	7	46	15
	Summer	Weekend	17/04/04	205	1	34	17	136	34
	Summer	Weekend	18/04/04	233	2	21	10	160	31
	Summer	Midweek	22/04/04	65	2	17	29	40	38
	Winter	Midweek	20/05/04	33	0	7	21	26	21
	Winter	Weekend	23/05/04	76	1	8	12	66	13
	Winter	Midweek	28/06/04	13	0	1	8	15	-15
	Winter	Weekend	24/07/04	65	0	15	23	51	22
	Winter	Weekend	01/08/04	124	4	8	10	99	20
	Winter	Weekend	08/08/04	12	0	2	17	11	8
	Winter	Midweek	16/08/04	3	0	0	0	2	33
	Winter	Midweek	10/09/04	13	0	1	8	12	8
	Winter	Weekend	11/09/04	23	0	4	17	22	4
	Winter	Midweek	16/09/04	8	0	0	0	7	13
	Winter	Midweek	24/09/04	3	0	0	0	2	33
	Winter	Weekend	24/10/04	42	0	7	17	31	26
	Winter	Weekend	25/10/04	223	0	16	7	137	39
	Total			1 195	10	145	13	863	28
Combined	Total			1 579	10	209	14	1 118	29

2.9 Feasibility of developing a web camera based index of fishing effort

The fourth objective of this programme was to develop an ongoing index of fishing effort for the Hauraki Gulf fishery. We monitored patronage at two of Auckland's busiest ramps, Takapuna and Half Moon Bay, as existing boat ramp data suggested that most of the trailer boat traffic at these ramps was related to fishing effort. Any index of trailer boat traffic should therefore be correlated with an index of fishing effort. Web cameras were installed at these two ramps, which provided time-stamped images once a minute, 24 hours a day, when fully functional.

Early configurations of the Takapuna system (installed 23/02/04) were unreliable, with 24 hours of usable minute-by-minute images available for only 44% of the days between installation and 30 November 2004. A far more reliable system, based on a later iteration of that developed at Takapuna, was installed at Half Moon Bay (06/04/04) which provided 24 hours of reliable data on 92% of the days until 30 November 2004. Both systems are now almost totally reliable, and data from the subsequent year will be explored as part of the QMA 1 wide programme REC200401.

Camera configurations differed according to the available resources (power, phone, suitable mounting points) and changed on several occasions as the systems were developed. Essentially, the web camera systems comprised a digital video camera with a power source and a means of transmitting images to a nearby receiver. Still images were captured by a frame grabber, time stamped, and stored chronologically on a PC hard drive. Batches of these images were then transmitted to a secure server via a router. The 1440 minute-by-minute images during each survey day were viewed as a slideshow using Image Viewer 2 software. The direction and nature of boats and vehicle movements at this timescale permits easy interpretation of all traffic, and the time at which each boat returned to the ramp was recorded. Public lighting and vehicle headlights both aid ready interpretation of night time traffic.

The utility of a web camera based index of boat ramp traffic was assessed by comparing counts of boats returning to each ramp with counts of boats returning to the other monitored ramp, counts of fishing boats made by aerial observers in Area 1 and the Hauraki Gulf, and daily snapper harvest estimates for Area 1 (Figure 12). These comparisons were, by necessity, restricted to those days where aerial overflights of the Hauraki Gulf took place, and camera data were available for the entire day. This gave us 16 days for Takapuna, and 20 days for Half Moon Bay, of which only 9 days were common to both ramps. Teething problems with the web camera systems have, therefore, limited the number of days available for these comparisons, yet the relationships appear promising, and all are significantly correlated.

The relationship between camera counts at the two ramps suggests that data from either ramp could be used to generate an index related to fishing effort. An index based on a combination of counts from the two ramps is preferable, however, as it would explain a greater proportion of the fishery and be more independent of localised weather, particularly the direction of the prevailing wind. The relationship between camera counts and daily harvest estimates for Area 1 is surprisingly close given possible seasonal changes in catch rates. These relationships will be examined further in two programmes: REC2004/01 – Estimation of recreational harvests of priority fish stocks; REC2005/06 – Monitoring recreational fishing effort and catches in QMA 1.

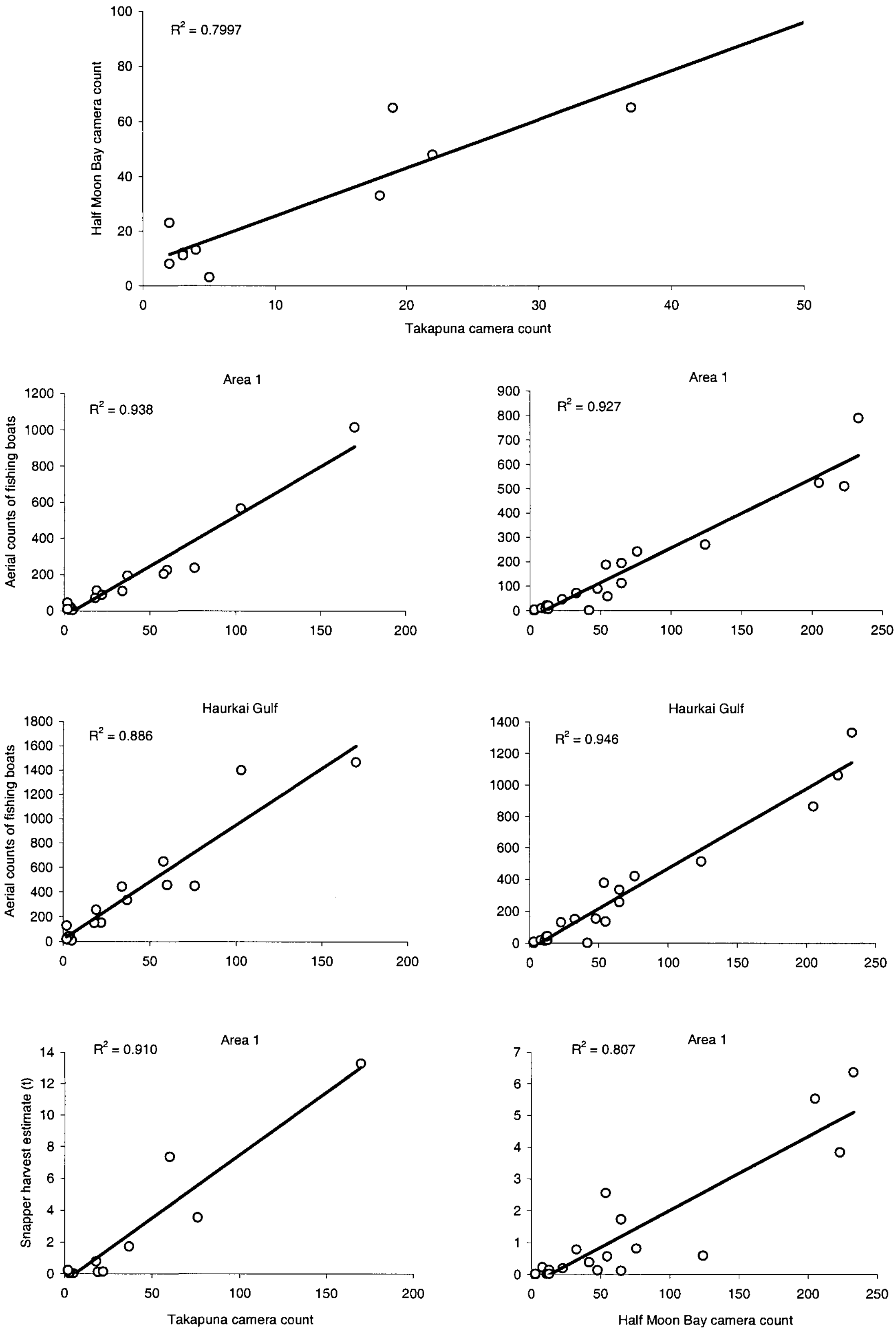


Figure 12: Relationships between web camera based counts of trailer boats returning to the Takapuna and Half Moon Bay boat ramps, and aerial overflight based estimates of fishing effort and snapper harvest. Aerial counts of fishing boats include all vessel types, with non-trailer boat counts rescaled as in Figures 4 and 5. All correlation coefficients are adjusted for degrees of freedom.

3.0 CONCLUSIONS

- An aerial overflight method was used to provide preliminary harvest estimates for snapper and kahawai caught by recreational fishers in the Hauraki Gulf for the year 1 December 2003 to 30 November 2004. The annual snapper harvest estimate of the assessed fishery was 1260.8 tonnes, and for kahawai, 37.8 tonnes

- These overflight estimates have reasonable precision, but with skewed bootstrap values for some area/day-type strata, which influenced the distribution of seasonal estimates.

- Other sources of recreational harvest not accounted for by the flights are also considered, including those associated with less frequently used vessel-based fishing methods, fishing from the shore, and the weighed in catch from the Lion Red Furuno Fishing Tournament.

- When all these harvest sources are combined, the 2003–04 recreational harvests of snapper and kahawai were 1334.2 and 55.8 tonnes respectively.

- Data from previous telephone diary surveys suggest that the annual (i.e., summer and winter combined) snapper harvest probably represents 40–50% of the total recreational harvest from SNA 1.

- The annual kahawai harvest from the Hauraki Gulf is thought to be about 17% of that taken in KAH 1, but this percentage was possibly lower in 2004 as suggested by a concurrent recreational kahawai catch sampling programme.

- Interviews of fishers collected concurrently and independently on the water suggest that the aerial count component of our method may be biased, possibly overestimating of the harvest by as much as 25%, but probably less.

- Web camera data suggesting about 29% of boats were missed by boat ramp interviewers, both outside and during the survey session, over a 24 hour period. Boats returning to the ramp outside survey hours will result in a harvest underestimate, whereas boats missed by interviewers during survey hours may result in a harvest overestimate (both about 15%). The latter is one explanation for the 25% discussed in the conclusion above.

- An a posteriori examination of wind speeds on randomly selected survey days suggests that the days selected before surveying may have marginally favoured favourable fishing conditions, which could lead to inflated harvest estimates

- The combined effect of the three known biases could result in our harvest estimates being positively biased by as much as 15%. There is, however, no evidence to suggest that our estimates are substantially biased.

- The feasibility of using web camera based boat ramp traffic data to provide an index of fishing effort was examined by comparing daily overflight data with camera counts of boats returning to two ramps on surveyed days. There are statistically significant relationships between daily boat ramp traffic counts and numbers of boats counted by aerial observers and with daily snapper harvest estimates.

4.0 ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries under project REC200202. The authors thank the many aerial observers and boat ramp interviewers who made this study possible. Particular thanks are also due to David Middleton, from SeaFIC, who reviewed the formulae in Appendix 5, and suggested a much more parsimonious means of analysing the data.

5.0 REFERENCES

Department of Conservation (1991). How many fish are caught at Taupo? Target Taupo. Special edition 1, Turangi: New Zealand Department of Conservation.

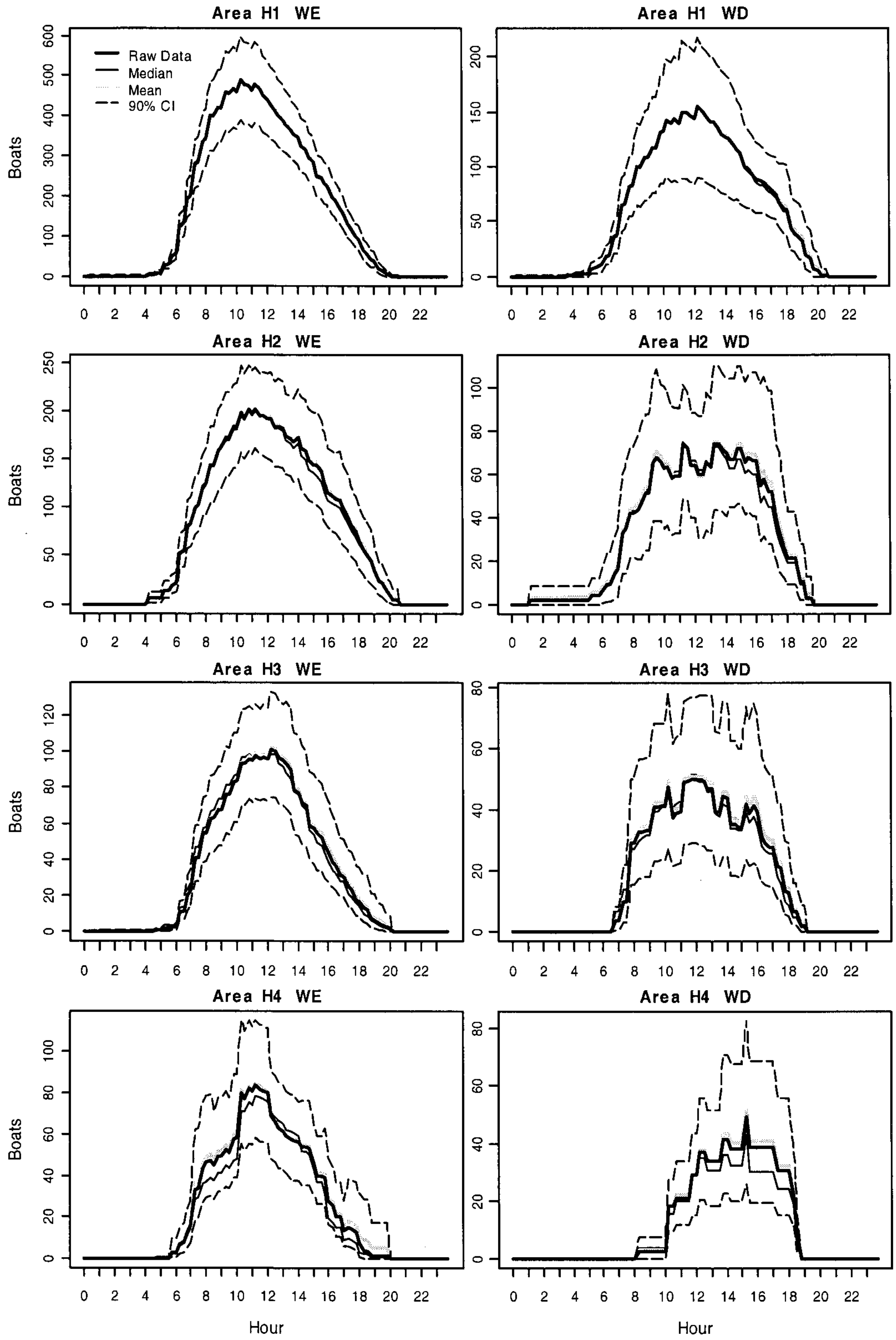
Hartill, B.; Armiger, H.; Tasker.; R.; Middleton, C.; Fisher, D. (2007). Monitoring the length and age composition of recreational landings of kahawai in KAH 1 in 2000–2001, 2001–02 and 2002–03. *New Zealand Fisheries Assessment Report2007/06.* 38 p.

Pollock, K.H.; Jones, C.M,; Brown, T.L. (1993). Angler survey methods and their applications in fisheries management. *American Fisheries Society Special Publication 25.* 371 p.

Watson, T.G., Hartill, B. (2005). Bayesian modelling of boat ramp traffic in SNA 1 since 1970: Towards an index of recreational catch. *New Zealand Fisheries Assessment Report 2005/33.* 52 p.

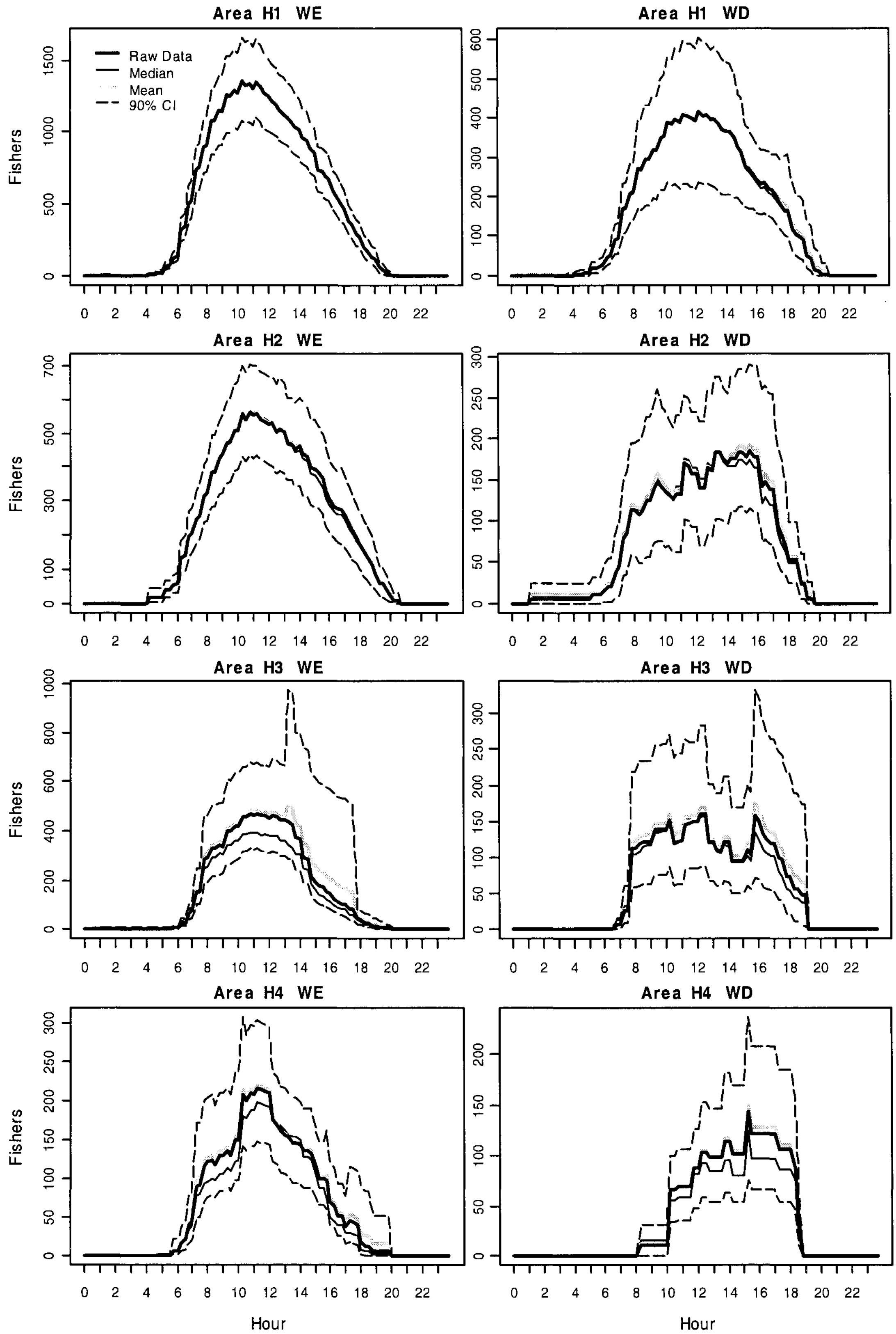
Appendix 1: Diurnal profiles of levels of fishing effort (numbers of boats and fishers), catch (number of fish and total weight of fish caught) and catch rates, associated with snapper and kahawai harvests in the four areas of the Hauraki Gulf, on weekends and midweek days during the summer of 2003–04.

Profiles of the number of recreational fishing boats by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



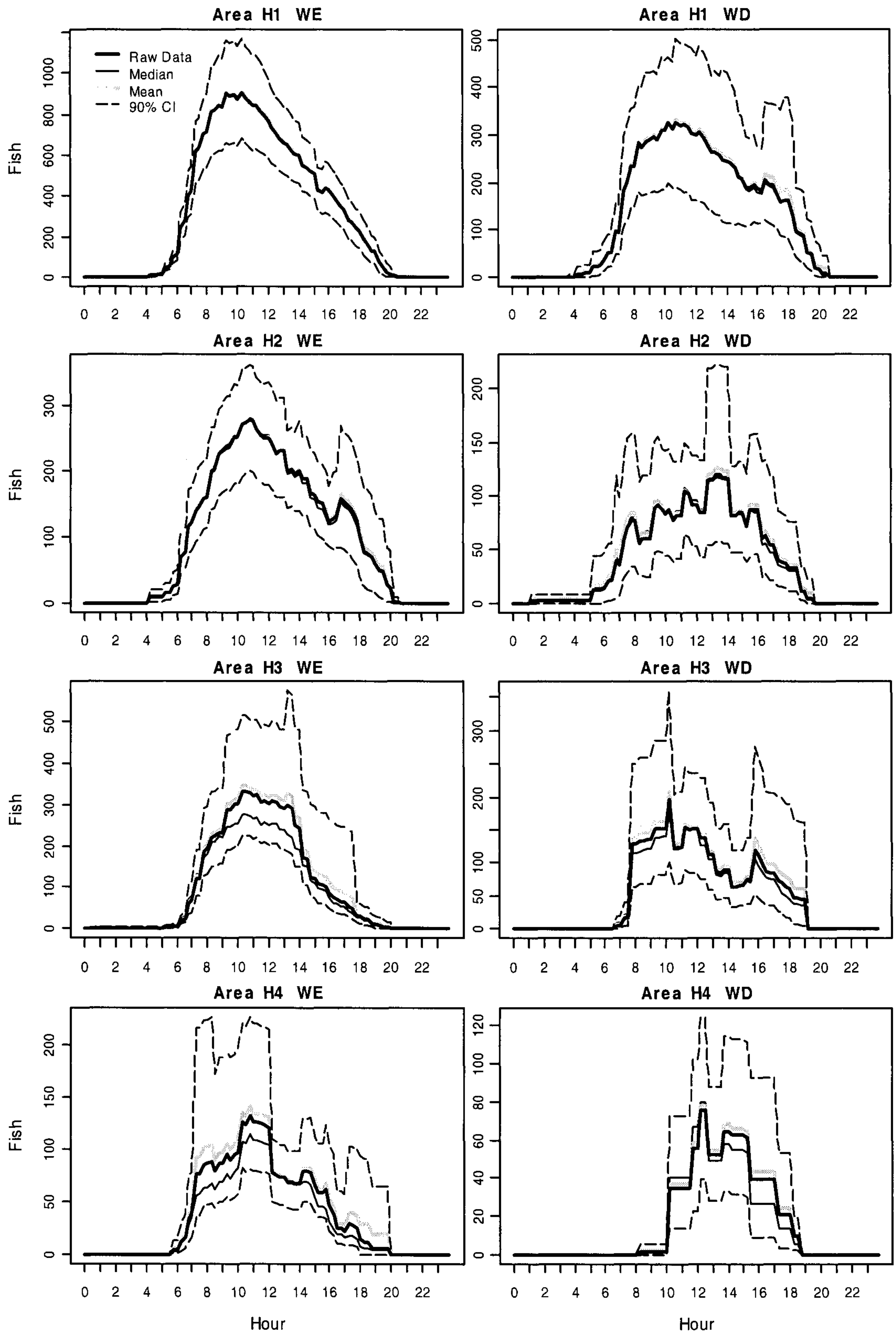
Appendix 1 continued: Summer profiles.

Profiles of the number of recreational fishers fishing by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



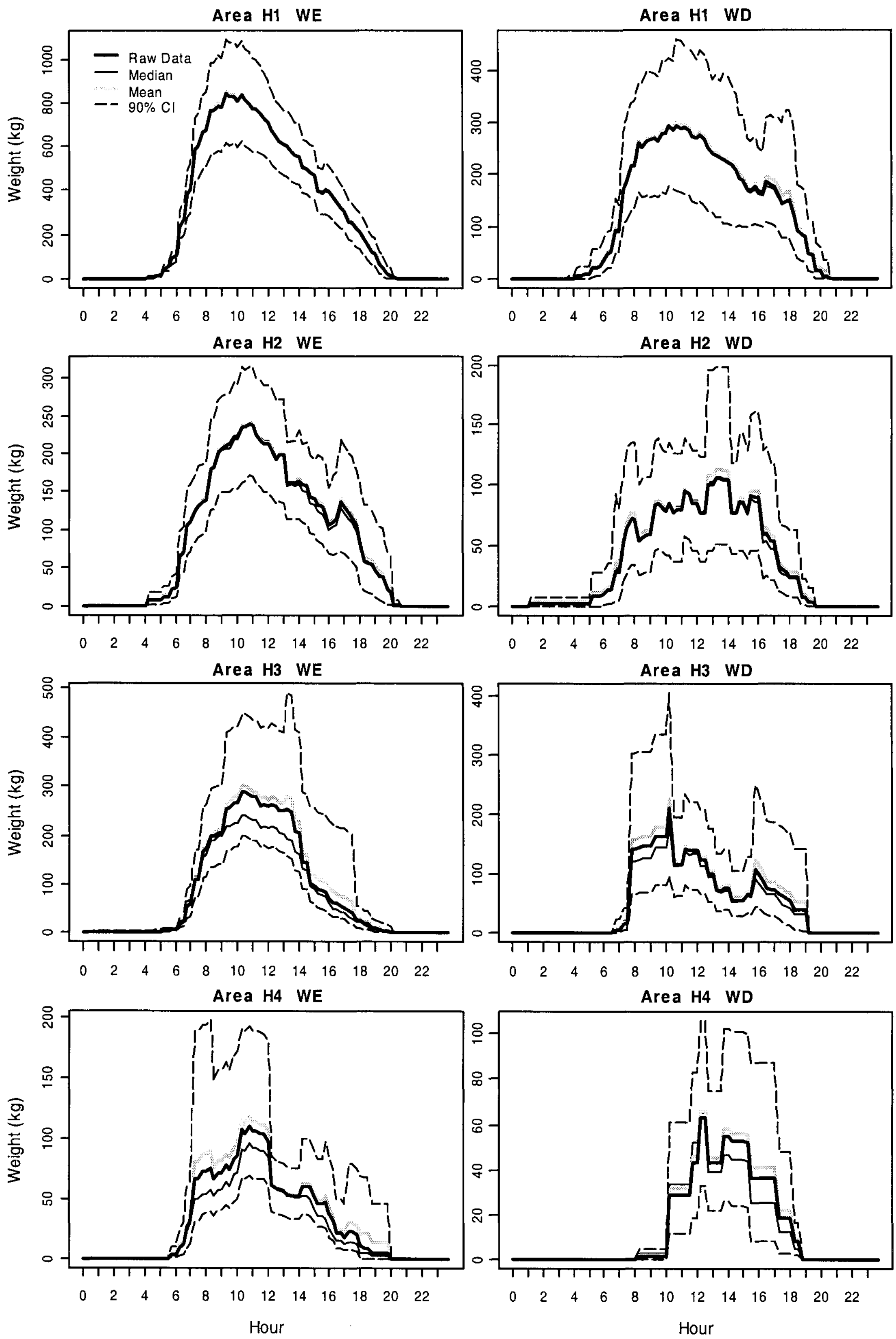
Appendix 1 continued: Summer profiles.

Profiles of the number of snapper caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



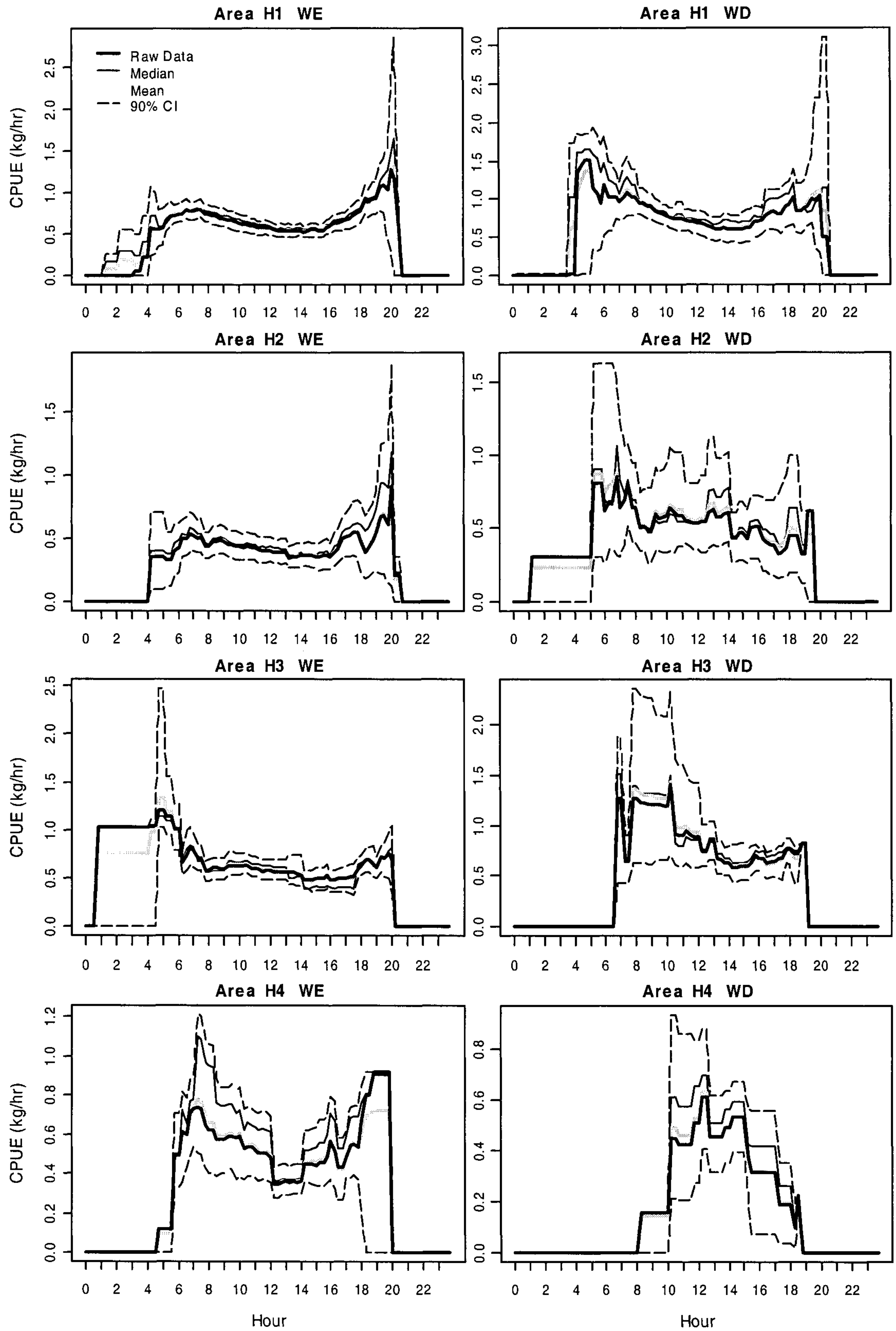
Appendix 1 continued: Summer profiles.

Profiles of the weight of snapper caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



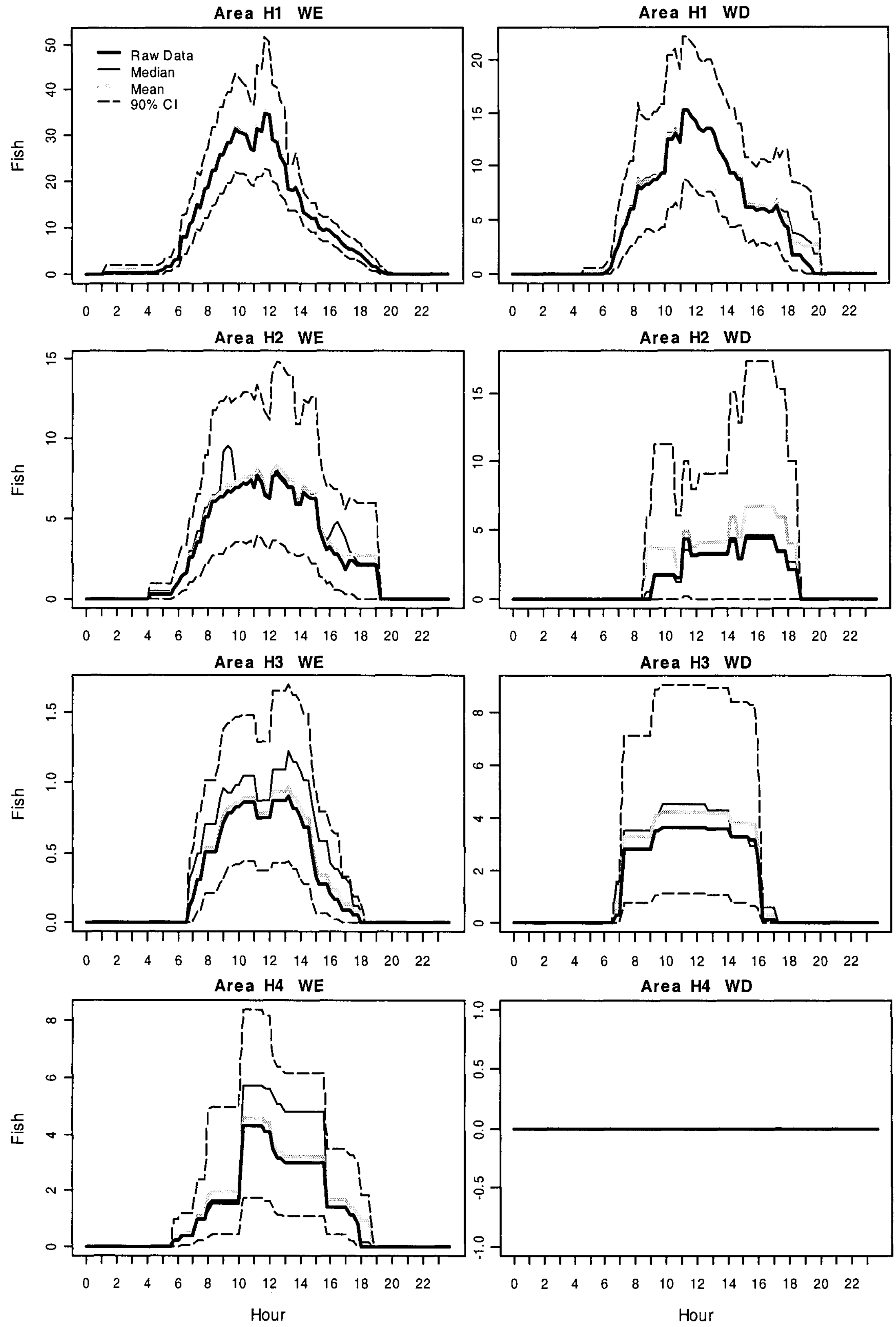
Appendix 1 continued: Summer profiles.

Profiles of snapper catch rates (kilograms per hour) by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



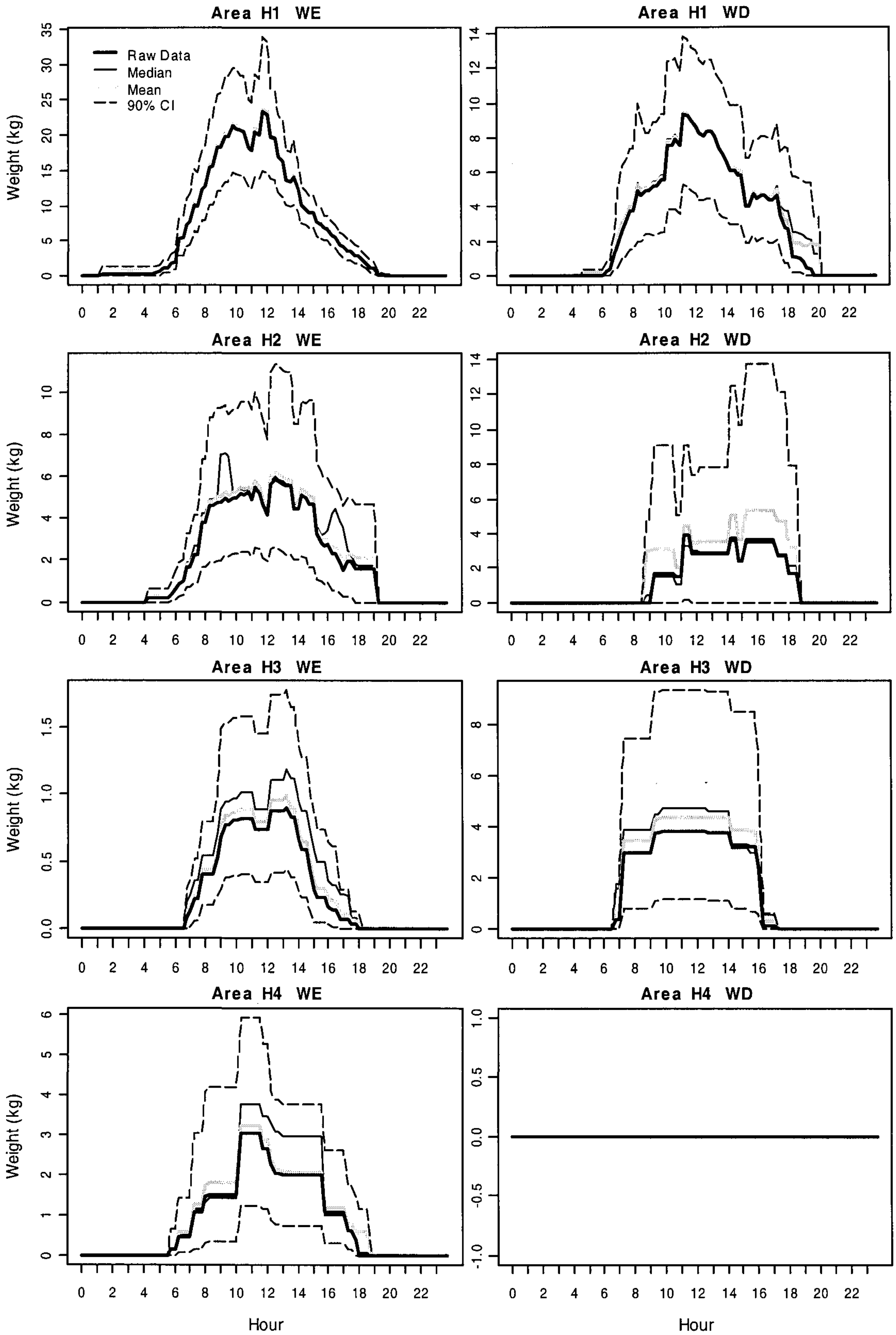
Appendix 1 continued: Summer profiles.

Profiles of the number of kahawai caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



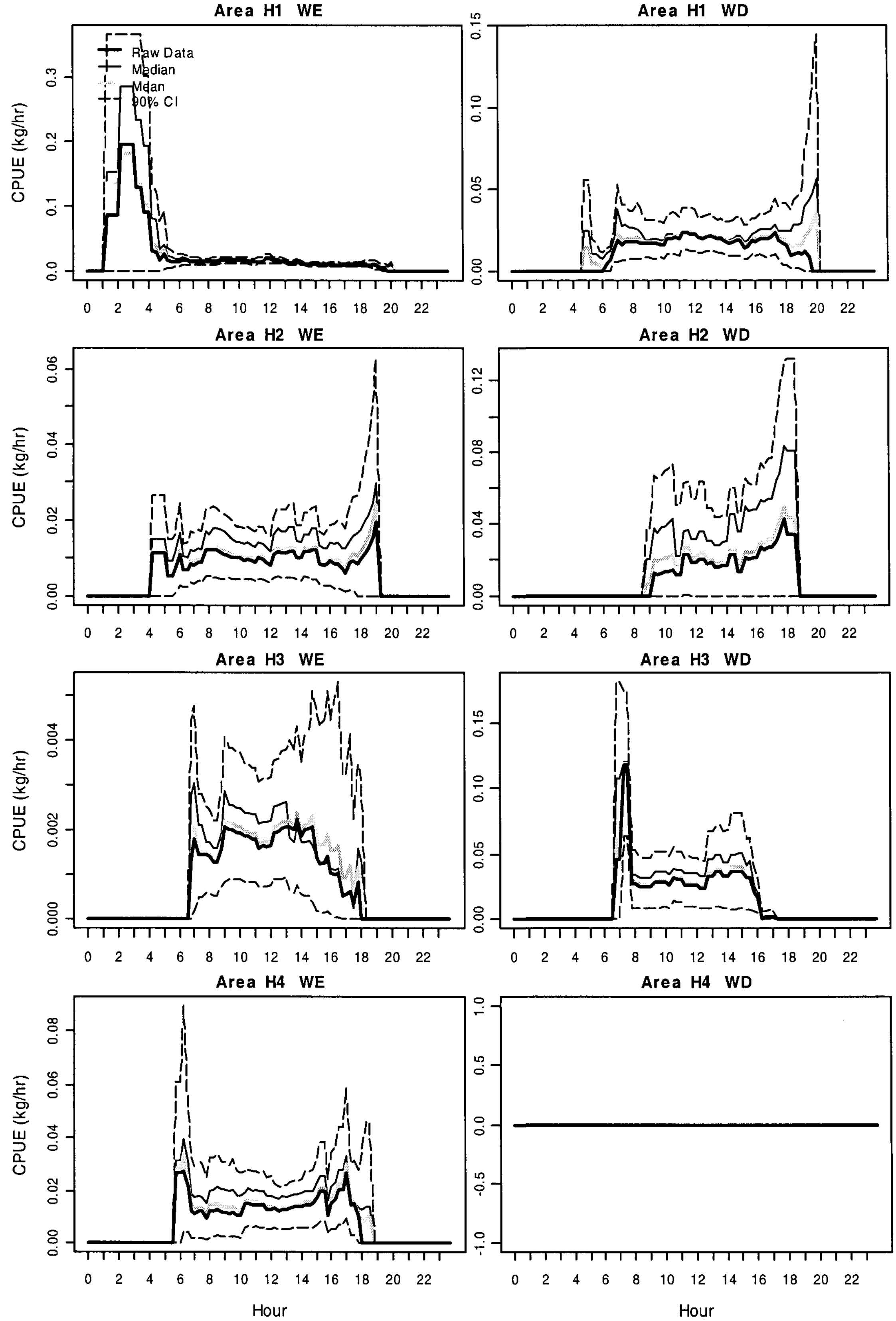
Appendix 1 continued: Summer profiles.

Profiles of the weight of kahawai caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



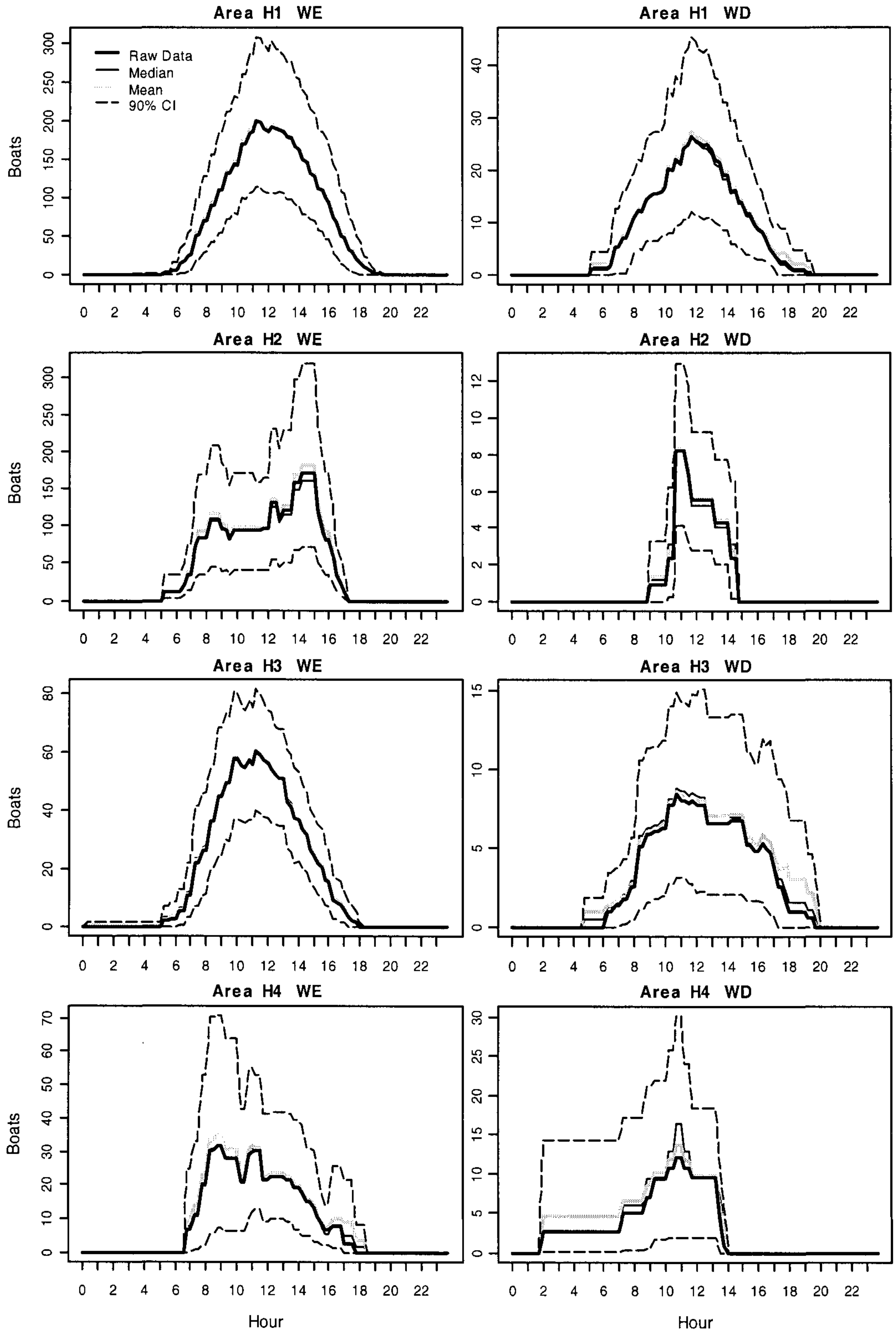
Appendix 1 continued: Summer profiles.

Profiles of kahawai catch rates (kilograms per hour) by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



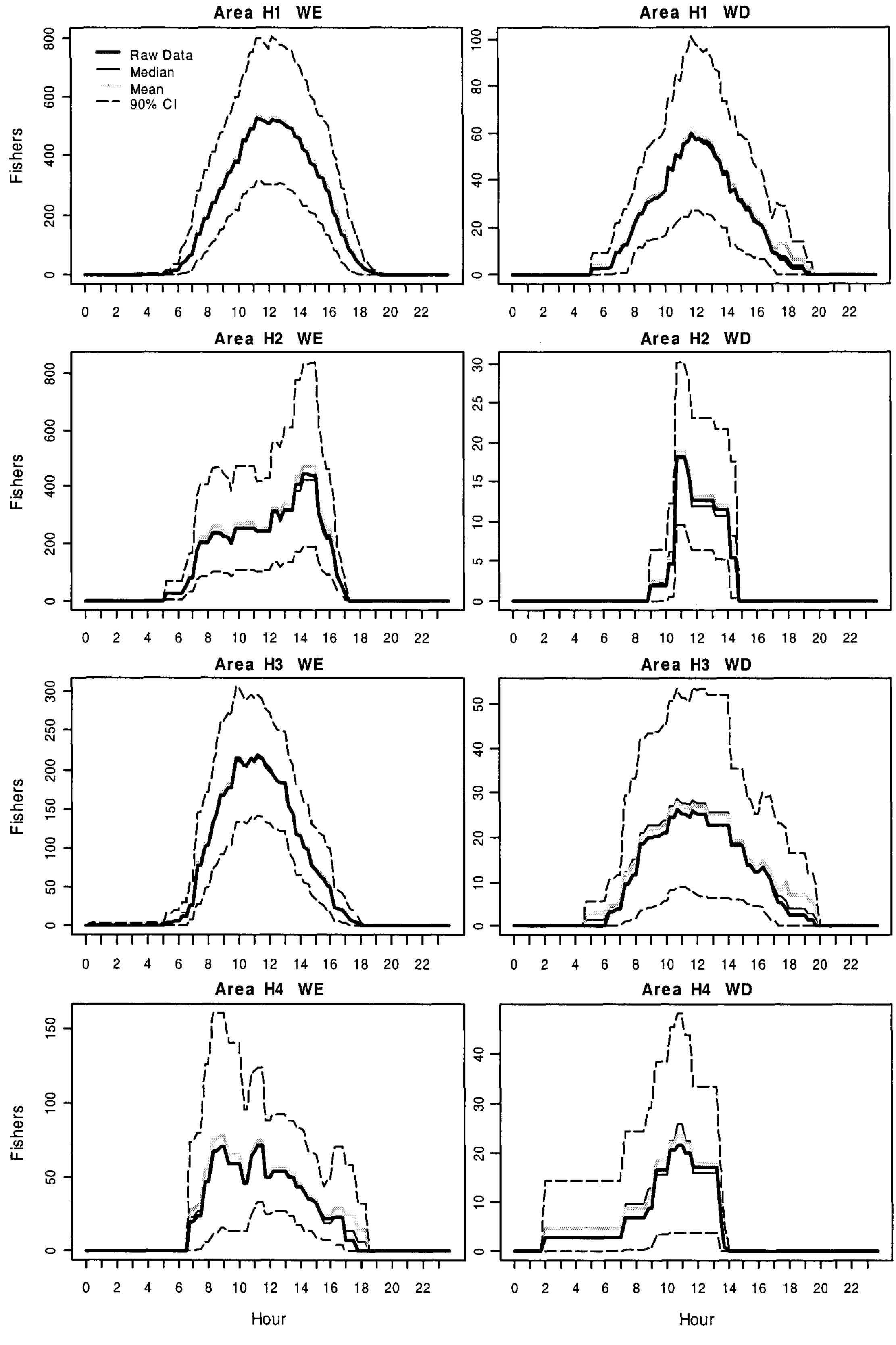
Appendix 2: Diurnal profiles of levels of fishing effort (numbers of boats and fishers), catch (number of fish and total weight of fish caught) and catch rates, associated with snapper and kahawai harvests in the four areas of the Hauraki Gulf, on weekends and midweek days during the winter of 2003–04.

Profiles of the number of recreational fishing boats by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



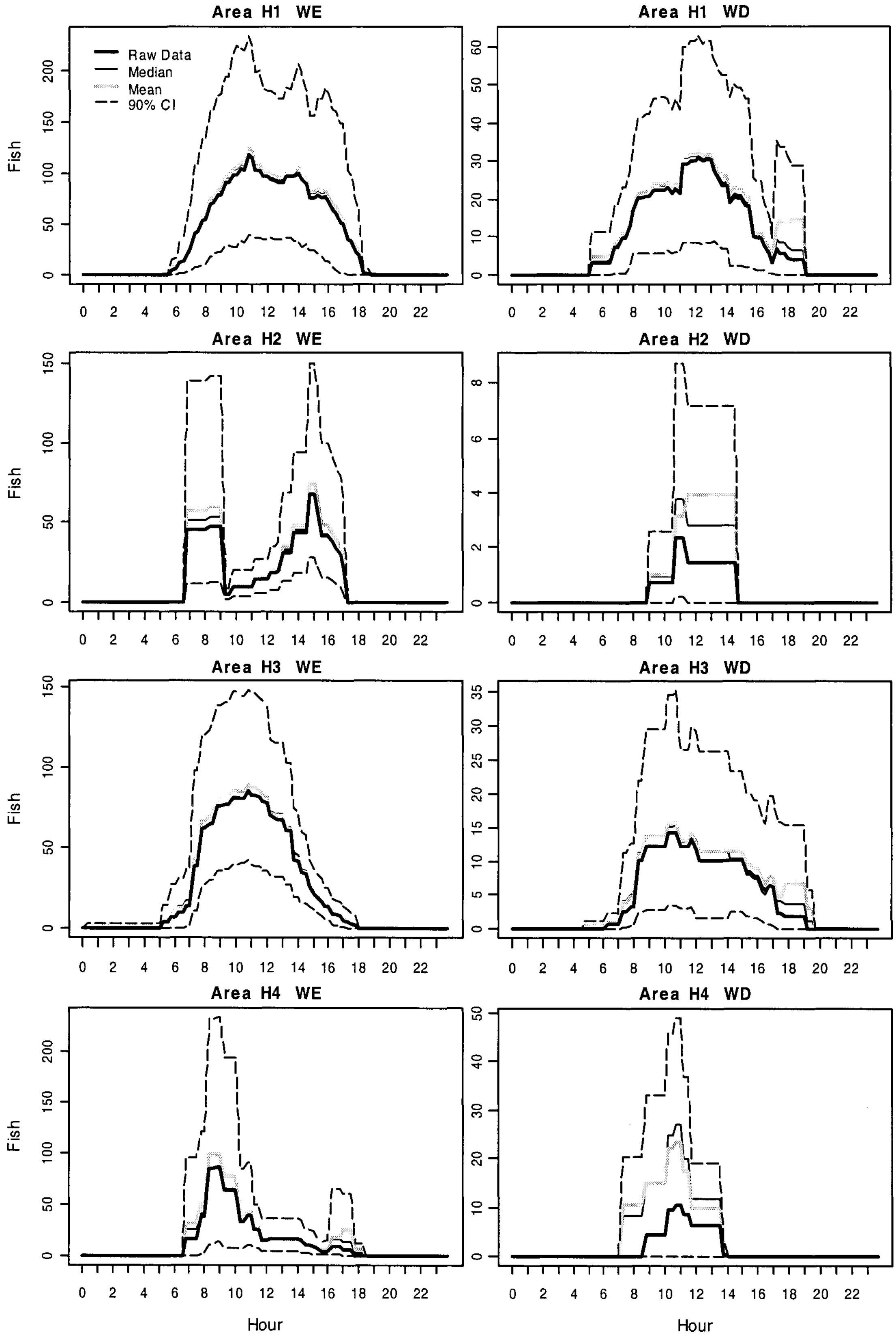
Appendix 2 continued: Winter profiles.

Profiles of the number of recreational fishers fishing by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



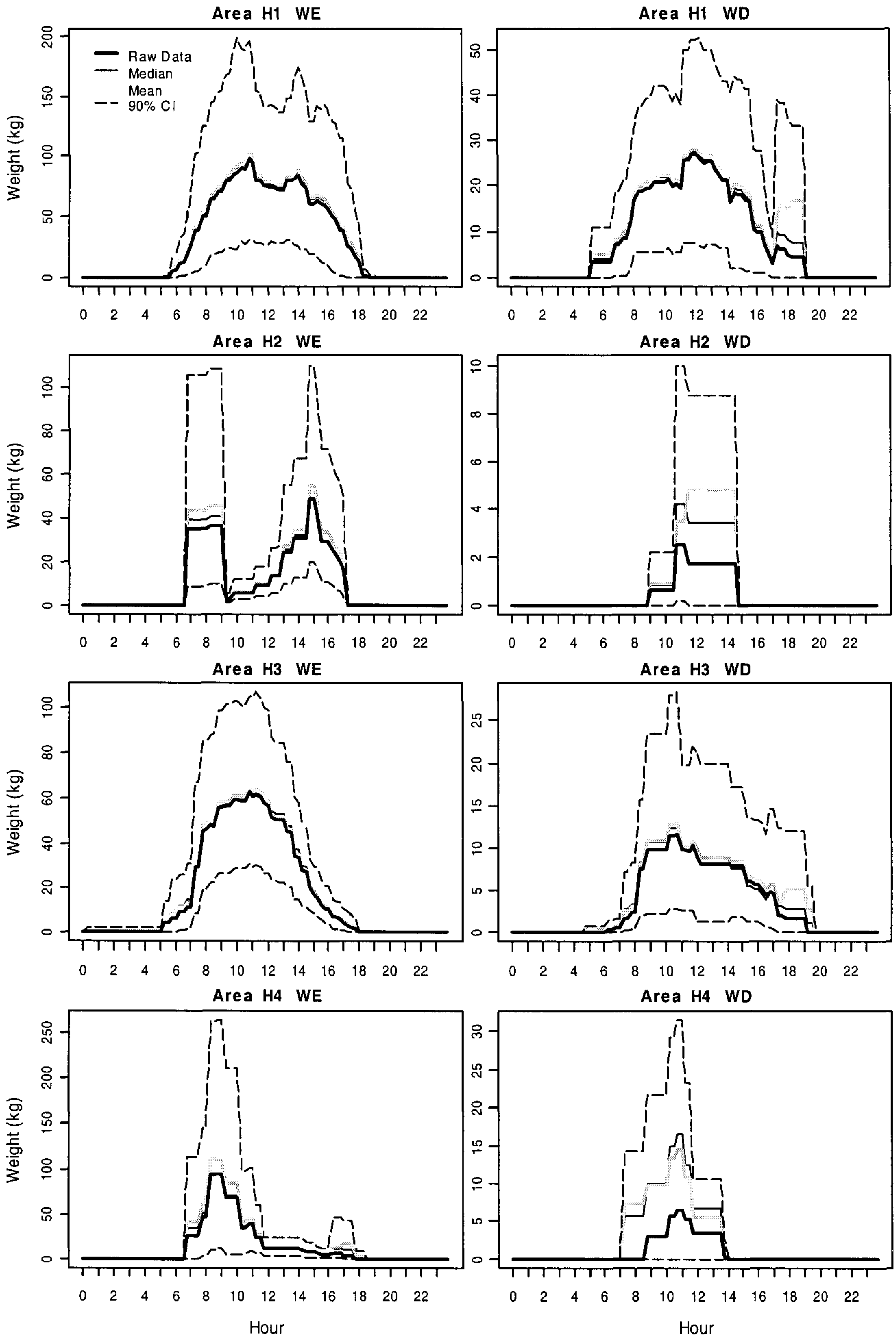
Appendix 2 continued: Winter profiles.

Profiles of the number of snapper caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



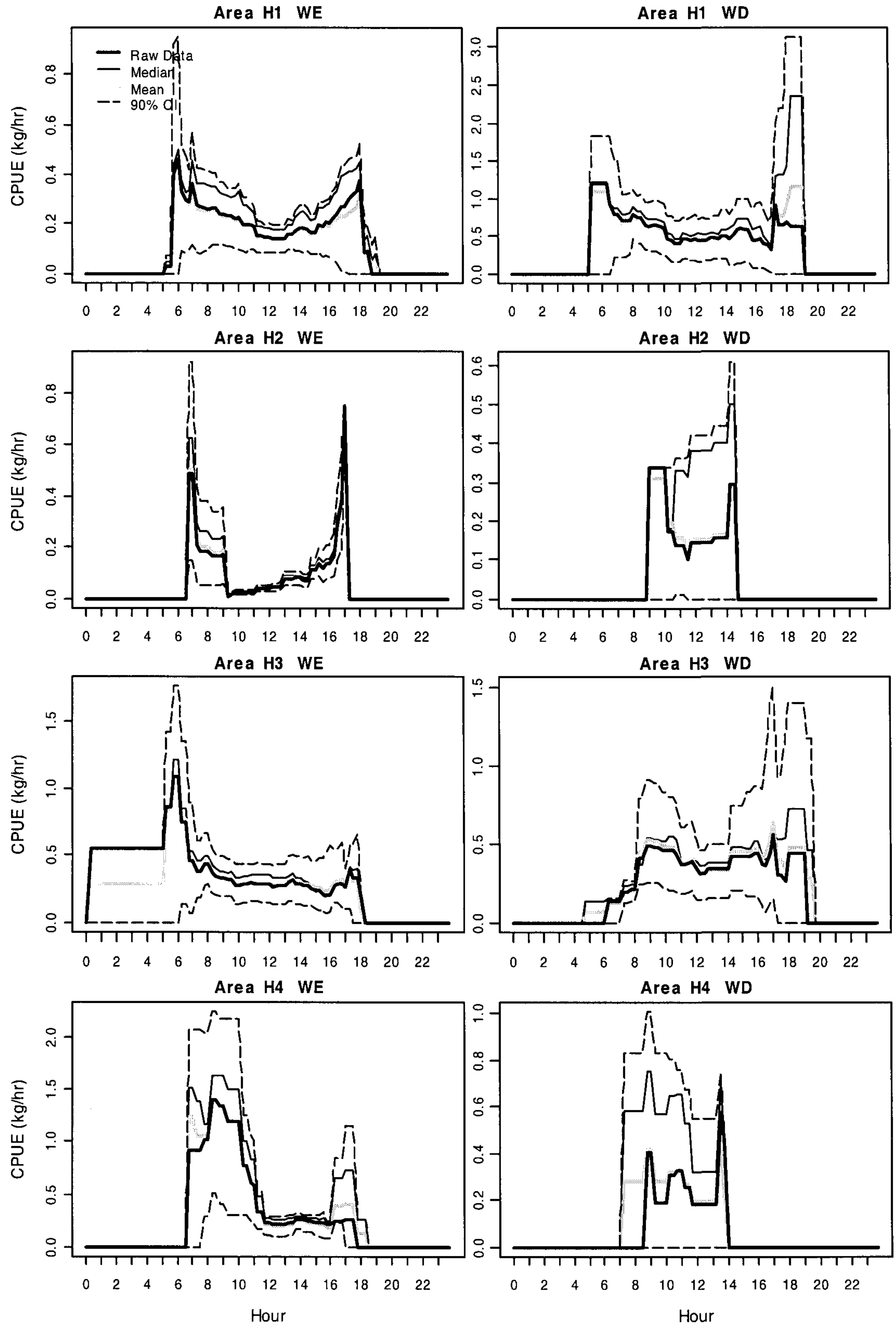
Appendix 2 continued: Winter profiles.

Profiles of the weight of snapper caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



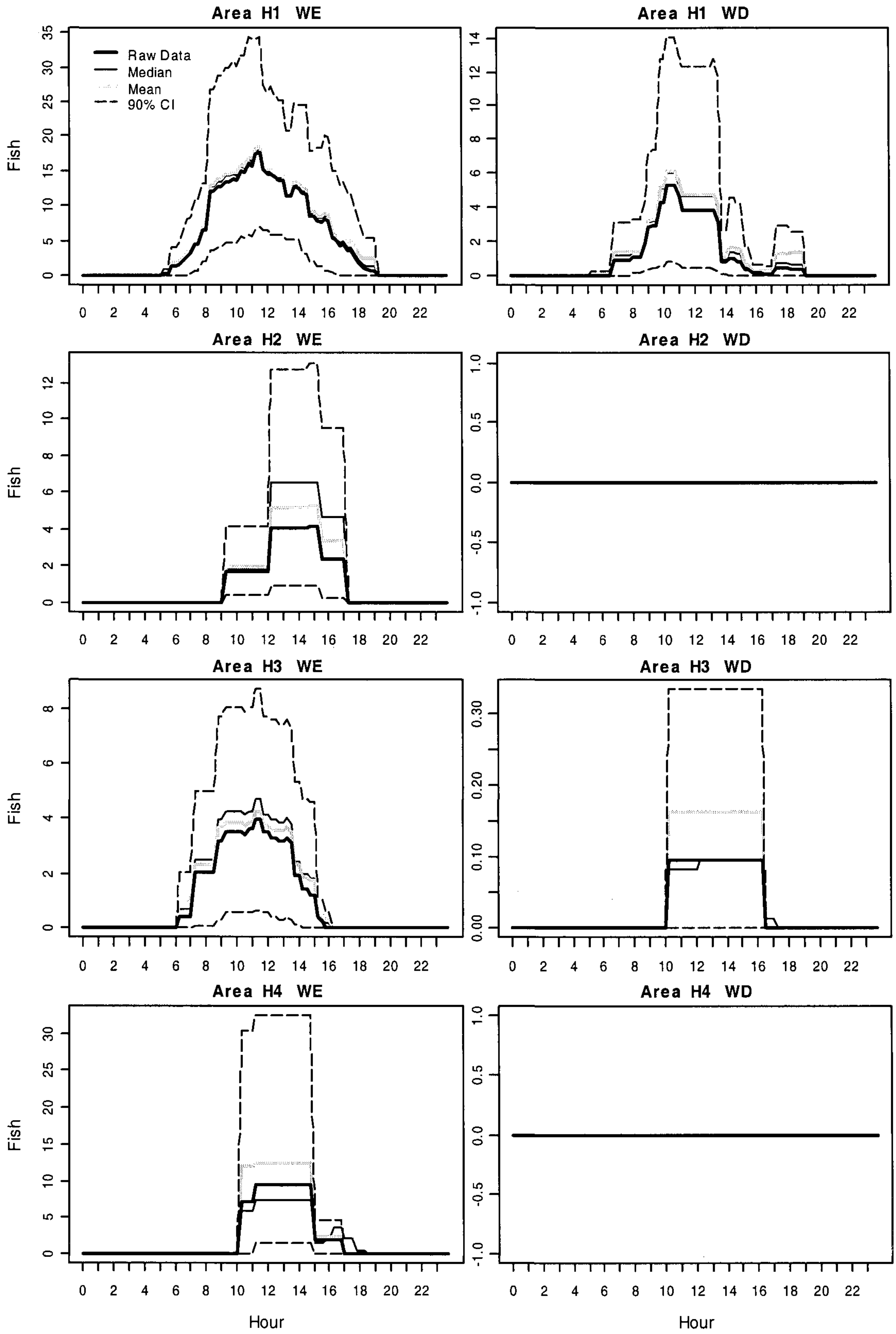
Appendix 2 continued: Winter profiles.

Profiles of snapper catch rates (kilograms per hour) by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



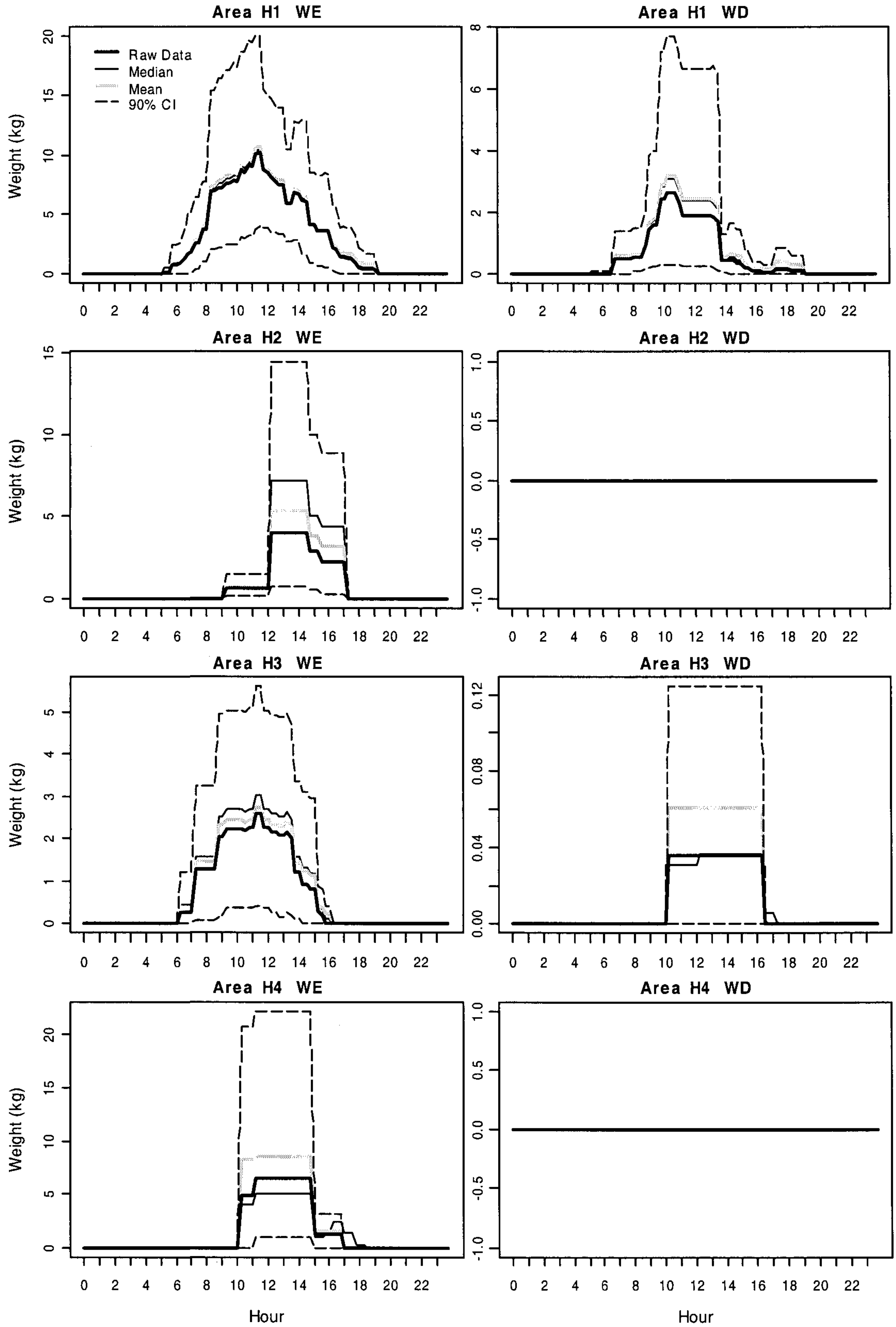
Appendix 2 continued: Winter profiles.

Profiles of the number of kahawai caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



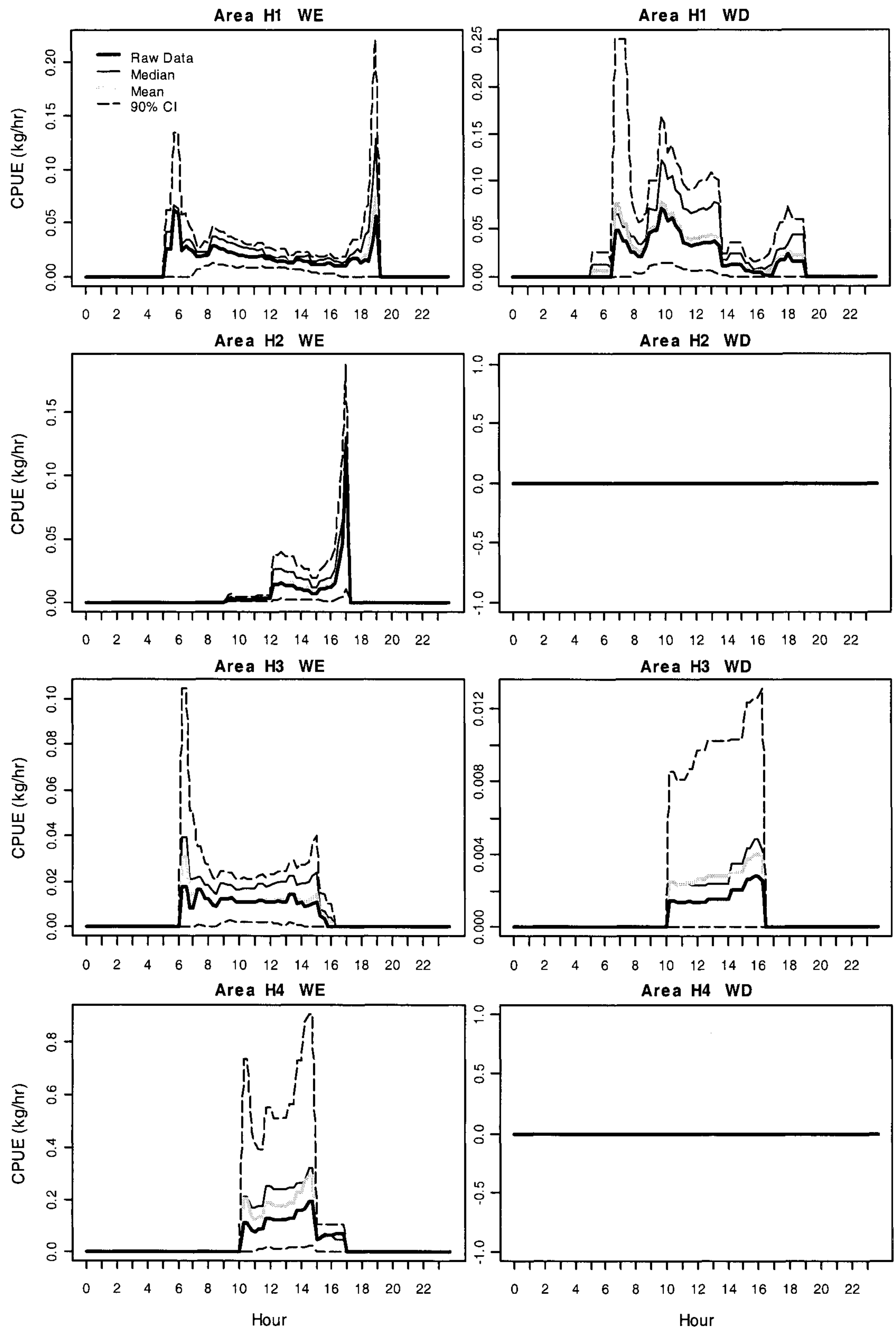
Appendix 2 continued: Winter profiles.

Profiles of the weight of kahawai caught by recreational fishers by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.

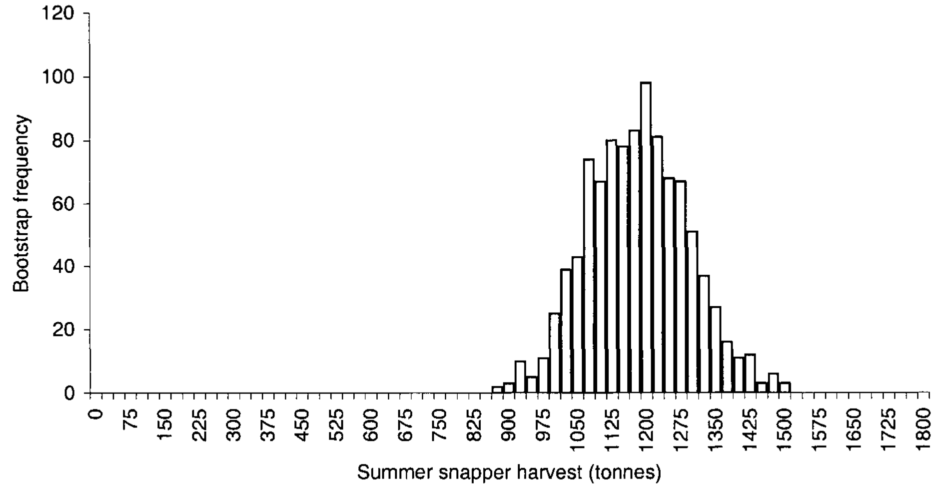


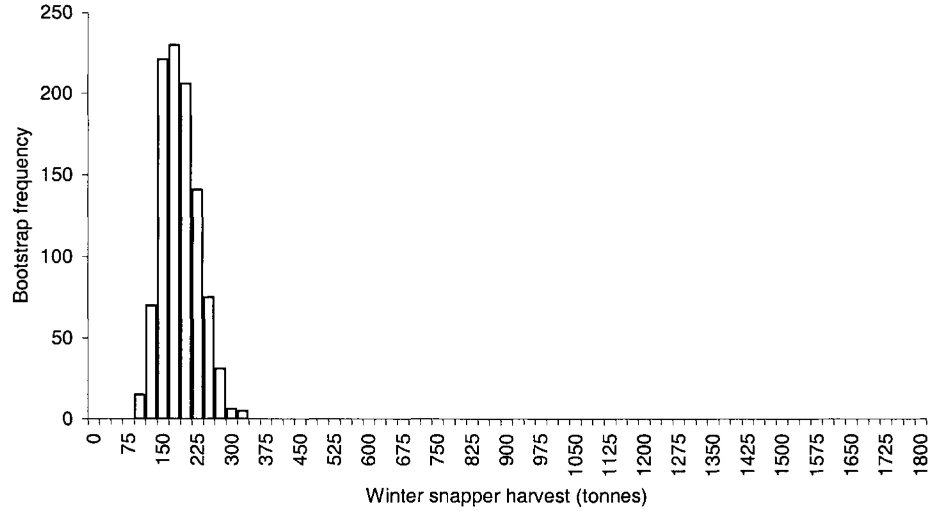
Appendix 2 continued: Winter profiles.

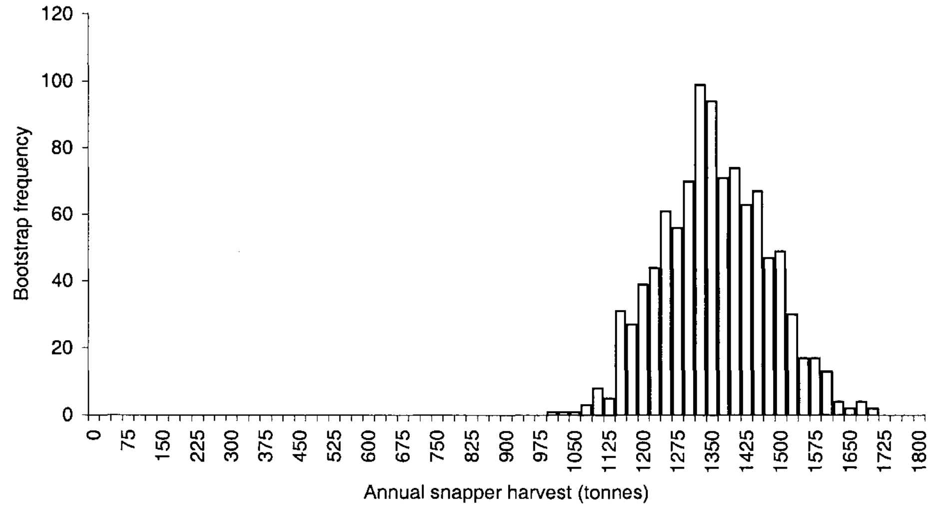
Profiles of kahawai catch rates (kilograms per hour) by area and day-type. Thick black lines are derived from actual data, thin black lines denote median bootstrap values, thick grey lines are derived from bootstrap means, and dashed lines denote 5% and 95% percentiles.



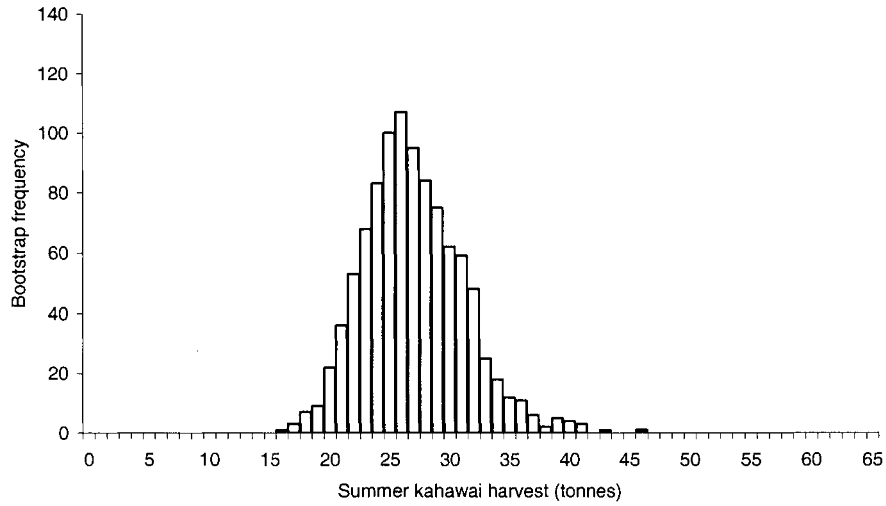
Appendix 3: Distribution of bootstrap estimates of Hauraki Gulf snapper harvest for summer, winter, and for summer and winter combined. Note that these estimates do not include adjustments for indirectly assessed fishing methods and the Lion Red Furuno Fishing Tournament, which are given in Table 4.

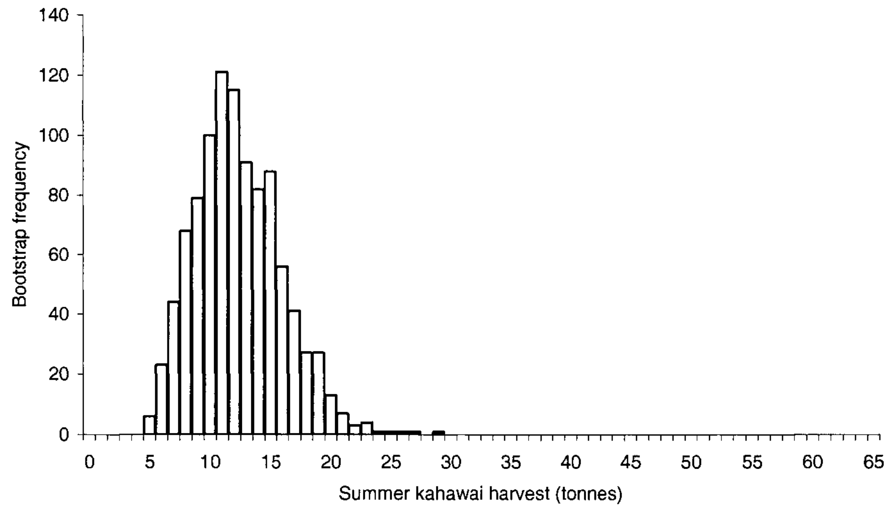


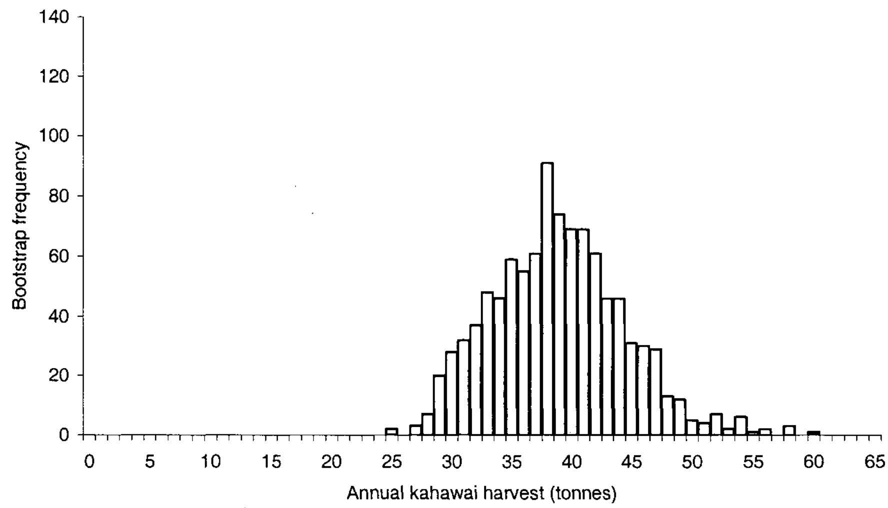




Appendix 4: Distribution of bootstrap estimates of Hauraki Gulf kahawai harvest for summer, winter, and for summer and winter combined. Note that these estimates do not include adjustments for indirectly assessed fishing methods and the Lion Red Furuno Fishing Tournament, which are given in Table 5.







Appendix 5: Analytical approach

Overview

Daily harvest estimates, collected according to a randomised, temporally stratified design, are weighted together appropriately to give either seasonal or annual harvest estimates.

An aerial overflight methodology (sensu Pollock 1994) is used to estimate harvests on survey days, and is based on two concurrently collected sources of data: counts of fishing boats made from an altitude of 500 feet, and interviews with fishers returning to boat ramps. The aerial counts provide an instantaneous estimate of the number of boats fishing in a given area at the time of the overflight, but the application of the boat ramp data is less intuitive, and a detailed explanation of the approach taken follows.

Random stratified design

Fishing effort, and hence catch, is highly variable, both temporally and spatially. A random stratified design was, therefore, employed to reduce the variance of our harvest estimates. The temporal stratifications were based on seasons (summer and winter) and day types (week days and weekend/public holiday days). Spatial stratifications were based on the zones denoted by dashed lines in Figure 2, which were used by aerial observers and in boat ramp interviews. In practice, however, it is advisable to combine these zones into larger strata, as there are usually insufficient data within most of these zones to derive reasonably precise estimates. Smaller zones should be combined on the basis of a preliminary review of catch composition, catch rates, and geomorphology.

Estimates of the average daily harvest for each combination of temporal and spatial strata were calculated as follows.

Boat ramp interview data

Boat ramp interviews were conducted only at key boat ramps throughout our study area, as full coverage of all access points was not logistically feasible. Data collected as part of these interviews can be used to determine where fishing took place, at what time, which methods were used, and which fish were caught by each fisher, for any given combination of method, area, and time. Usually the interviewer was able to measure the catch, but when this was not possible, a count or estimate of the number of fish of each species was made and the nature of that count recorded. From these data it is possible to estimate average catch rates (or harvest rates when fish were landed) in terms of the number of fish, and the weight of fish via the length weight relationship

$$w = \alpha \cdot l^{\beta} \tag{1}$$

where the parameters α and β are species specific.

On survey days, interviewers were stationed at these ramps for a 13 hours, which ended at dusk (the proportion of fishers returning to boat ramps outside these hours can be estimated separately, from web camera data collected at selected ramps). The interview data collected over this period are combined to provide a profile of relative fishing effort and catch throughout the day. At the busier ramps, at the busier times, interviewers were not able to approach all vessels returning to the ramp, yet any fishing effort and catch associated with these boats must be considered if a profile is to be truly representative.

Interviewers were instructed to note the time at which each boat returned to the ramp, and classify them as: interviewed, interviewed but not fishing, refused but fishing, refused (activity unknown), or not interviewed. We use this time stamped-sequence of interview classifications to account for boats which were not approached (or refused to be interviewed) at a given ramp *r*, on a given day *d*, as follows:

If the data of i_rth boat b_{i_r} were unavailable, we looked at the next boat $b_{i_r+\delta}$ after b_{i_r}, for which detailed data were available, and simply assigned a copy of all $b_{i_r+\delta}$'s data to b_{i_r}. But if no data were available for subsequent boats, we considered boats returning before boat b_{i_r}, i.e., $b_{i_r-\delta}$ and copied its data to b_{i_r}.

In some instances, interviewers were unable to measure a fisher's catch, and only a count of the catch was available. We used the average weight of fish measured from other landings to estimate the weight of these unmeasured catches.

Daily boat count profile estimation

From the outset, we consider effort at two levels; at the level of a group of fishers who fish from a boat (collectively termed boat effort) and at the individual fisher level (termed fisher effort). The number of interviewed boats which were fishing at any given time of day (a boat effort profile) was generated by combining data from all interviewed boats.

Each boat's effort is distributed in *K* time bins, termed *k*, where boat *i* started at k_s^i and ended at k_e^i,

$$b_i(k) = \begin{cases} 0, k < k_s^i \\ 1, k_s^i \leq k \leq k_e^i \\ 0, k > k_e^i \end{cases} \tag{2}$$

If fishing takes place in two or more areas during a trip, the effort associated with each area is considered separately. Values from individual boats were then combined

$$b(k) = \sum_{i=1}^{v} b_i(k) \tag{3}$$

where *v* is the number of fishing boats interviewed and *b(k)* in the number of boats that were fishing at time *k*. These estimates can then be considered in series, to produce profiles of how numbers of fishing vessels have changed throughout the day.

Scaling up interview data to account for all boats fishing – flight-interview ratios

b(k) is based on a subsample of all boats fishing on day *d*, as only a subsample of ramps was surveyed, yet many fishers return to unsurveyed ramps and their catch and effort must be considered. Aerial counts of fishing vessels provide a means of scaling our subsample up to account for all catch and effort taking place on the day.

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

$$\rho_d = \frac{c_d(k_f)}{b(k_f)} \tag{4}$$

Effort and harvest profile

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

$$e_{ij}(k) = \begin{cases} 0, k < k_s^{ij} \\ \dfrac{k_e^{ij} - k_s^{ij} - \Delta k^{ij}}{k_e^{ij} - k_s^{ij}}, k_s^{ij} \le k \le k_e^{ij} \\ 0, k > k_e^{ij} \end{cases} \tag{5}$$

Individual fisher profiles can then be combined as boat profiles by summing the effort in each time bin:

$$e_i(k) = \sum_{j=1}^{J} e_{ij}(k) \tag{6}$$

Similarly individual fisher and boat profile of harvest will be

$$h_{ij}(k) = \begin{cases} 0, k < k_s^{ij} \\ \dfrac{h_{ij}(k_s^{ij}, k_e^{ij})}{k_e^{ij} - k_s^{ij}}, k_s^{ji} \le k \le k_e^{ij} \\ 0, k > k_e^{ij} \end{cases} \tag{7}$$

and

$$h_i(k) = \sum_{j=1}^{J} h_{ij}(k) \tag{8}$$

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

The total number of interviewed fishers who fished, and the harvested catch, can be calculated for each time bin, k, by

$$\tilde{e}(k) = \sum_{i=1}^{v} e_i(k) \tag{9}$$

and

$$\tilde{h}(k) = \sum_{i=1}^{v} h_i(k) \tag{10}$$

for a given survey day. Values calculated for each time bin, k, can then be considered in series, to produce profiles of how effort and catch has changed throughout the day.

Estimate of day effort and harvest

The estimates of fishing effort and catch that were calculated for each time bin are based on a subsample of all fishers, as many fishers return to unsurveyed ramps. Our interview based estimates were scaled up to account for all fishers (interviewed and uninterviewed) using a survey day specific scalar, ρ_d, which is based on an instantaneous aerial overflight estimate of all fishing effort, as previously discussed.

$$e_d(k) = \tilde{e}_d(k) \cdot \rho_d = \sum_{i=1}^{n} \left(e_{di}(k) \cdot \rho_d\right) = \sum_{i=1}^{n} \left(e_{di}(k) \cdot \frac{c_d(k_f)}{b_d(k_f)} \right) \tag{11}$$

for fisher effort, and

$$h_d(k) = \tilde{h}_d(k) \cdot \rho_d = \sum_{i=1}^{n} \left(h_{di}(k) \cdot \rho_d\right) = \sum_{i=1}^{n} \left(h_{di}(k) \cdot \frac{c_d(k_f)}{b_d(k_f)} \right) \tag{12}$$

for harvest.

From these, survey day specific estimates of the number of hours fished, and fish harvested, are calculated by summing up the estimated derived for each time bin on that day, d.

$$e_d = \sum_{k=1}^{K} e(k) = \sum_{k=1}^{K} \tilde{e}(k) \cdot \rho_d \tag{13}$$

and

$$h_d = \sum_{k=1}^{K} h(k) = \sum_{k=1}^{K} \tilde{h}(k) \cdot \rho_d \tag{14}$$

Temporal stratification of daily estimates

As we adopted a random stratified design to reduce variance, separate estimates are required for each temporal stratum. Daily estimates of effort and catch were, therefore, averaged within their respective strata, where m is the number of days surveyed within each stratum.

$$\hat{e}_d = \frac{1}{m} \cdot \sum_{d=1}^{m} e_d \tag{15}$$

and

$$\hat{h}_d = \frac{1}{m} \cdot \sum_{d=1}^{m} h_d \tag{16}$$

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

$$\hat{H} = N \cdot \hat{h}_d = \frac{N}{m} \cdot \sum_{d=1}^{m} h_d \tag{17}$$

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

Catch rate profiles

Catch rate profiles are derived by dividing harvest profiles by their respective effort profile.

$$\text{CPUE} = \frac{\hat{H}}{\hat{E}} \tag{18}$$

Utility of profiles

For harvest estimation, only two profiles are used; those for boat effort and harvest weight.

The boat profile is required to estimate the number of boats (fishing parties) whose catch was measured which were fishing at the time of the overflight. This number of boats is used in conjunction with the aerial count of (supposedly) all recreational vessels fishing in an area to provide a scalar (see equation 4), which is used to scale up the harvest landed at surveyed boat ramps during the survey day.

Potentially, a more simpler alternative to generating a daily profile of boat effort would be to ask fishing parties if they were fishing at the time of the overflight. When the interviewer specifies a particular time of fishing, however, it is a leading question, which may produce biased results. Further, the timing of the overflight may be partially unpredictable, and hence unknown on the day of the interview.

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

Catch weight profiles are also used to estimate the harvest, as the area under these curves is the total catch landed to surveyed ramps on each survey day (which is scaled up using equation 4). It is not, however necessary to diurnally profile the catch, as the weights of each landing can simply be summed (with some form of consideration given to boats which were missed by interviewers, but still returned to surveyed ramps on a survey day).

Profiles of effort (for boats and fishers), catch (weight and numbers), and hence catch rates, were generated in this study as we wished to obtain a more holistic picture of the fishery than rather simply estimating the harvest. The generated profiles have made it possible to explore sources of bias, which should be an integral part of any harvest estimation study.

Variance estimation

Stratum-specific variance estimates were generated by a bootstrapping procedure. Survey days from each seasonal/day-type/area stratum were selected with replacement. In turn, data from fishing parties interviewed on that day were selected with replacement, and were used to construct profiles of fishing effort and catch, as described above. Each bootstrapped survey day profile was then scaled up by the aerial count on the associated day. When there were insufficient interview data for profiling on a selected day, profile data was selected at random from one of the stratum days which had sufficient data for profiling. Bootstraps were performed 1000 times, from which mean, median, and 5% and 95% percentile profiles were generated.