Ministry for Primary Industries
Manatū Ahu Matua

Modelling of recreational fishing effort in QMA 1 from 1970 to 2009

New Zealand Fisheries Assessment Report 2015/26

R. Bian,
B. Hartill

ISSN 1179-5352 (online)
ISBN 978-0-477-10595-8 (online)

April 2015

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

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

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

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

Contents

EXECUTIVE SUMMARY

Bian, R.; Hartill, B. (2011). Modelling of recreational fishing effort in QMA 1 from 1970 to 2009.
New Zealand Fisheries Assessment Report 2015/26. 50 p.

Long term regional trends in recreational fishing effort in QMA 1 were first modelled in 2005, based primarily on data provided by boat ramp surveys conducted sporadically between December 1991 and April 2003. Most of the sampling effort undertaken in early boat ramp surveys took place on weekends and public holidays between January and April, and little information was available on levels of fishing effort at other times of the year.

In this study we have updated this model to include data collected during more recent and extensive boat ramp surveys, conducted between December 2003 and April 2009. The data provided by these surveys provide far greater insight into factors influencing levels of fishing effort at times when lower levels of fishing effort are expected, such as during the working week, during winter months, and, on days with higher wind speeds. The full data set also provides observational data for a longer 18 year period, which should improve the ability of this model to predict trends in recreational fishing over the long term. Temporal and environmental effects estimated by this Bayesian model were projected back to 1970, given the daily weather records supplied by NIWA and regional population growth data provided by Statistics New Zealand.

The indices of recreational fishing effort generated by this hierarchical model suggests that there has been a gradual decline in fishing effort in East Northland since the early 1990s, with little change in the level of effort in the Hauraki Gulf and the Bay of Plenty since 1970. These trends suggest that although there has been population growth in all three regions over this period, any potential increase in the number of fishers has been offset by a decline in the per capita tendency to go fishing. Although all three regional indices are projected back to 1970, observational data on fishing effort are available prior to December 1990, and any projections before this date should be regarded with caution.

The hierarchical model structure used in these analyses was adapted to model changes in recreational boating effort based on data provided by an alternative source of information on recreational effort; web camera based counts of boats returning daily to four key boat ramps in QMA 1. The first of these web camera systems became operational in the Hauraki Gulf, in early 2004, and they provide a cost effective means of monitoring levels of recreational fishing effort in a far more regular and representative manner than was previously possible.

Further modelling was also required to determine the proportion of these vessels that would have been fishing, as web camera based vessel counts will include vessels used for other purposes, such as water skiing and sight seeing. The data used to model the probability that each vessel had been fishing was also derived from boat ramp surveys conducted between December 1990 and April 2009.

Regional indices of boating effort (fishing related or otherwise) derived from the modelling of web camera data were then combined with associated regional fishing probability indices, to predict trends in fishing effort. The standardised indices of effort generated from this combined web camera/fishing probability model also suggested that there had been little change in the number of trips undertaken annually over the five years for which data were available, as had been suggested by the first boat ramp interview model.

We conclude that the indices derived from the boat ramp interview model will be more reliable than those derived from the combined web camera/fishing probability model, because of the broad confidence intervals associated with the latter model, and because web camera data are only available for a comparatively short five year period.

1. INTRODUCTION

Recreational fishers account for a substantial proportion of the harvest taken from many inshore fisheries, yet our understanding of the temporal dynamics of their catch and effort is poor. Most of our understanding on recreational fisheries comes from surveys conducted in FMA 1 which have provided estimates of annual harvest, and in some cases, effort. The methods used in these surveys have varied considerably (tagging programmes in 1984 and 1985 (Sullivan et al. 1988); telephone diary surveys in 1993–94 (Teirney et al. 1997), 1996 (Bradford 1998), 1999–00 (Boyd & Reilly 2004), and 2000–01 (Boyd et al. 2004); and aerial-access surveys in 1994 (Sylvester 1996), 2003–04 (Hartill et al. 2007e) and 2004–05 (Hartill et al. 2007b)). A comparison of estimates across time suggests that harvest estimates derived from at least some of these surveys may have been biased to a significant but unquantifiable degree, either positively or negatively. Any modelling of recreational catch and effort based on survey estimates is therefore problematic given the limited availability of reliable harvest estimates and the comparatively short period over which they have been collected.

Many of the surveys listed above have relied in part on interviews conducted with recreational fishers returning to boat ramps at the end of a fishing trip. There have also been numerous other boat ramp surveys which have been conducted for other purposes, such as the characterisation of a localised fishery, or to monitor the age composition of the KAH 1 stock (annually between 2001 and 2008). The same interview format was used in almost all of these surveys and these data collectively provide the most comprehensive and consistent time series available on catch rates and effort in QMA 1. This study focuses primarily on creel survey data on the time at which each observed vessel returned to a surveyed boat ramp and whether or not fishing effort was associated with that trip.

Watson & Hartill (2005) used boat ramp data collected between 1991 and 2003 to model relative changes in levels of recreational fishing effort since 1970. Hierarchical Bayesian modelling methods were used to estimate temporal (year, month class, day type and hour class) and environmental (wind speed, wind direction, tide state, ramp and region) effects that determine the rate at which recreational fishing vessels returned hourly to 26 boat ramps during surveyed hours, given regional population growth between 1991 and 2003. Samples drawn from the posteriors for these temporal and environmental effects were used to predict hourly traffic rates at each of the 26 boat ramps over the period 1970 to 2003, given the observed incidence of average daily wind speeds, wind directions and tidal states. This projection of samples drawn from posterior distributions derived from a model implemented in WinBUGS (Windows Bayesian Inference using Gibbs sampling) produced plausible indices of increasing recreational fishing effort for the Hauraki Gulf and East Northland, although the estimated rate of change in the Bay of Plenty was relatively static.

In this study we incorporate further data collected during boat ramp surveys conducted between late 2003 and 2008. The addition of these data significantly improves the predictive power of the model because interviewers were present at boat ramps from soon after dawn till dusk, over a complete 24 month period from a sample of days selected between 1 December 2003 and 30 November 2005. These interviews therefore provide far better coverage of conditions during the year, given prevailing weather, at all times of day. The collection of data before late 2003 was, by comparison, heavily biased towards weekend sampling during summer and autumn days with favourable weather, and there were little data available for other times of the year.

Boat ramp traffic data have also recently become available from a second source; a network of web cameras established at six key boat ramps in QMA 1 (Hartill et al. 2007c, Hartill et al. 2010). Images from three of these cameras have been interpreted to provide counts of boats retrieved on most days between 5/12/2004 and 4/12/2005 and on 60 days per annum since then.

Both of these data sources are modelled here in a similar fashion to that described by Watson & Hartill (2005), and projected regional indices of effort derived from these models are compared and discussed.

2. DATA SOURCES

Four datasets were considered in this study: boat ramp survey data, web-camera based counts of vessel retrievals, historical weather data, and regional population growth data derived from five yearly national censuses conducted by the Department of Statistics.

2.1 Boat ramp surveys

The primary source of information on recreational fishing effort used in this study is derived from boat ramp interviews conducted since December 1990. Information on the number of recreational fishing boats encountered per hour at a selection of key ramps is used to model changes in the number of vessel trips undertaken over time, given prevailing weather conditions and increasing population growth.

Boat ramp interviews have been the basis of most recreational research conducted in QMA 1 since 1990, although the purpose of these surveys has differed. New Zealand's first large-scale boat ramp survey was conducted in 1990–91 to collect baseline information on harvest rates by recreational fishers throughout the Auckland Fisheries Management Area (AFMA) (Sylvester 1993). Most interviewing occurred on weekends between Boxing Day 1990 and June 1991. In 1994, boat ramp interviews were conducted throughout the year to verify aspects of a concurrent telephone/diary survey. The length composition of recreational catches measured during these boat ramp interviews was used to validate those reported by diarists. These boat ramp data were also used in conjunction with an aerial survey to estimate the snapper harvest from the Hauraki Gulf, which was compared with estimates derived from a telephone/diary survey (Sylvester 1996).

A nationwide boat ramp survey was conducted over a twelve month period throughout 1996, to estimate the mean weights of fish species caught by recreational fishers (Hartill et al. 1998). These mean fish weight estimates were used in conjunction with estimates of annual average fisher catch derived from diarist data, and telephone survey estimates of fisher prevalence, to provide estimates of the national recreational harvest of key species (Bradford 1998). A further small-scale survey conducted in 1998, focussed on fishing in three harbours, the Bay of Islands, Tauranga Harbour, and Ohiwa Harbour, although fishing parties returning to these harbours after fishing on the open coast were also interviewed (Hartill & Cryer 2001). Boat ramp surveys were conducted annually between 2001 and 2008 to collect information on the length and age composition of catches of recreational landings of kahawai (Hartill et al. 2007a, Armiger et al. 2006, Hartill et al. 2007d, Hartill et al. 2008, Armiger et al. 2009). Interviews during the surveys were conducted at key boat ramps throughout QMA 1 on weekends and public holidays between 1 January and 30 April. Although recreational fishers were regarded as a kahawai population sampling tool, the methods used in these interviews was the same as that used in previous surveys, and an attempt was made to interview all fishing parties regardless of whether or not they landed kahawai.

The most extensive boat ramp surveys conducted to date were of the Hauraki Gulf fishery in 2003–04 (Hartill et al. 2007e) and the QMA 1 fishery in 2004–05 (Hartill et al. 2007b). These surveys were part of larger aerial-access survey programmes which provided regional snapper and kahawai harvest estimates for 12 month periods. Boat ramp interviews were scheduled to take place on 45 days randomly preselected according to a random stratified design. The stratifications used in these surveys were based on seasonal (summer – 1 December to 30 April and winter – 1 May to 30 September) and day type (midweek days and weekends/public holidays) definitions. Interviewers were usually present at their assigned ramp from approximately 0800 hours till dusk, regardless of the prevailing weather conditions. These surveys therefore provided data on traffic flows during winter months and occasionally on windier days when interviewing would normally have been cancelled.

Regardless of the objective and design of these surveys (Table 1), the interview format and information collected in all interviews, and types of information used to define each interview session, remained unchanged. This standardisation of interview methods means that data are comparable across a range of temporal scales: days (midweek days vs weekend days) months and years. All surveys, except that in 1998, covered the full geographic range fished by recreational fishers in QMA 1.

Table 1: Summary of recreational boat ramp surveys that have taken place in QMA 1 since 1991.

Survey	Survey period	Interviewing duration (h)	Purpose
1991	17/11/90 – 28/07/91	4	Recreational fishery characterisation
1994	02/01/94 – 26/06/94	4	Telephone/diary validation
1996	30/12/95 – 02/01/97	2	Mean fish weight estimates
1998	01/12/97 – 19/12/98	2	Small three ramp characterisation
2001	03/01/01 – 29/04/01	4–6	Kahawai length and age composition
2002	02/01/02 – 09/05/02	4–6	Kahawai length and age composition
2003	01/01/03 – 27/04/03	4–6	Kahawai length and age composition
2003–04	01/12/03 – 30/11/04	All daylight hours	Harvest estimation and kahawai catch sampling
2004–05	01/12/04 – 30/11/05	All daylight hours	Harvest estimation and kahawai catch sampling
2006	01/01/06 – 27/04/06	4–6	Kahawai length and age composition
2007	01/01/07 – 27/04/07	4–6	Kahawai length and age composition
2008	01/01/08 – 27/04/08	4–6	Kahawai length and age composition
2009	01/01/09 – 27/04/09	4–6	Kahawai length and age composition

N.B. Another survey was conducted in 1999–2000, by Kingett Mitchell & Associates Ltd, but data from this survey are not currently available in an electronic format, and information on all types of boat ramp traffic was not collected.

To some extent the varied objectives and sampling designs used in previous surveys has meant that the distribution of sampling effort in space and time has been very patchy (Table 2), and hierarchical methods are used here to infer changes in effort for those circumstances where few if any observations are available.

Trends in recreational effort for QMA 1 were modelled at a regional level because environmental conditions were considered unacceptably heterogeneous over larger spatial scales. Most previous surveys of recreational (and many commercial) fisheries in QMA 1 have divided this management area up into three regions: East Northland, the Hauraki Gulf, and the Bay of Plenty; and these regional definitions are used here too.

The selection of boat ramps considered in the previous 2005 model was reviewed and 8 of the 26 ramps previously considered were dropped from the data set. These ramps were dropped from the dataset because they were used infrequently by fishers, because of intermittent and unpredictable harbour bar closures, or because interviewers approached fishers at public and neighbouring club ramps in an ad hoc manner during the same interview session. Data collected at Auckland's busiest boat ramp (Half Moon Bay) in 2001 were also excluded from the analysis of boat ramp traffic rates, because the interviewer had only recorded data from interviews with parties who had landed kahawai. No information is therefore available on other parties not interviewed, not fishing, or who landed species other than kahawai. No boat ramp interviews were conducted in the Hauraki Gulf in 1997–98 and 1998–99.

The final selection of boat ramps is given in Figure 1. Fishers using these ramps will account for a substantial proportion of the overall level of effort taking place in QMA 1, as they are the most popular ramps in their area. Boat ramp traffic rates are generally higher at sites close to population centres, such as Whangarei (Parua club and Parua public), Auckland (Takapuna, Westhaven and Half Moon Bay), Tauranga (Sulphur Point) and Whakatane (Whakatane) (Figure 2).

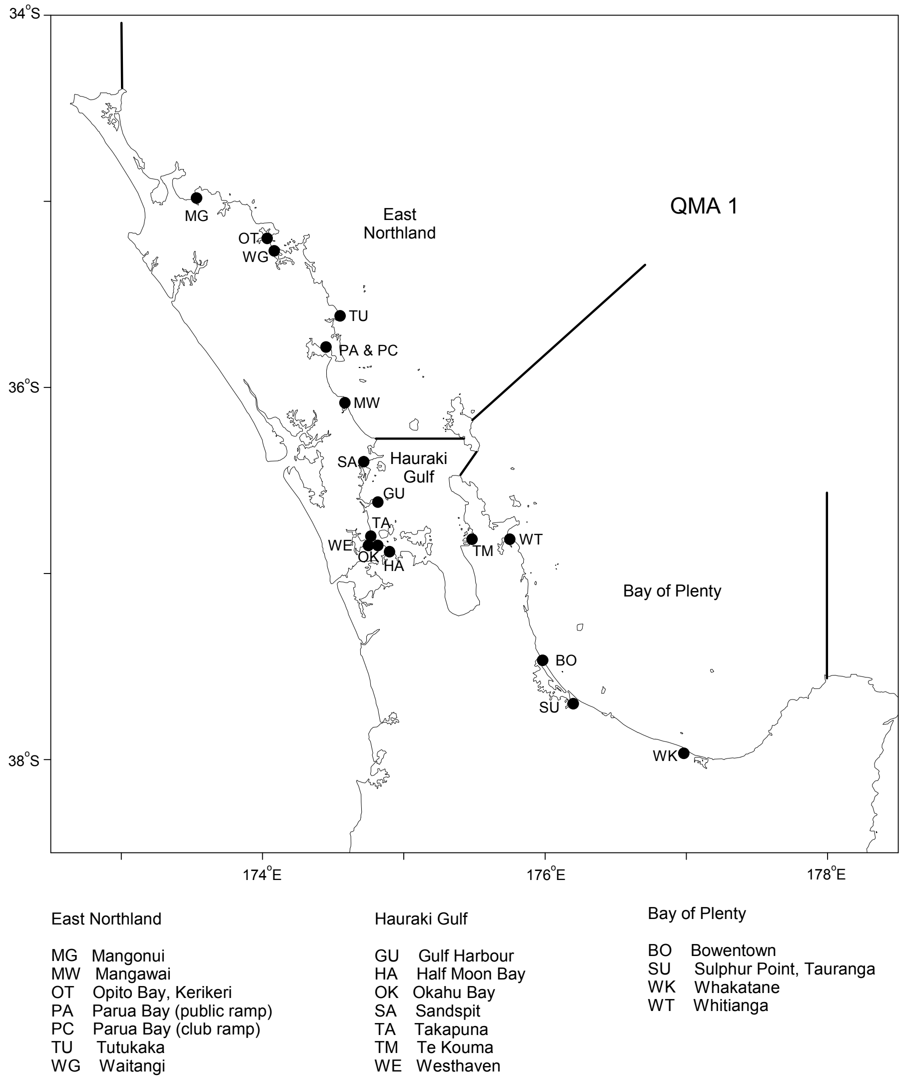


Figure 1: Location of key boat ramps in East Northland, Hauraki Gulf, and Bay of Plenty.

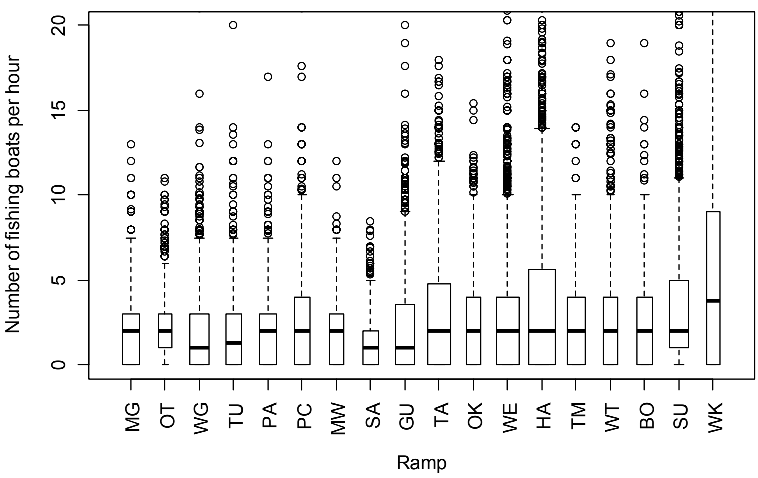


Figure 2: Number of recreational fishing boats encountered per hour of interviewing at each boat ramp. The order in which ramps are plotted runs from Mangonui in northern East Northland to Whakatane in the eastern Bay of Plenty. The y-axis is truncated at 20 boats per hour. See Figure 1 for the location of each ramp.

Table 2: The number of hours that boat ramp interviewers were present at key boat ramps in the three regions of QMA 1, by fishing year and month.

Region	Fishing year	October	November	December	January	February	March	April	May	June	July	August	September	Total hours	Number of ramps
East Northland	1990–91	–	–	17	81	8	122	76	69	45	–	–	–	418	4
	1993–94	–	–	–	58	65	68	82	46	52	–	–	–	371	4
	1995–96	–	–	8	67	64	87	102	37	19	18	10	6	418	4
	1997–98	–	–	22	17	14	24	26	20	18	18	18	12	189	1
	1998–99	20	18	–	–	–	–	–	–	–	–	–	–	38	1
	2000–01	–	–	–	201	202	226	265	–	–	–	–	–	894	7
	2001–02	–	–	–	271	202	202	166	–	–	–	–	–	841	7
	2002–03	–	–	–	222	227	210	221	–	–	–	–	–	880	7
	2003–04	–	–	–	160	119	241	305	–	–	–	–	–	825	7
	2004–05	–	–	257	525	372	451	435	57	168	152	181	55	2 653	7
	2005–06	111	184	–	270	172	186	222	–	–	–	–	–	1 145	7
	2006–07	–	–	–	202	213	171	221	–	–	–	–	–	807	7
	2007–08	–	–	–	264	198	250	149	–	–	–	–	–	861	7
	Total	131	202	304	2 338	1 856	2 238	2 270	229	302	188	209	73	10 340	
Hauraki Gulf	1990–91	–	–	24	83	29	165	133	101	15	–	–	–	550	6
	1993–94	–	–	–	93	107	177	306	206	182	–	–	–	1 071	6
	1995–96	–	–	–	25	18	21	35	34	15	14	8	4	174	4
	1997–98	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	1998–99	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	2000–01	–	–	–	172	143	122	136	–	–	–	–	–	573	6
	2001–02	–	–	–	228	204	196	162	–	–	–	–	–	790	7
	2002–03	–	–	–	233	202	175	179	–	–	–	–	–	789	7
	2003–04	–	–	438	589	453	301	301	89	62	55	205	280	2 773	7
	2004–05	136	88	253	597	453	506	498	73	152	166	163	55	3 140	7
	2005–06	120	185	–	246	176	241	213	–	–	–	–	–	1 181	7
	2006–07	42	194	171	322	368	250	306	67	73	112	79	154	2 138	7
	2007–08	127	183	246	427	322	343	240	–	–	–	–	–	1 888	7
	Total	425	650	1 132	3 015	2 475	2 497	2 509	570	499	347	455	493	15 067	
Bay of Plenty	1990–91	–	–	22	97	27	119	96	70	23	12	–	–	466	4
	1993–94	–	–	–	62	29	44	78	36	84	–	–	–	333	4
	1995–96	–	–	–	55	54	55	34	22	18	18	15	8	279	4
	1997–98	–	–	14	8	2	19	15	10	18	26	23	8	143	2
	1998–99	21	16	9	–	–	–	–	–	–	–	–	–	46	2
	2000–01	–	–	–	26	28	24	43	–	–	–	–	–	121	4
	2001–02	–	–	–	42	31	34	89	3	–	–	–	–	199	4
	2002–03	–	–	–	41	44	43	79	–	–	–	–	–	207	4
	2003–04	–	–	–	30	31	64	71	–	–	–	–	–	196	4
	2004–05	–	–	223	444	348	376	397	35	115	123	123	40	2 224	4
	2005–06	95	158	–	94	48	57	73	–	–	–	–	–	525	4
	2006–07	–	–	–	49	61	51	92	–	–	–	–	–	253	4
	2007–08	–	–	1	40	41	59	65	–	–	–	–	–	206	3
	Total	116	174	269	988	744	945	1132	176	258	179	161	56	2 974	
Grand Total		672	1 026	1 705	6 341	5 075	5 680	5 911	975	1 059	714	825	622	30 605	18

Most boat ramp interviewing has taken place on weekends and public holidays, when the intensity of recreational fishing effort is generally greatest (Table 3, Figure 3). Most of the information on midweek traffic rates comes from the 1996 national mean weight estimation survey and aerial overflight surveys conducted in the Hauraki Gulf in 1993–94 and 2003–04 and in QMA 1 in 2004–05. These surveys have also provided most of the information on traffic rates during the winter months and early spring. Traffic rates tend to peak in the late afternoon and early evening, as fishers return to boat ramps after a day's fishing (Figure 3).

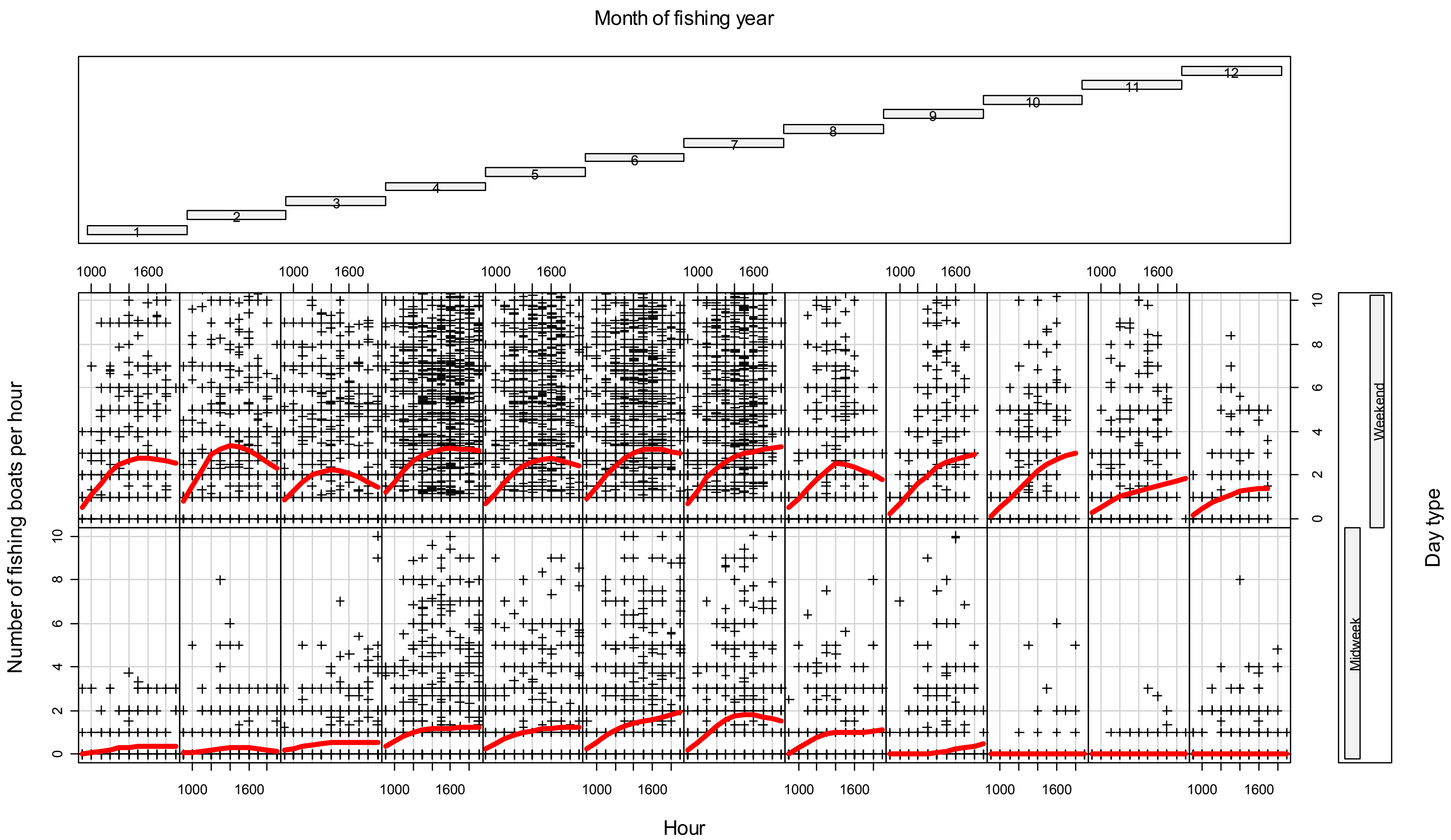


Figure 3: Number of recreational fishing boats encountered per hour of interviewing at a given ramp, by day type and month of the fishing year, by fishing year. 1=October,…,4=January,..., 12=September.

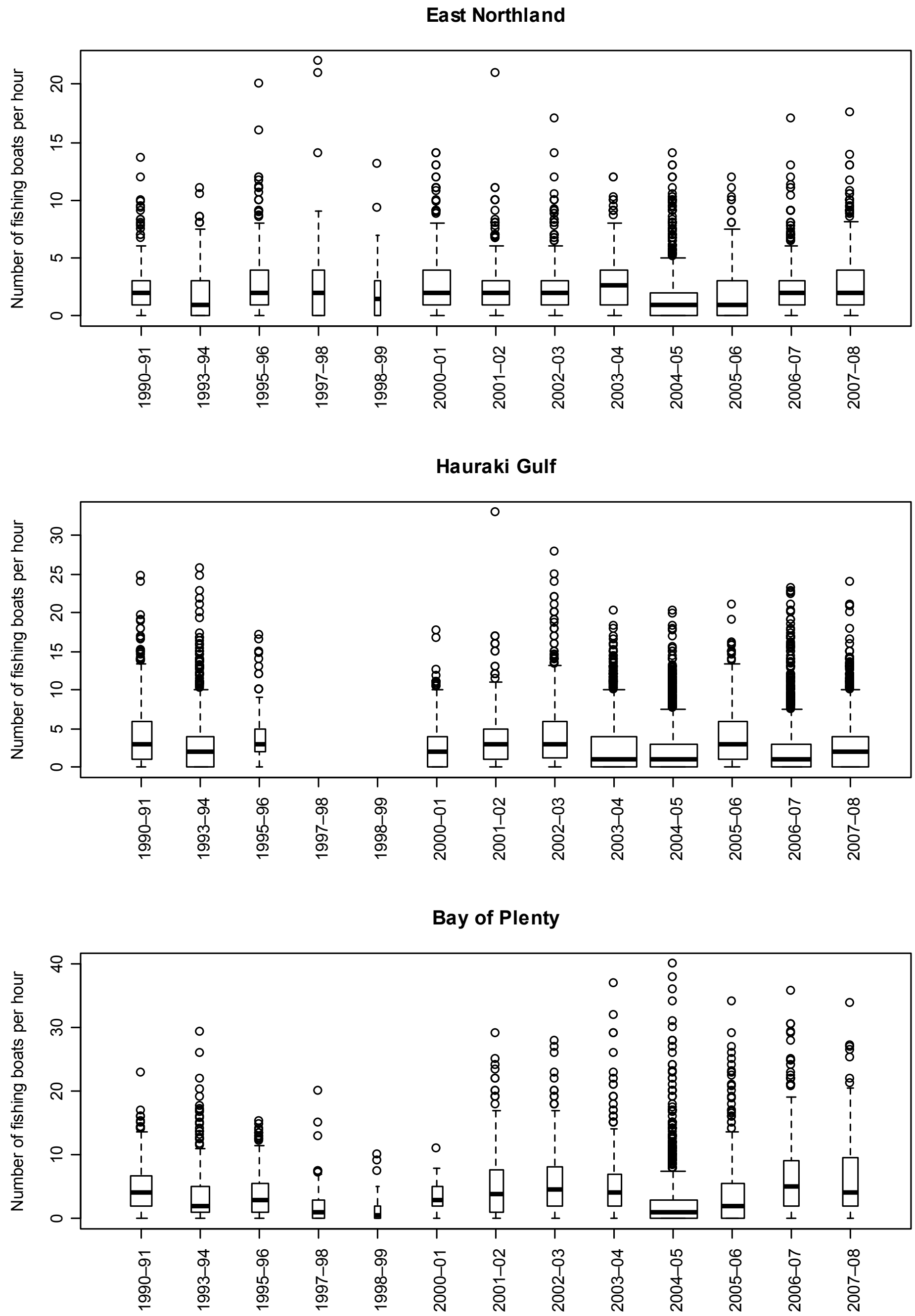


Figure 4: Number of recreational fishing boats encountered per hour of interviewing by region by fishing year.

Although there appears to be a marked interannual variability in traffic rates in Figure 4, this is a reflection of the differing sample designs used in each survey. For example, there appears to be a marked drop in levels of effort in the Hauraki Gulf in 2003–04 and throughout QMA 1 in 2004–05, but this is because interviews in these years were undertaken as part of an aerial overflight survey, when a substantial proportion of interviewing took place on midweek and winter days, when lower traffic levels are expected (see Figure 3). Unstandardised indices of boat ramp traffic will not take any bias arising from non-random and hence unrepresentative sample designs into account, and this illustrates the need for a standardised analytical approach, as discussed later on.

Table 3: Summary of the number of boat ramp interview sessions taking place on weekends/public holiday days and midweek days during each of the surveys conducted in East Northland, Hauraki Gulf and the Bay of Plenty.

Region	Fishing year	Weekend/ public holiday	Midweek	All	Weekend proportion
East Northland	1990–91	365	53	418	0.87
	1993–94	343	28	371	0.92
	1995–96	266	152	418	0.64
	1997–98	60	129	189	0.32
	1998–99	20	18	38	0.53
	2000–01	880	14	894	0.98
	2001–02	816	25	841	0.97
	2002–03	855	25	880	0.97
	2003–04	797	28	825	0.97
	2004–05	1 576	1 077	2 653	0.59
	2005–06	984	161	1 145	0.86
	2006–07	772	35	807	0.96
	2007–08	821	40	861	0.95
	All	8 555	1 785	10 340	0.83
Hauraki Gulf	1990–91	461	89	550	0.84
	1993–94	676	395	1 071	0.63
	1995–96	111	63	174	0.64
	1997–98	–	–	–	–
	1998–99	–	–	–	–
	2000–01	557	16	573	0.97
	2001–02	750	40	790	0.95
	2002–03	768	21	789	0.97
	2003–04	1 777	996	2 773	0.64
	2004–05	1 853	1 287	3 140	0.59
	2005–06	1 025	156	1 181	0.87
	2006–07	1 439	699	2 138	0.67
	2007–08	1 384	504	1 888	0.73
	All	10 801	4 266	15 067	0.72
Bay of Plenty	1990–91	400	66	466	0.86
	1993–94	288	45	333	0.86
	1995–96	147	132	279	0.53
	1997–98	53	90	143	0.37
	1998–99	19	27	46	0.41
	2000–01	118	3	121	0.98
	2001–02	173	26	199	0.87
	2002–03	203	4	207	0.98
	2003–04	187	9	196	0.95
	2004–05	1 291	933	2 224	0.58
	2005–06	419	106	525	0.80
	2006–07	233	20	253	0.92
	2007–08	190	16	206	0.92
	All	3 721	1 477	5 198	0.72
Grand Total		23 077	7 528	30 605	0.75

Interviewers have been consistently tasked with recording the time at which recreational fishing boats returned to boat ramps, and classifying the types of interviews that took place. Interview classifications include: fishing related activity (I), non-fishing activity (O), not approached as the interviewer was already occupied (N), and fisher refusal (R). Refusals were comparatively uncommon (about 1%), but when interviewers encountered high traffic rates, some fishing parties were often not approached (Table 4). The probability that a boat party which was not interviewed but had been fishing (N or R) can be inferred from the activities of those parties which were interviewed (I or O). It was therefore possible to obtain estimates of the number of recreational fishing boats returning to each boat ramp per hour, as interviewers were also instructed to note down the time at which each boat returned to the ramp. Data were only used if the interviewer was present at the ramp for the full 60 minutes of each hour.

Table 4: Summary of trip descriptor categories recorded by interviewers for boats returning to key boat ramps in East Northland, Hauraki Gulf, and the Bay of Plenty – all years combined.

Region	Ramp	Fishing (I)	Not fishing (O)	Not interviewed or refused (N or R)	Proportion fishing when interviewed
East Northland	Mangonui	2 695	778	522	0.78
	Opito bay	2 084	633	352	0.77
	Waitangi	3 510	1 844	507	0.66
	Tutukaka	2 076	925	742	0.69
	Parua Bay (public)	3 168	669	545	0.83
	Parua Bay (club)	3 084	473	1 102	0.87
	Mangawai	1 881	1 092	315	0.63
	Total	18 498	6 414	4 085	0.74
Hauraki Gulf	Sandspit	1 337	1 465	151	0.48
	Gulf Harbour	3 441	956	737	0.78
	Takapuna	5 940	2 700	2 476	0.69
	Westhaven	5 836	3 064	2 244	0.66
	Half Moon Bay	10 960	4 528	5 147	0.71
	Okahu Bay	2 222	1 128	835	0.66
	Te Kouma	3 365	20	255	0.99
	Total	33 101	13 861	11 845	0.70
Bay of Plenty	Whitianga	1 832	1 323	1 599	0.58
	Bowentown	2 555	892	731	0.74
	Sulphur Point	5 164	3 168	2 760	0.62
	Whakatane	2 692	326	4 108	0.89
	Total	12 243	5 709	9 198	0.68
Grand total		63 842	25 984	25 128	0.71

The boat ramp survey data used for this analysis are different from those used in the previous analysis (Watson & Hartill 2005) for the following reasons:

- Surveys conducted between December 2003 and April 2009 were added to the survey dataset, increasing the number of surveys considered to 12.
- Fishing year (October to September) was used and because of this the 1998 survey were split into fishing years 1997–98 and 1998–99, raising the number of fishing years considered to 13.
- Twelve month categories were used instead of 4 month categories (the months January to April) and a fifth combined 8 month category (May to December inclusive).
- Data were only used if the interviewer was present at the ramp for the full 60 minutes of each hour.
- Eight ramps were excluded from the 26 surveyed ramps, so data were only used from 18 consistently surveyed ramps for this analysis

Generalised linear modelling was used to determine which temporal and environmental variable best explained traffic rates at each boat ramp (Table 5).

Table 5: Summary of temporal and environmental variables used in the generalised linear modelling of recreational boat ramp traffic.

Variable	Type	Description
Fishing year	cat 13	1990–91, 1993–94, 1995–96, 1997–98, 1998–99, 2000–01,…2007–08
Month	cat 12	Oct, Nov, Dec, Jan, Feb, …, Sep
Day type	cat 2	Weekday, Weekend/Public holiday
Hour	cat 14	0400–0700, 0800, 0900, …,1800, 1900, 2000–2300
Wind speed	cat 4	0 to <11 knots, 11 to < 17 knots, 17 to < 22 knots, 22 knots plus
Wind direction	cat 2	Onshore, Offshore
Tidal state	cat 4	High, Outgoing, Low, Incoming

2.2 Web-camera data

Boat ramp traffic data have also recently become available from a second source; a network of web cameras established at six key boat ramps in QMA 1 (Table 6). Images collected from four of these cameras were interpreted to provide daily counts of the number of vessels returning to each ramp over a 12 month period between 5/12/2004 and 4/12/2005 (Hartill et al. 2007c). These data were used to optimise a temporally random stratified subsampling design and counts have been made of vessels returning to three boat ramps (one per region), on 60 randomly preselected days in all subsequent years (Figure 6). Images from a second boat ramp in the Hauraki Gulf (Half Moon Bay) have not been interpreted since December 2006.

The trends in boat ramp traffic seen in these web camera data are similar to those seen in the boat ramp data discussed in the previous section. Daily traffic rates peak over summer and autumn, and are usually higher on weekends and public holidays (Figure 5)

Although web camera imagery can be used to provide a count of the total number of vessels returning to a boat ramp over a full 24 hour period, the activity of these boats is unknown. An additional model was therefore required to determine the probability that each vessel fished, to convert daily web camera based vessel counts of all vessels (fishing or otherwise) into estimates of the number of fishing vessels that returned to the ramp on that day. The data used to determine the proportion of vessels fishing on a day were the boat ramp data described in the previous section, specifically the relative incidence of activity codes I and O (as summarised in Table 4).

Table 6: Number of days for which daily vessel count data are available by from four boat ramps, by month of the fishing year.

Region	Ramp	Fishing year	October	November	December	January	February	March	April	May	June	July	August	September	Total
East Northland	Waitangi	2004–05	–	–	31	31	28	31	30	31	30	31	31	30	304
		2005–06	31	30	31	5	4	8	7	4	3	3	3	3	132
		2006–07	9	5	6	5	5	8	6	4	3	3	3	3	60
		2007–08	8	4	8	2	4	5	6	4	2	1	2	4	50
		2008–09	8	5	7	5	4	8	7	3	–	–	–	–	47
Hauraki Gulf	Takapuna	2004–05	–	–	17	31	28	31	28	29	30	26	31	30	281
		2005–06	31	30	29	5	4	8	7	4	3	3	3	3	130
		2006–07	9	5	6	5	5	8	5	4	3	3	3	3	59
		2007–08	7	4	8	5	4	9	6	4	2	4	2	2	57
		2008–09	–	–	–	–	–	1	7	4	2	4	3	3	24
Bay of Plenty	Sulphur Point	2004–05	–	–	17	31	28	31	30	29	30	31	31	30	288
		2005–06	30	30	31	5	4	8	7	4	3	3	3	3	131
		2006–07	9	5	6	5	5	8	6	4	3	3	3	3	60
		2007–08	8	4	8	5	4	9	6	4	2	4	2	2	58
		2008–09	8	5	7	5	4	8	7	4	2	4	3	3	60

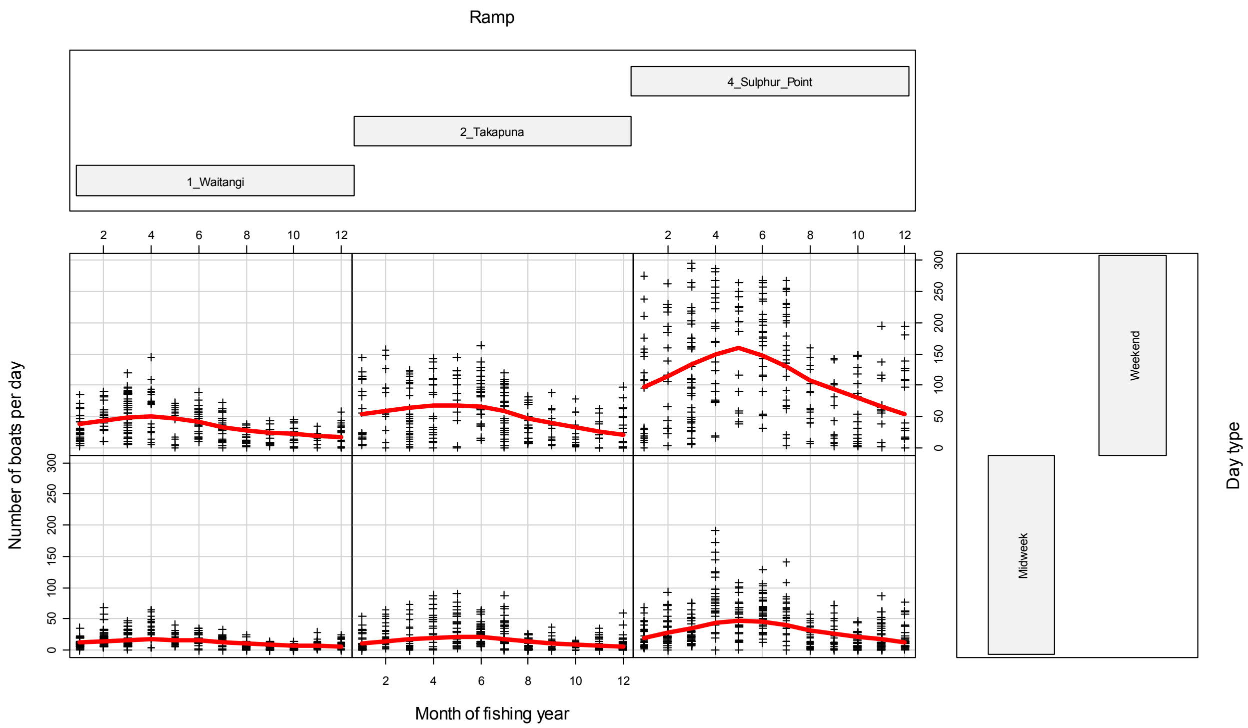


Figure 5: Number of recreational boats (fishing or otherwise) returning daily to boat ramps overlooked by web cameras, by month and day type. 1=October,…,4=January,..., 12=September.

2.3 Climate data

It is widely assumed that prevailing weather conditions can have a considerable influence on levels of recreational fishing effort. Watson & Hartill (2005) used Generalised Linear Modelling to assess the relative influence of a range of climate variables on fishing effort, and concluded that the main environmental determinants of effort were wind speed, wind direction and tidal state. The climate data sets used in the 2005 Bayesian traffic model were therefore updated to cover the period 1 October 1970 to 30 September 2009.

Wind speed and wind direction data were extracted from the National Climate Database (CLIDB), for the same weather stations considered in the previous study. Only a few stations have been maintained since 1970, however, and for the Bay of Plenty it was necessary to combine data from two sites to extend the available time series back as far as 1970 (Table 7). In the Hauraki Gulf, Auckland Airport data were used in preference to those from the Leigh Marine Laboratory station, as the latter is sheltered from the prevailing south/westerly winds. This was clearly evident when Leigh data were compared with those collected from other Hauraki Gulf sites. When environmental data were not available (e.g. Bay of Plenty wind speed data in the early 1970s), data from the Hauraki Gulf were used as a substitute.

Table 7: Data extracted from the National Climate Database that were used in an initial exploration of environmental variables likely to influence recreational fishing effort.

Environmental variable	Area	location	Date range
Daytime wind speed (0700 to 1900 hours)	East Northland	Whangarei Airport	01/01/70 to 31/12/91
		Whangarei Airport AWS*	01/01/92 to present
	Hauraki Gulf	Auckland Airport	01/01/70 to present
	Bay of Plenty	Whakatane Airport	30/11/74 to 30/05/90
		Tauranga Airport AWS*	31/05/90 to present
Daytime wind direction (0700 to 1900 hours)	East Northland	Whangarei Airport	01/01/70 to 31/12/91
		Whangarei Airport AWS*	01/01/92 to present
	Hauraki Gulf	Auckland Airport	01/01/70 to present
	Bay of Plenty	Whakatane Airport	30/11/74 to 30/05/90
		Tauranga Airport AWS*	31/05/90 to present

* Automatic Weather Station

Wind speed and wind direction data were considered at the daily scale, with average values calculated for daylight hours only (0700 to 2000). This approach was adopted as the timing of a boat returning to a boat ramp was considered a crude and lagged descriptor of the timing of fishing effort. Levels of boat ramp traffic are generally higher on days with lower average wind speeds, especially when the wind is offshore (Figure 6). Most of the interviewing that has occurred has taken place on days with low to moderate wind speeds

Tidal state was also considered to be a likely determinant of fishing effort, and hourly tidal predictions were generated from a NIWA Tide Model (Walters 1988). These hourly tidal estimates were then categorised into four tidal state bins of equal length. Hourly tidal state estimates and daily environmental variables were then linked to hourly estimates of boat ramp traffic. Tidal state appears to have little influence on traffic rates at surveyed boat ramps (Figure 7).

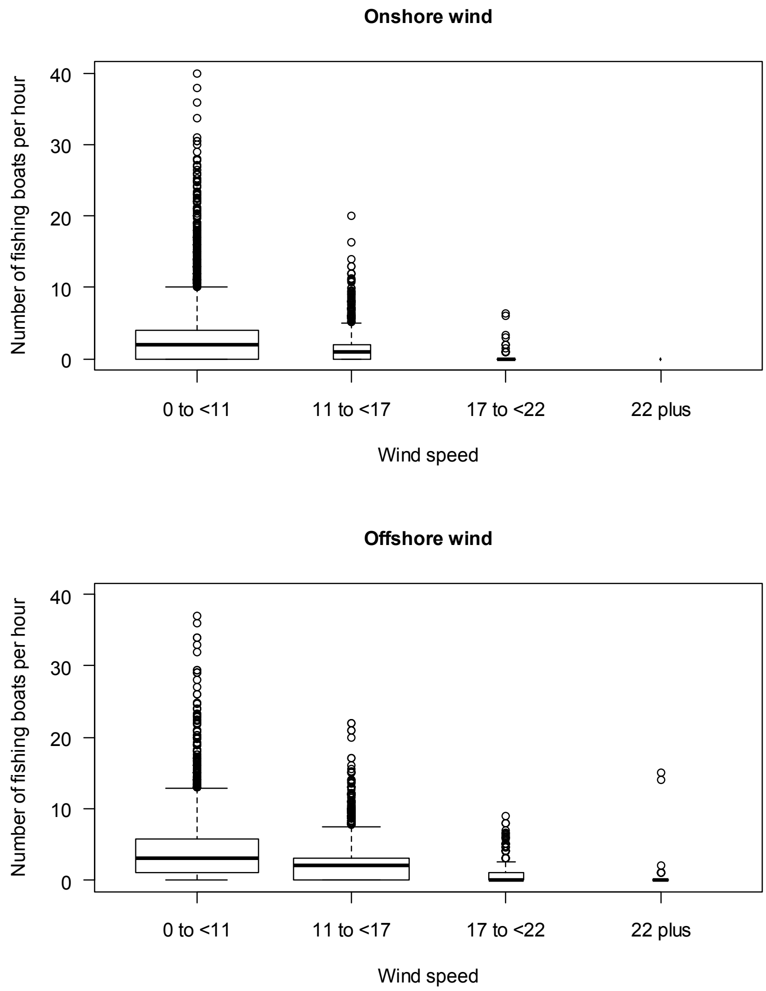


Figure 6: Number of recreational fishing boats encountered per hour of interviewing by wind speed category. The upper panel gives the distribution of hourly counts on days with onshore winds and the bottom panel gives the distribution of hourly counts on days with offshore winds

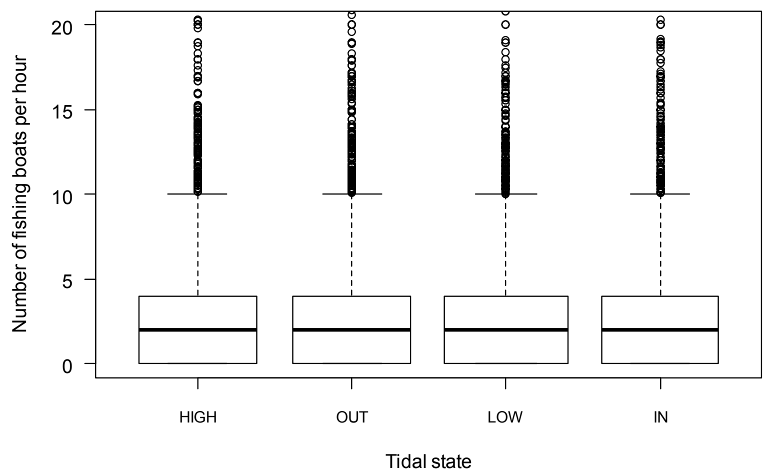


Figure 7: Number of recreational fishing boats encountered per hour of interviewing by tidal state. The y-axis is truncated at 20 boats per hour.

2.4 Population growth

Population growth is likely to be a key determinant of changes in fishing effort. National census data collected by Statistics New Zealand since 1970 were used to provide an index of population growth for each of the three regions considered in this model. As census data were collected on a five yearly basis, estimates in the intervening years were calculated by Statistics New Zealand, given annual statistics on births, deaths, and immigration. Main Urban Area classifications were used to describe population growth in each region, and these were: Northland for the East Northland fishery, Central Auckland for the Hauraki Gulf fishery, and South Auckland - Bay of Plenty for the Bay of Plenty fishery (MUAs, Figure 8). Annual population estimates for each region were then divided by the population in 1970, to provide an index of population growth (Figure 9). These regional indices of population growth were used for predictive purposes when deriving indices of fishing effort going back to 1970, as concurrent population abundance should be considered when modelling the tendency, and hence intensity, of fishing.

Figure 8: Statistical areas, Main Urban Areas and Secondary Urban Areas used by Statistics New Zealand when summarising census data.

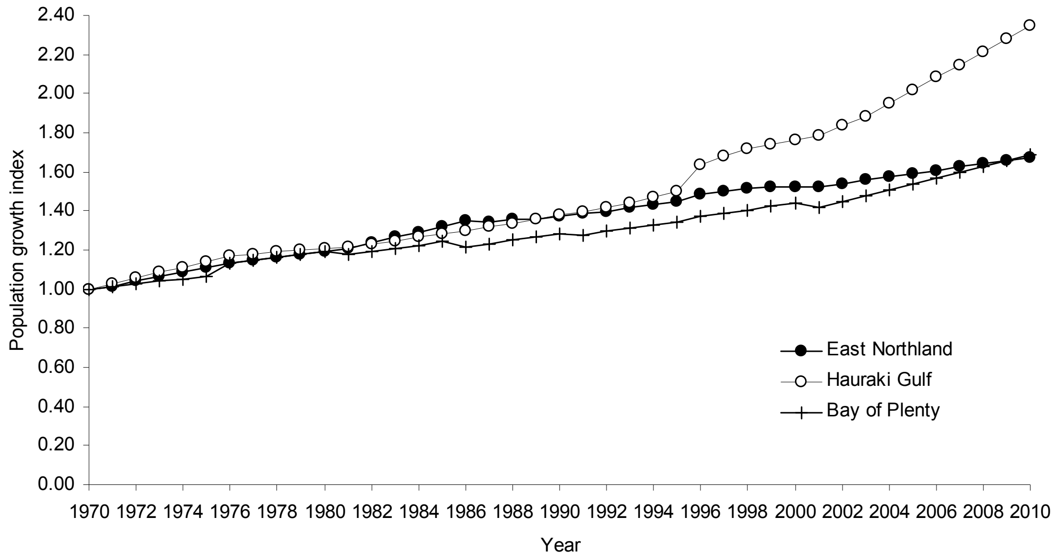


Figure 9: Indices of population growth in East Northland, the Hauraki Gulf and the Bay of Plenty since 1970.

3. METHODS AND RESULTS

3.1 General methods

The analytical methods used in this study are closely based on those used by Watson & Hartill (2005), which we will refer to from here on as the 2005 model. This approach is broadly based on Generalised Linear Modelling methods commonly used to generate standardised indices of catch per unit effort (CPUE) in which:

$$\mathrm{CPUE} = \exp[\mathrm{B} \bullet \mathrm{Z} + \mathrm{Y_t}]$$

where Z is a matrix of time-independent indicator variables, either continuous or categorical, that represent environmental conditions that may influence the catch, B a vector of estimated coefficients, and Y_t a vector of estimated categorical coefficients that represent the catch rate for each year t. This is generally referred to as a log linear model.

In this study we model relative changes in fishing effort in QMA 1 since 1970 given concurrent environmental, temporal, spatial, and social conditions. In particular, we use direct observations of the number of recreational fishing boats returning to a given boat ramp per hour, to estimate the number of trips per hour per capita. This measure of effort can be written as:

$$\mathrm{Effort} = \exp[\mathrm{B} \bullet \mathrm{Z} + \mathrm{Y_t} + \ln(\mathrm{P})_\mathrm{t}]$$

where B is as above, P_t the population, or population index, for each year t, and Y_t the recreational fishing effort (fishing trips) per unit population for each year t. We assume that Effort can be described by a Poisson distribution, and that the estimated coefficients, B and Y, on the right hand side of the above equation are normally distributed.

As in 2005, we used Bayesian hierarchical models implemented in WinBUGS version 1.4 (Windows Bayesian Inference Using Gibbs Sampling - Sturtz et al. 2005), because this approach is well suited to mixed effects modelling and can be used to interpret relatively sparse and unbalanced data sets such as those used here, in a statistically robust manner. This is an important consideration, because most of the boat ramp interview data available have been collected in a temporally non-random manner, and there is relatively little information on levels of effort during week days, in the winter and early spring, and on days when the weather is not conducive to fishing. The hierarchical structure of the Bayesian model overcomes these limitations by pooling data across similar combinations of explanatory variables, thereby improving the applicability of any results achieved. The amount and strength of this pooling effect is formally determined by the specification of priors and the amount of data available. When few data exist therefore, the pooling effect is stronger, and vice versa for when large amounts of data exist. One key assumption of this approach is that the data are in some way exchangeable, and some care has to be taken when determining sensible hierarchies.

The structure of the Bayesian models used in this study are closely based on that used by Watson & Hartill (2005), who initially used Generalised Linear Modelling to infer the relative influence of environmental and temporal variables on traffic rates observed at boat ramps during surveys conducted between 1991 and 2003. The most informative main effects identified from this exploration (in order of ranked significance) were: ramp, hour, wind speed, day type, month, tide, and wind direction. First order interaction terms were also considered in these analyses, most of which were considered in the hierarchical structure of the Bayesian model used by Watson & Hartill (2005) (see Appendix 1a).

The influence of regional population growth is also considered within these models because the size of the population of inhabitants in an area will have a direct effect on the number of fishing trips that take place in nearby waters. Population growth is therefore considered to be a likely explanatory variable which should be considered within the model. By estimating the per-capita level of fishing effort within the model, we are also able to use the predictions of this model to predict/project levels of fishing effort at other times when boat ramp survey data are not available, given the continual index of population growth derived from five yearly censuses conducted by Statistics New Zealand.

The structure of the Bayesian models used in this study and associated code can be seen in Appendices 1a, 2a, and 3a. The results of three Markov chains with randomly generated starting points were compared to evaluate the convergence of each model. The consistency of indices from these independent chains was used to evaluate how well the three chains converged (Francis 2006).

3.2 Alternative modelling of two sources of information on recreational effort

The 2005 model used boat ramp data collected between 1991 and 2003 to predict changes in levels of recreational fishing effort in East Northland, the Hauraki Gulf, and the Bay of Plenty since 1970. This Poisson distributed model has now been updated to include boat ramp data that has since been collected between December 2003 and April 2009 (see Tables 1 and 2). The measure of effort considered in this model was the number of recreational boats that had fished and returned to a given ramp during a given hour. We refer to this model from here on as the *interview model*.

Data from two sources were used to derive effort indices from a second source of data; web camera counts of boats returning to four key ramps in QMA 1. Additional modelling of boat ramp data were also required to determine the proportion of these boats that would have been fishing, as some of the boats observed on web camera imagery would have been used for purposes other than fishing. The *camera count* and *proportion fishing* sub-models are collectively referred to as the *camera model*.

The methods and results of these two alternative approaches will be considered in turn, followed by a comparison of the regional effort indices produced by these models.

3.3 The interview model

This Bayesian model was run for 110 000 iterations, including a burn in interval of 10 000 iterations. The following 100 000 iterations were thinned by a factor of 10 to provide a posterior sample of 10 000 estimates for each effect. All estimated temporal and environmental effects, except those relating to regional rates of change in effort per capita per hour, are represented in canonical indices (Francis 1999).

The annual indices of effort derived from this model (Figure 10) are very similar to those obtained in the previous 2005 model. Subtle differences are mostly due to the fact that the definition of year used in the 2005 model ran from December to November in the following year, whereas the definition used in this model is based on the fishing year (October to September).

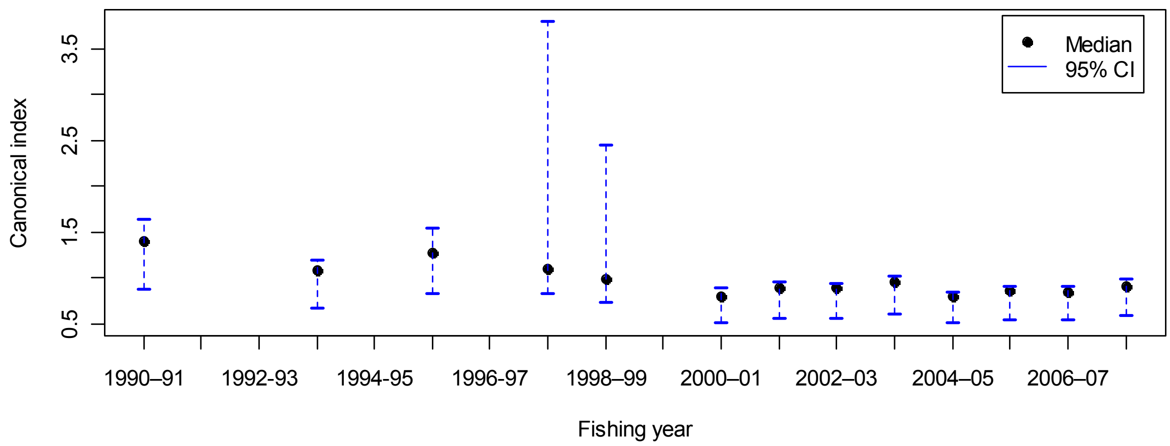


Figure 10: Canonical year effects predicted by the *interview model*.

This standardised index suggests that there appears to have been little if any change in levels of fishing effort since 1990–91. This is because the model predicts a gradual decline in the per capita tendency to go fishing in all three regions, when all other environmental effects including population growth are taken into account (Figure 11). These regional rate estimates are based on the slopes of linear projections of the per capita tendency to go fishing over time. These estimates suggest that there has been a slight decline in the tendency of inhabitants of the Bay of Plenty to go fishing since 1990–91, with a more pronounced decline in East Northland, and to a greater extent, in the Hauraki Gulf.

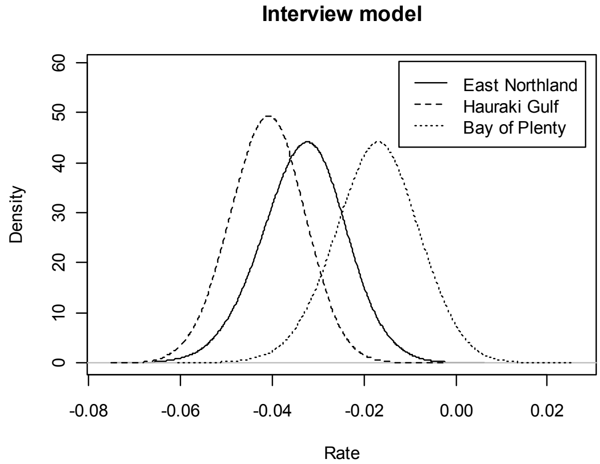


Figure 11: Annual change in the per capita tendency to go fishing by region, as predicted by the *interview model*.

In 2005 it was necessary to combine the months of May to December into a single categorical bin, because of the limited amount of data available over this eight month period (generally considered winter-like in terms of the amount of fishing activity). The inclusion of boat ramp data collected since December 2003 as part of this model has meant that far more information has become available for the winter months, and it is now possible to estimate a standardised index of fishing effort for every month of the fishing year (Figure 12). Predictably, this index shows that fishing effort is highest between January and April, and lowest during the winter, in July and August.

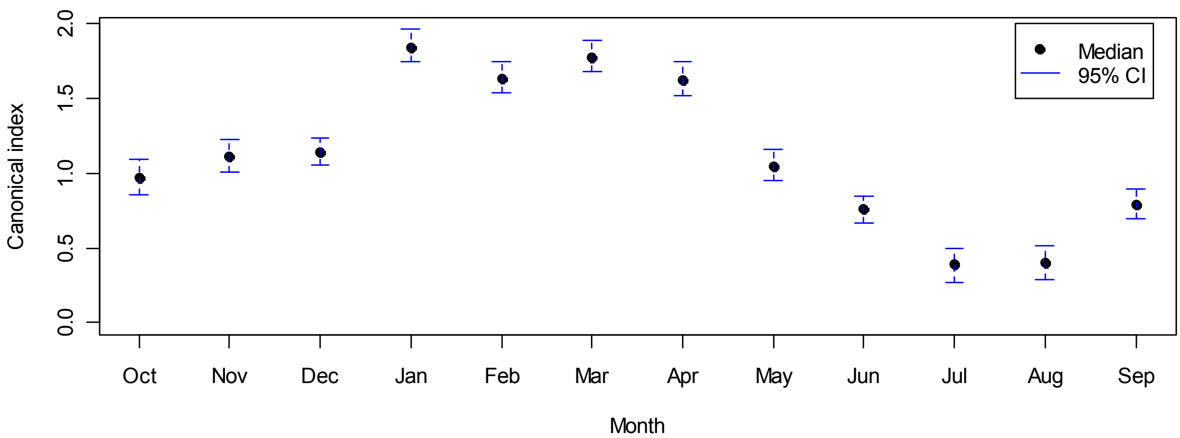


Figure 12: Month effects predicted by the *interview model*.

The standardised ramp effects seen in Figure 13 are broadly similar to those seen in the box plots of unstandardised traffic rates at each ramp, as shown in Figure 2. The rate at which recreational fishing boats return to boat ramps is usually lower at ramps in East Northland and higher in the Bay of Plenty, given temporal and environmental influences.

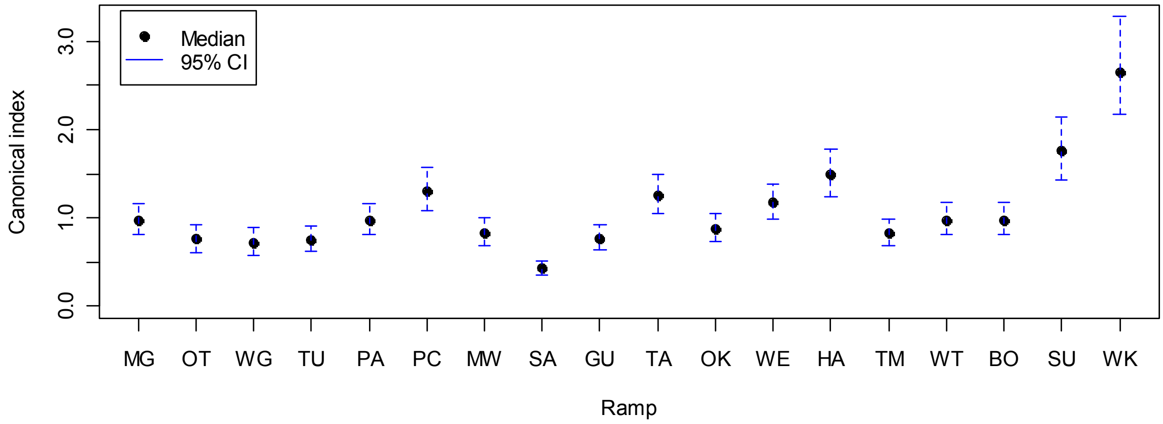


Figure 13: Ramp effects predicted by the *interview model*.

The hour effects estimated for midweek (MW) and weekend/public holiday (WE) days differ significantly (Figure 14). The number of fishing boats returning to surveyed ramps per hour was predicted to be far higher on weekends and public holidays than during the working week. The predicted rate at which midweek fishers return to surveyed ramps peaks in the evening, whereas weekend/public holiday traffic rates appear to increase steadily from early morning, reaching a peak at around 1500 in the afternoon. Changes in the timing of dusk throughout the year and the impact that this has on the shape of diurnal profiles of effort are only considered indirectly, as month effects.

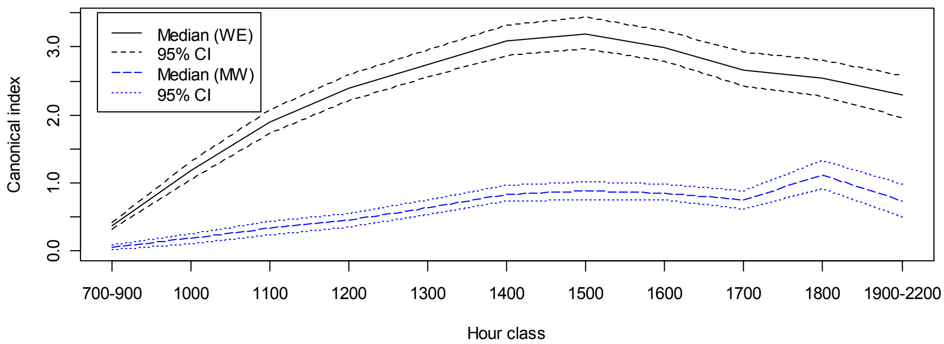


Figure 14: Hour effects for midweek (MW) and weekend/public holiday (WE) days predicted by the *interview model*.

Environmental effects on fishing effort are shown in Figure 15. Tidal state appeared to have little influence on the rate at which vessels returned to boat ramps. Predicted wind speed effects show that levels of fishing effort decline significantly with increasing wind speed. The confidence intervals associated with the effect for wind speeds in excess of 22 knots are comparatively broad because of the limited number of observations available. Although boat ramp traffic rates are predicted to be higher on offshore wind days than on onshore wind days, the relative magnitude of this difference is small relative to that seen between wind speed effects.

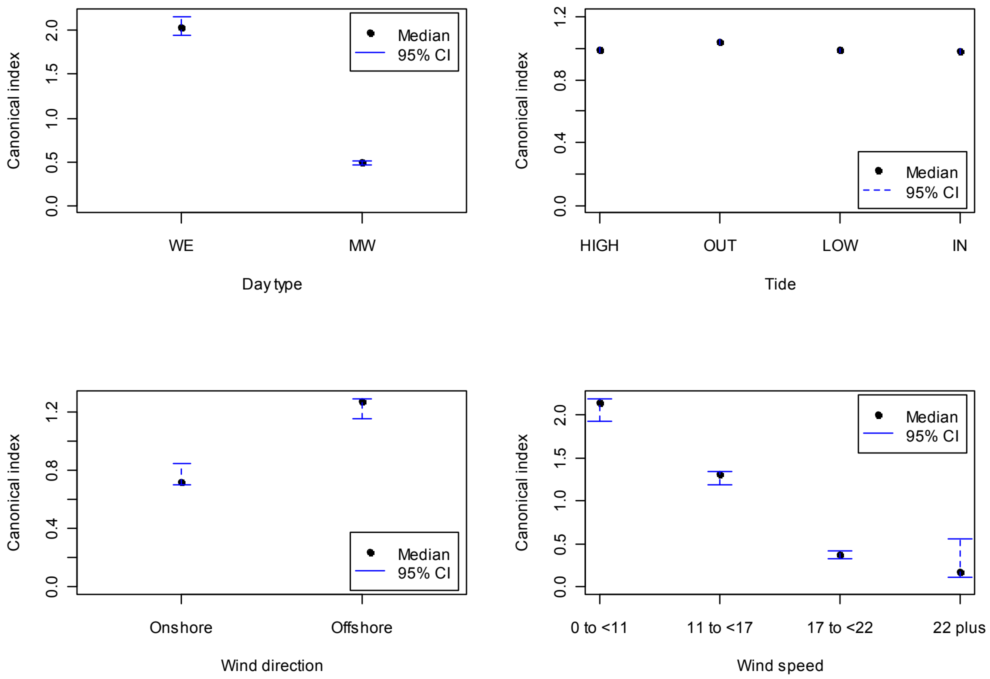


Figure 15: Canonical day type (top left), tide (top right), wind direction (bottom left), and wind speed (bottom right) effects predicted by the *interview model*.

The degree of convergence achieved by this model was assessed by comparing the cumulative distribution of estimates produced by three independent MCMC chains as seen in Francis (2006). Cumulative probability distributions for a selection of estimated effects are given for the following categories, the 1990–91 fishing year, 1500 hours on weekend days, the month of June, the Sulphur Point ramp, the wind speed category 0 to 11 knots, and weekend days (Figure 16). The high degree of overlap between the three distributions shown on each cumulative distribution plot suggests that the model converged sufficiently after a burn in period of 10 000 iterations.

An overview of the results of these convergence trails, for a wider range of effects is given in Appendix 1b.

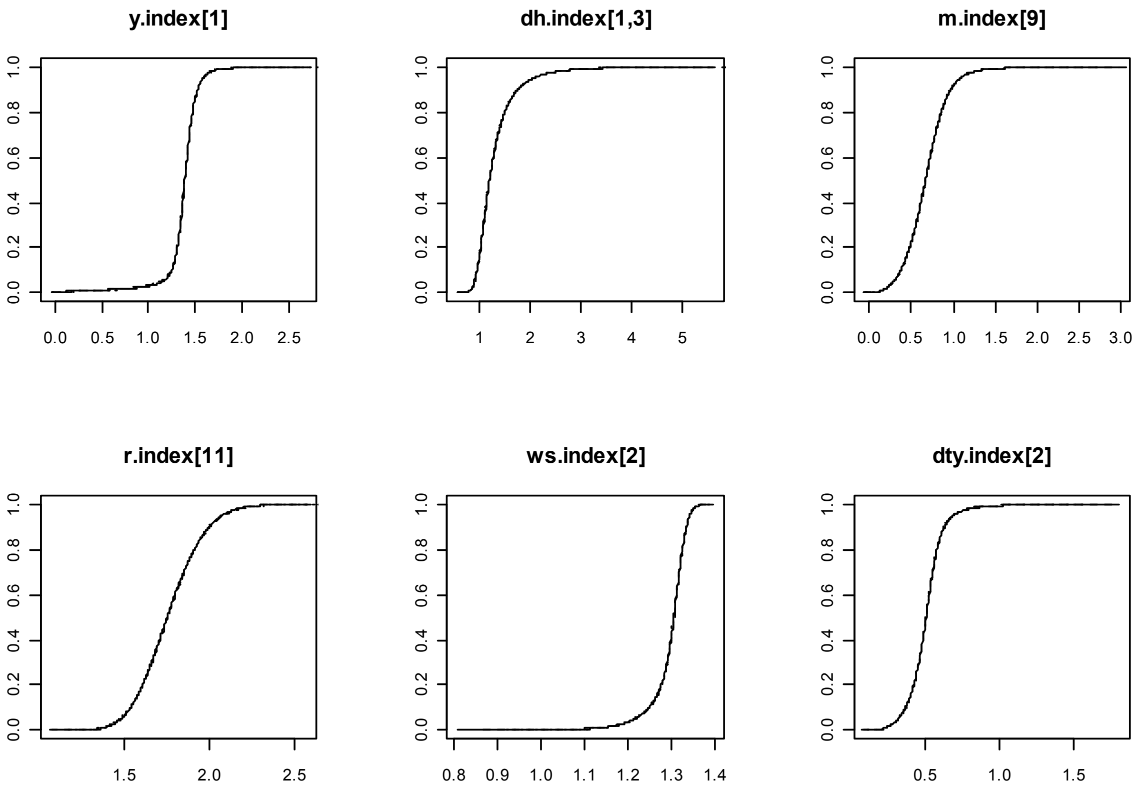


Figure 16: Cumulative probability distributions for three *interview model* runs for: a fishing year effect, a time of day effect, a month effect, a boat ramp effect, a wind speed effect, and a day type effect.

3.3.1 Long term projection of interview model effects

A C++ simulation model developed by Watson & Hartill (2005) was then used to combine daily regional climate records and regional indices of population growth with the estimated effects described above, to predict daily fishing vessel ramp traffic at surveyed boat ramps for the period 1970 to 2009. Estimates of uncertainty associated with these predictions are based on a further tenfold thinning of the 10 000 samples obtained from posterior samples generated for each effect.

During a review of the code used in this simulation model we found that the population growth rate term had been duplicated by mistake and this error has now been corrected. The number of fishing boats N_f returning to ramp r on day d in month m of year y was calculated as follows

$$N_f = [1 + \sigma \cdot (y - y_0)] \cdot e^{r+d+m+w_s+w_d} \cdot p \cdot h \cdot \rho$$

where σ is the annual change rate of N_f; y_0 is the reference year (2008), and r, d, m, w_s and w_d are the estimated effects for ramp, day type, month, wind speed and wind direction respectively; p is the regional index of population growth for the region where ramp r is located; h is the number of hour classes; and ρ is a ratio used to correct for seasonal changes in day length, calculated by

$$\rho = \begin{cases} 1 & \text{if } h_d \le h \\ h_d / h & \text{if } h_d > h \end{cases}$$

where h_d is the daylight hours on a day, h is the actual hour of each hour bin. In the previous 2005 model ρ was calculated as

$$\rho = h / h_d \text{ when } h_d > h .$$

Tidal effects were not considered in this simulation because they were not significantly different from each other (see Figure 15).

It should be noted that this prediction is for the total number of boats, N_f, in a given time interval and includes the effect of any population increase or decrease, and the estimated per capita change in the tendency to go fishing.

Regional indices of recreational effort were obtained by summing up the predictions of N_f for all days within a month or year, across all ramps within each region, which we assumed were representative of the population of ramps within each area. These indices should be regarded in a relative sense, as the proportion of effort returning to surveyed versus unsurveyed ramps is unknown.

The indices of recreational fishing effort derived from individual year effects and from the longer term projections provided by the C++ simulation model show similar trends for each region (Figure 17). These indices suggest that there has been a slight decline in recreational fishing effort in East Northland since the mid 1990s, but that there has been little relative change in Hauraki Gulf and the Bay of Plenty since 1970. The most marked discrepancy between the long term trend and estimates derived from individual year effects is in the Bay of Plenty, where predictions from the year effects for the years 2006–07 and 2007–08 are much higher. Levels of interannual variability in long term fishing effort indices in East Northland and the Hauraki Gulf are more variable than in the Bay of Plenty, where weather conditions are more consistent from year to year.

The long term trends in all three regions are markedly flatter than those predicted in 2005. These differences are mostly due to the fact that in the 2005 model the regional population growth rate terms were applied twice by mistake.

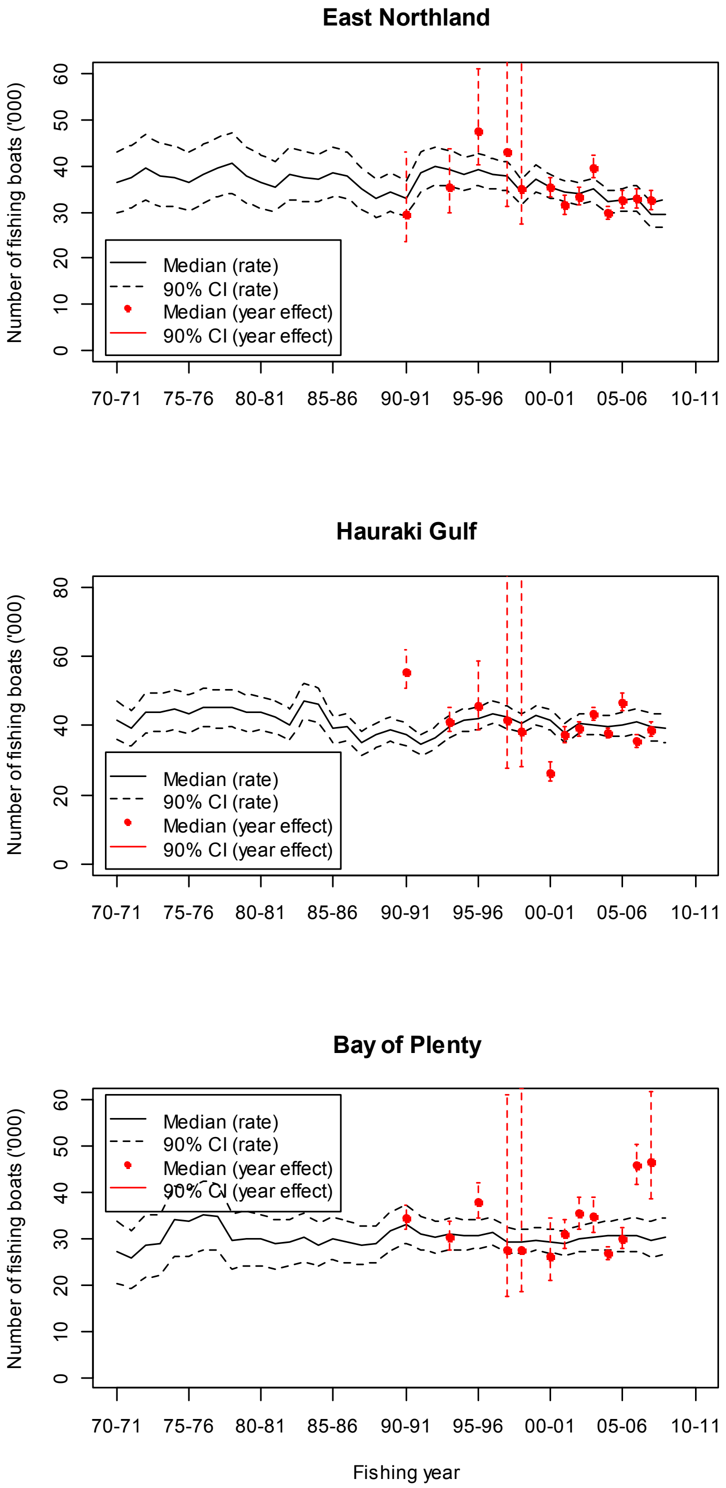


Figure 17: Regional indices of recreational fishing effort derived from projections of effects estimated by the *interview model*. Estimates for individual years with error bars are predictions derived solely from the *interview model* and the continual indices are long term projections based on simulations created using the C++ code.

Seasonal trends in fishing effort are clearly evident when monthly indices of fishing effort are calculated for each region (Figure 18).

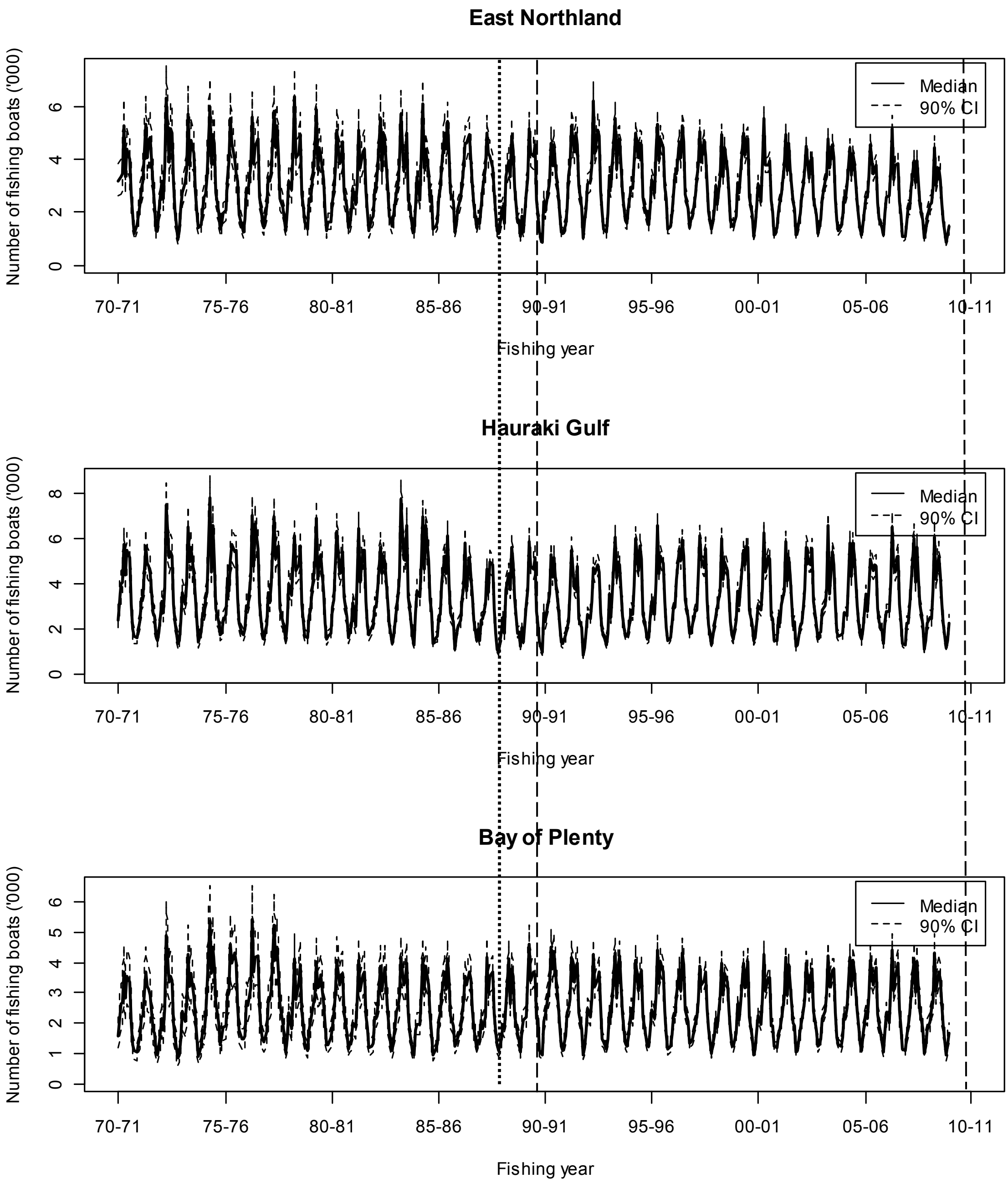


Figure 18: Seasonal trends in fishing effort for three regions of QMA 1 for the period 1 October 1970 to 30 September 2009. The dotted line denotes the timing of cyclone Bola (in March 1988), and the dashed lines denote the period over which boat ramp data were collected and used in this model.

3.4 The camera model

This model combined the results of two independent Bayesian sub-models to estimate changes in recreational fishing effort since 1970. The first of these sub-models was a Bayesian model of web camera based counts of the number of recreational vessels returning daily to four boat ramps in QMA 1 between December 2004 and October 2009 (see Table 6). We refer to this sub-model from here on as the *camera count sub-model*.

These daily vessel counts only provide a loose measure of recreational fishing effort, however, because an unknown proportion of the boats observed returning to a given ramp on a given day will have been used for purposes other than fishing. A further associated binomial model was therefore required to predict the proportion of vessels that would have been fishing on these days. The data used for these predictions were boat ramp data on the reported activity of fishing parties interviewed during the same boat ramp surveys considered in the *interview model*. The structure of this model, hereafter referred to as the *proportion fishing sub-model* is closely based on that used in the *interview model*.

The combination of predicted effects from these two sub-models were then combined in a *camera model*, to provide regional indices of the number of boats that had been fishing using C++ simulation code similar to that used to provide a long term index for the *interview model*.

3.4.1 The camera count sub-model

Web camera based counts of the number of recreational vessels returning daily to one boat ramp in East Northland, two boat ramps in the Hauraki Gulf, and one boat ramp in the Bay of Plenty between December 2004 and October 2009 were modelled using a structure closely based on that used for the *interview model* (compare Appendices 1a - *interview model* structure, and 2a - *camera count sub-model* structure).

This model was run for 200 000 iterations, including a burn in period of 100 000 iterations. The length of the burn in period for this model was much longer than the other models because it was slow to converge. The following 100 000 iterations were thinned by a factor of 10 to provide a posterior sample of 10 000 estimates for each of the estimated effects. All estimated temporal and environmental effects, except for those relating to regional rates of change in effort per capita per hour, are represented in the following canonical plots.

The year effects for the five fishing years that the web cameras have been in operation were of a similar magnitude, with overlapping confidence intervals (Figure 19). The medians of the posterior distributions for regional estimates of annual rates of change were very close to 0, especially in the Bay of Plenty.

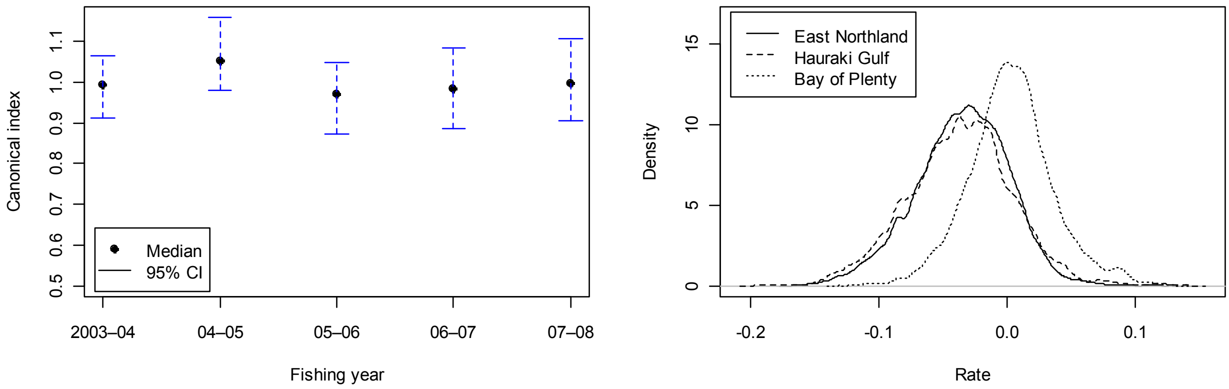


Figure 19: Canonical year effects and estimates of annual rates of change in the per capita tendency to go boating by region predicted by the *camera count sub-model*.

The relative differences between the ramp effects estimated by this sub-model are broadly similar to those seen in the *interview model* (see Figure 13), with daily traffic levels at Sulphur Point (SU) being higher on average than at Half Moon Bay (HA), and far higher than at Takapuna (TA) and Waitangi (WG) (Figure 20).

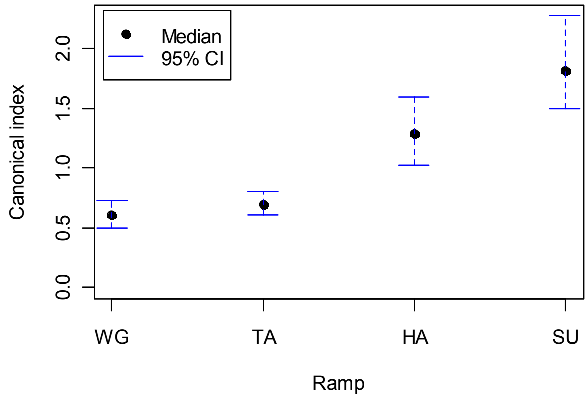


Figure 20: Canonical ramp effects predicted by the *camera count sub-model*.

The remaining month, day type, wind direction and wind speed effects obtained from the *camera count sub-model* all show patterns broadly similar to those seen on the *interview model* (Figure 21). Boat ramp traffic rates generally higher between late spring and early autumn, on weekends and public holidays, when the wind is offshore and when wind speeds are low.

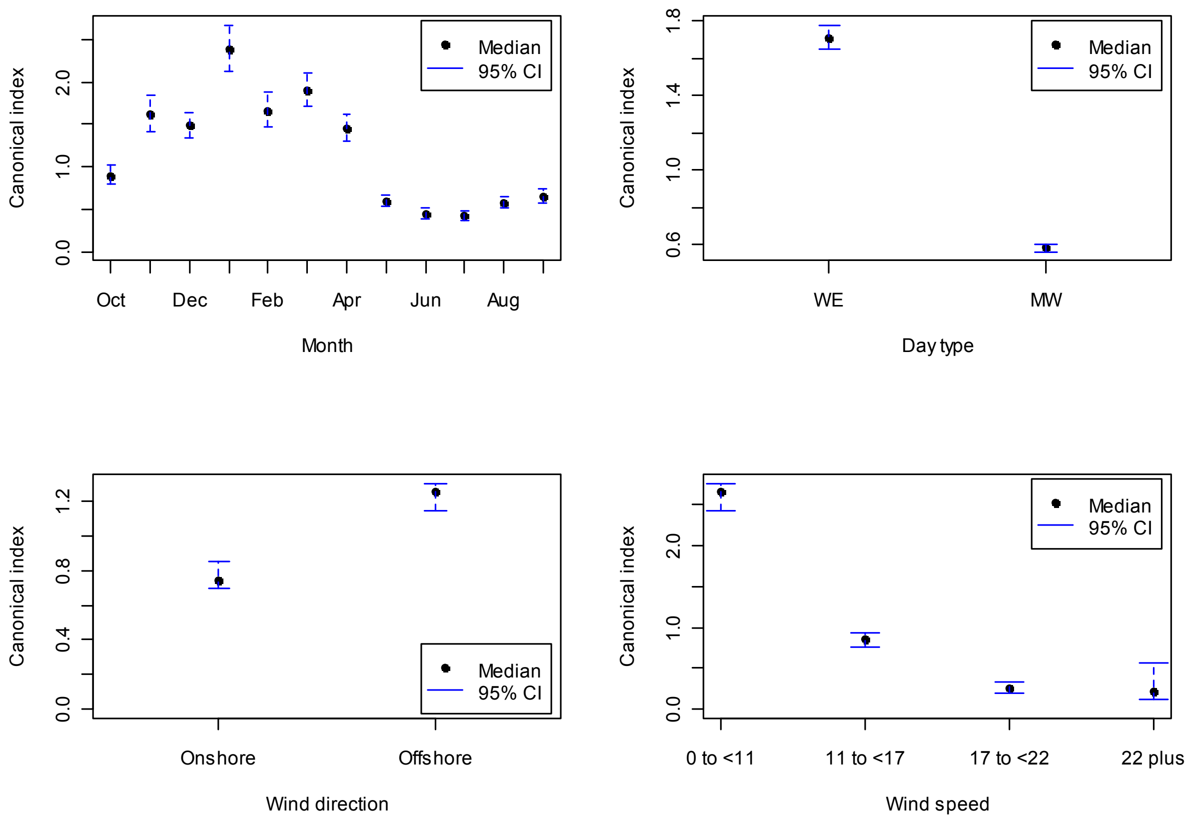


Figure 21: Canonical month (top left), day type (top right), wind direction (bottom left), and wind speed (bottom right) effects predicted by the *camera count sub-model*.

Cumulative probability distributions for a selection of estimated effects are given for three separate MCMC chains, for the following categories, the 1990–91 fishing year, 1500 hours on weekend days, the month of June, the Sulphur Point ramp, the wind speed category 0 to 11 knots, and weekend days (Figure 22). The high degree of overlap between the three distributions shown in plot suggests that the model has converged sufficiently after a burn in period of 10 000 iterations. An overview of the results of these convergence trails is shown for a wider range of effects in Appendix 2b.

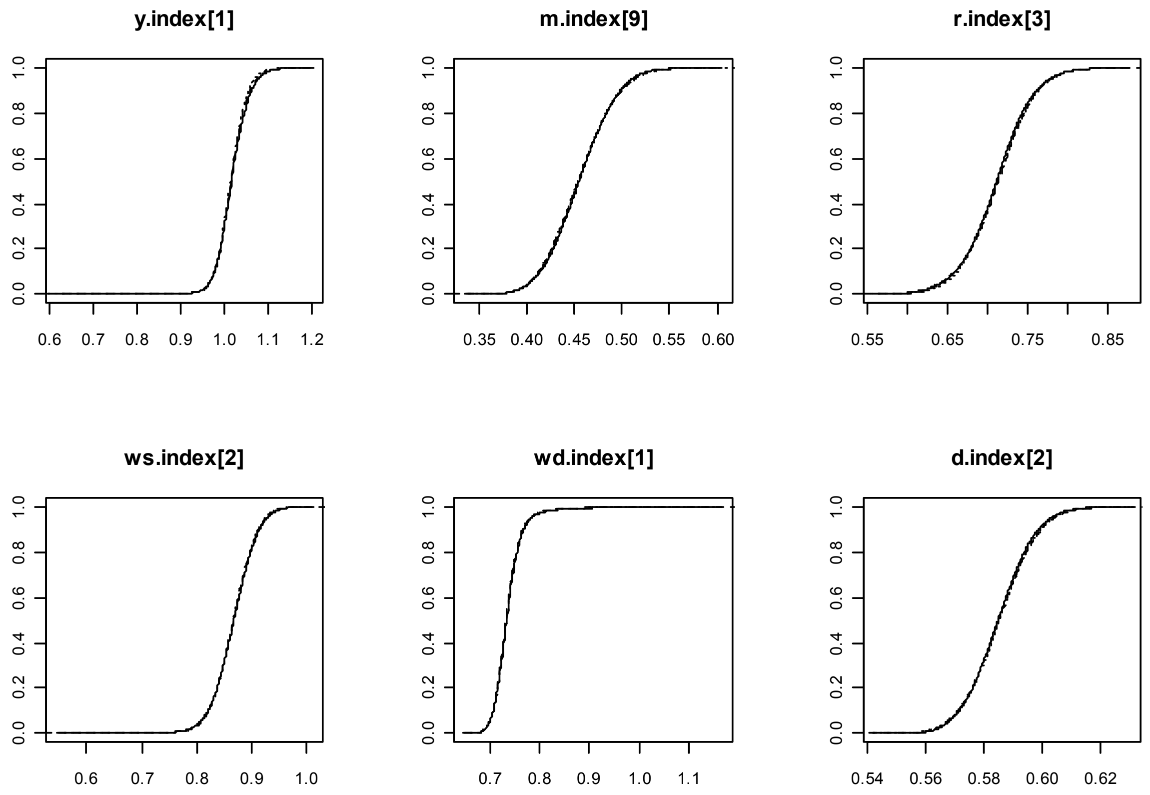


Figure 22: Cumulative probability distributions for three *interview model* runs for: a fishing year effect, a time of day effect, a month effect, a boat ramp effect, a wind speed effect, and a day type effect.

3.4.2 The proportion fishing sub-model

Boat ramp interview based data on the activity of encountered boats was used to estimate the daily proportion of boats observed by web cameras that would have been used for fishing. Although binomial modelling was used, the structure of this model was once again closely based on that used in the *interview model* (compare Appendices 1a - *interview model* structure, and 3a – *proportion fishing sub-model* structure).

This model was run for 110 000 iterations, including a burn in period of 10 000 iterations. The following 100 000 iterations were thinned by a factor of 10 to provide a posterior sample of 10 000 estimates for each of the estimated effects. All estimated temporal and environmental effects, except those relating to regional rates of change in effort per capita per hour, are represented in the following plots. The temporal and environmental effects estimated by this model were not transformed to canonical indices and directly reflect how the fishing boat probabilities were influenced by temporal and weather conditions.

The variation in annual estimates of the proportion of boats fishing was low relative to the width of associated 95% confidence intervals (Figure 23). The median of the posteriors for annual rates of change in the proportion of boats fishing in East Northland and Bay of Plenty were close to zero, but in the Hauraki Gulf it is estimated that the proportion of trips associated with fishing has gradually declined.

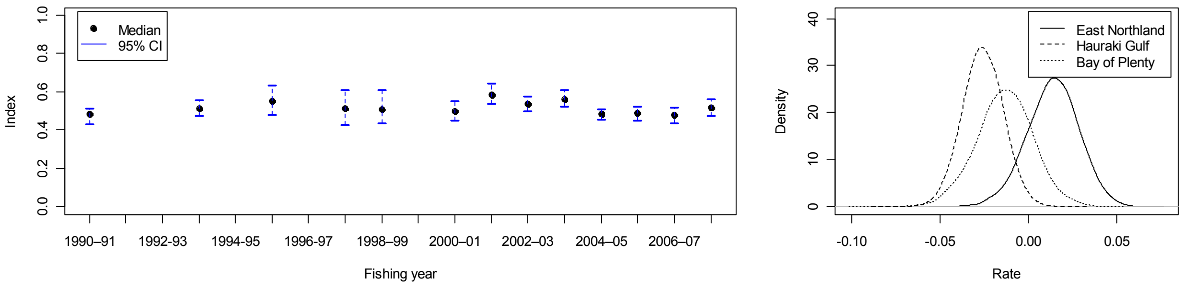


Figure 23: Year effects (left) and estimated regional annual rates of change in the proportion of boats used for fishing as predicted by the *proportion fishing sub-model* (right).

Predictions of the proportion of boats fishing at each ramp differ markedly, despite large confidence intervals (Figure 24). The proportion of boats fishing was predicted to be very high at Te Kouma (TM) which is a popular departure point for fishers who fish in and around the Coromandel mussel farms. The low proportion at Sandspit (SA) may be because long and short term residents of Kawau Island launch their boats at this ramp. Ramp effects for the four ramps overlooked by web cameras (WG, TA, HA, and SU) are in the middle of the range estimated for all ramps.

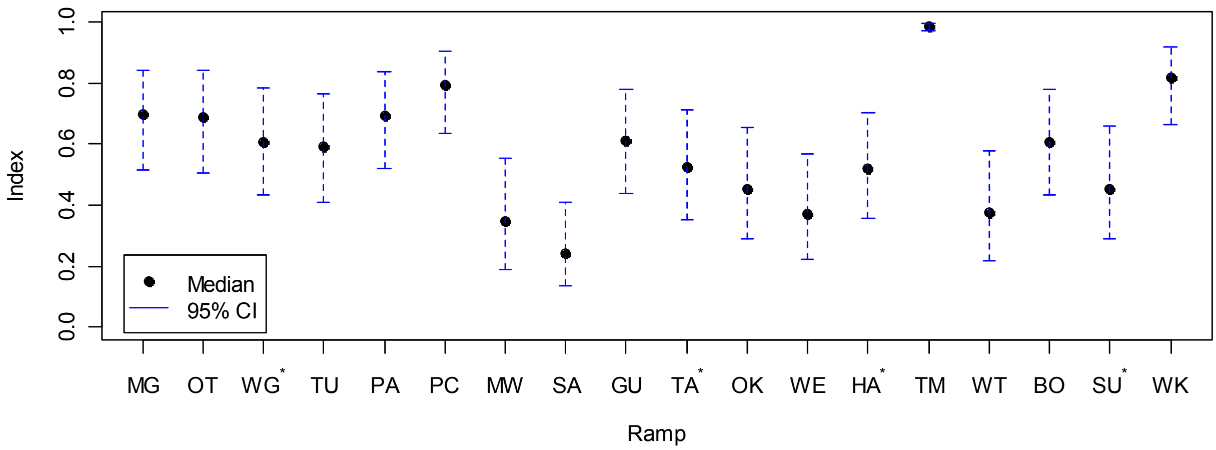


Figure 24: Ramp effects predicted by the *proportion fishing sub-model*. Ramp codes marked with an asterisk are for those boat ramps overlooked by a web camera.

There is relatively little contrast in most of the remaining effects. Although there is a seasonal trend in the month effects, the degree of variation between effects is less marked than in other models. The proportion of boats that are fishing is greatest in April and lowest in January (Figure 25). There was a significant difference between the day type effects with a higher proportion of boats predicted to be fishing on weekend days than during the midweek. Although there was little diurnal trend in weekend hour effects, an increasing proportion of the mid week boats went fishing as the day progressed. There was very little if any contrast in the tidal and wind direction effects, although there is a suggestion that a higher proportion of boats are used for fishing on days with low winds.

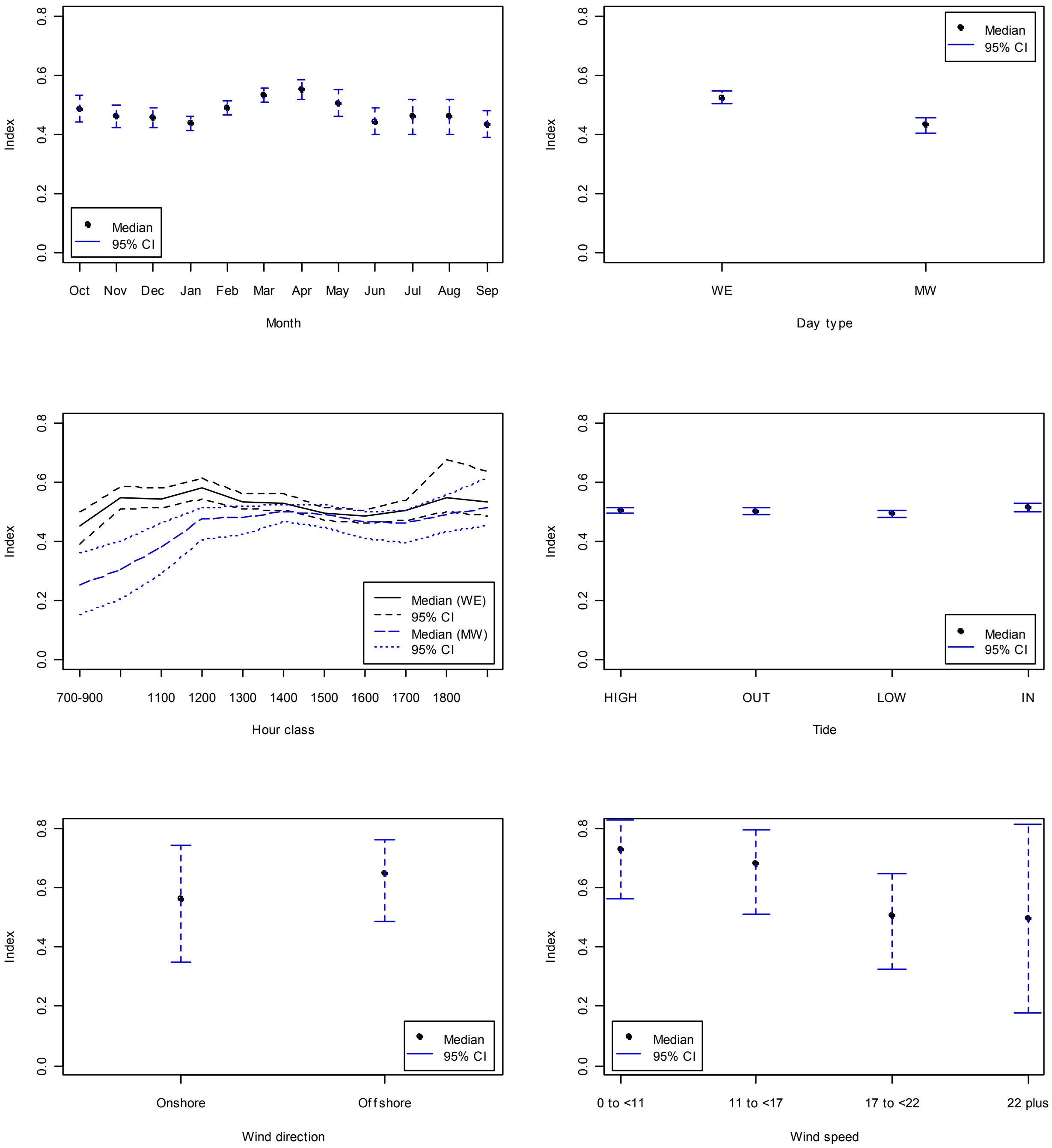


Figure 25: Month (top left), day type (top right), hour (mid left), tide (mid right), wind direction (bottom left), and wind speed (bottom right) effects predicted by the *proportion fishing sub-model*.

There is considerable overlap between the distributions for estimated effects obtained from three independent model runs, although slight differences were evident for some effects (Figure 26). These results suggest that a reasonable degree of convergence has been achieved after a burn in period of 100 000 iterations.

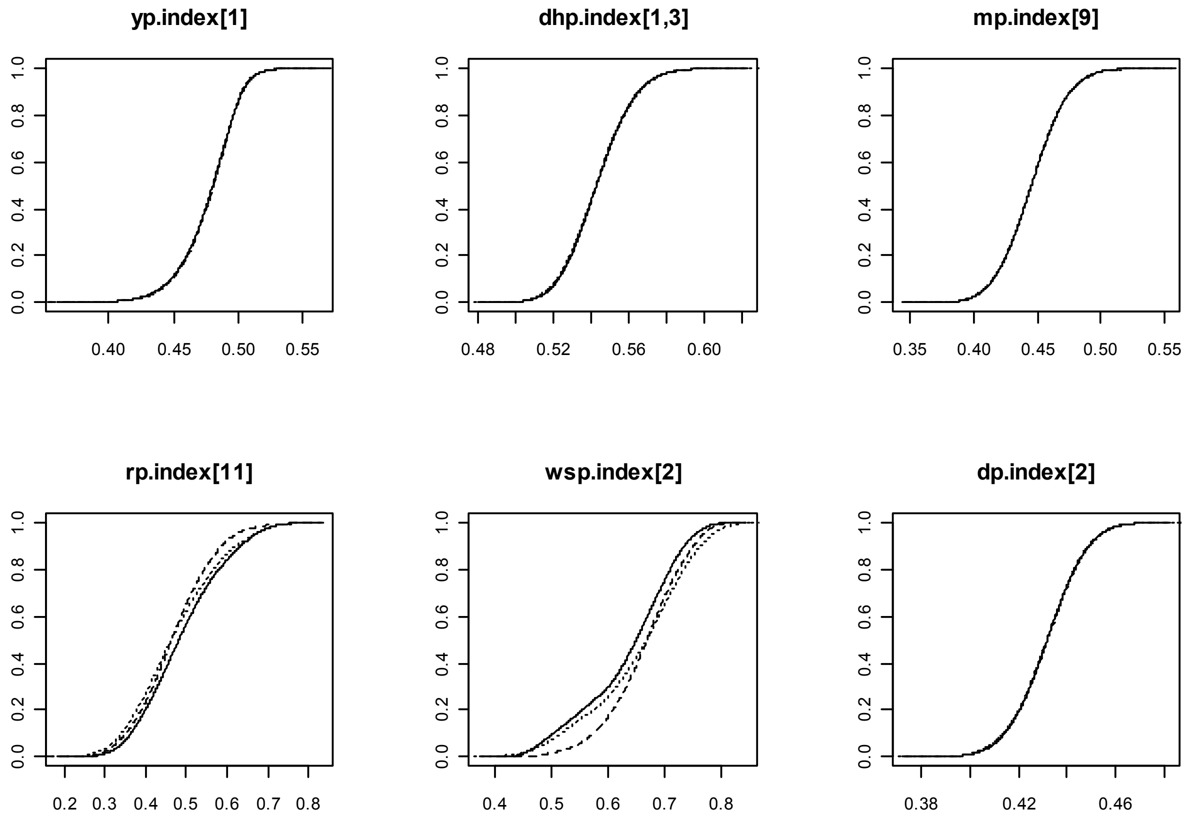


Figure 26: Cumulative probability distributions for three *interview model* runs for: a fishing year effect, a time of day effect, a month effect, a boat ramp effect, a wind speed effect, and a day type effect.

3.4.3 Combining effects from camera sub-models and projecting back to 1970

The C++ simulation code used to predict daily levels of fishing boat traffic between 1970 and 2009, based on environmental data and effects estimated by the *interview model* (see Section 3.3.1), was used again, to provide separate projections of effects estimated by the *camera count* and *proportion fishing* sub-models over the same period.

The projection of effects estimated from the *camera count sub-model* to predict the number of boats (fishing or otherwise) N_b returning daily to a given ramp *r* on a given day *d* was calculated as

$$N_b = [1 + \sigma \cdot (y - y_0)] \cdot e^{r+d+m+w_s+w_d} \cdot p$$

where *r* is a ramp effect, *d* is a day type effect, *m* is a month effect, w_s is a wind speed effect, and w_d is a wind direction effect, and *p* is the population growth index for the region in which a ramp is located. Samples were drawn from the posterior distribution for each effect given the daily incidence of each categorical state during the period assessed.

Daily predictions of the proportion of these boats that would have been fishing were calculated given samples drawn from the posterior distributions generated by the *camera count sub-model*, as follows

$$P_f = \text{logit}^{-1}[\sigma \cdot (y - y_0) + r + d + m + w_s + w_d]$$

where r is a ramp effect, d is a day type effect, m is a month effect, w_s is a wind speed effect, and w_d is a wind direction effect.

The prediction of the number of fishing boats on that day N_f was the product of the daily predictions from these simulations.

$$N_f = N_b \cdot P_f$$

Long term trends in fishing effort were calculated by summing daily predictions of the number of boats fishing within each fishing year. Estimates of uncertainty associated with these predictions were based on 1000 samples drawn from the posterior distributions for each effect.

The utility of the indices generated from both the *camera count sub-model* and the *proportion fishing sub-model* appears to be very limited. Although the trend seen in individual year effects generated by the *camera count-sub model* appears to follow the same trajectory as the long term trend, the level of uncertainty evident in the projection of effects back to 1970 is unacceptably large (Figure 27, left panels). This is perhaps not surprising given the fact that web camera count data are only available for a five year period between December 2004 and September 2009.

Estimates of the proportion of boats fishing during surveyed years (year effects) are highly variable, and this variability is not evident in the long term trend (Figure 27, right panels). This is either because estimated year effects are poor predictors of the proportion of boats that have fished, or because long term estimates of the average rate of change in the proportion of boats that are fishing do not reflect short term fluctuations in these proportions. In either case the predictions of the *proportion fishing sub-model* cannot be used to reliably convert web camera based counts of all recreational boats (fishing or otherwise) into counts of fishing boats.

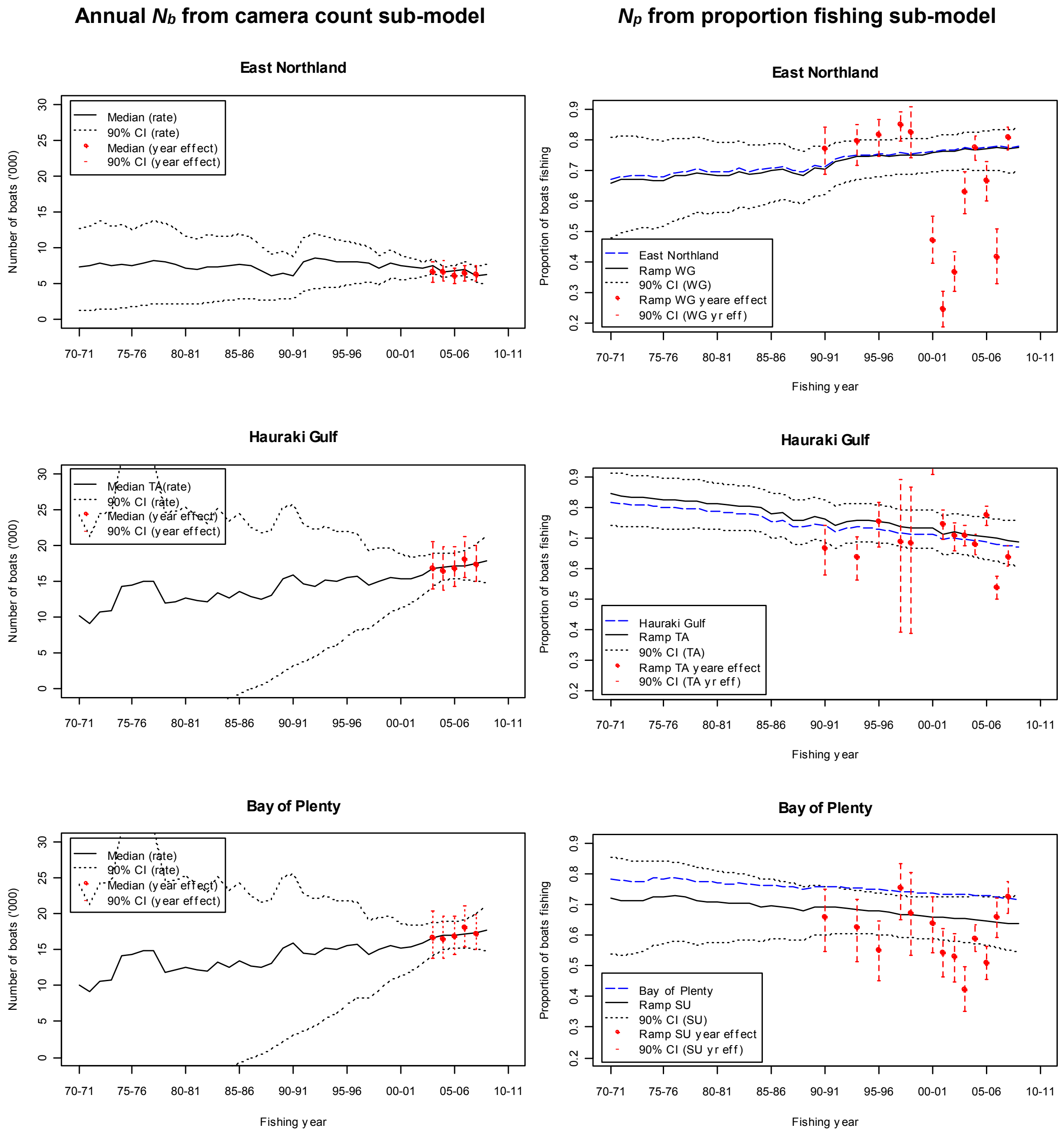


Figure 27: Predicted annual number of boats returning to the Waitangi boat ramp (WG) in East Northland (top left), the Takapuna boat ramp (TA) in the Hauraki Gulf (left), and the Sulphur Point boat ramp (SU) in the Bay of Plenty (bottom left); and predicted proportion of boats that were fishing in East Northland and at WG (top right), in the Hauraki Gulf and at TA (right), and in the Bay of Plenty and at SU (bottom right).

3.5 Comparing effort indices generated from the interview and camera models

Long term indices of recreational fishing effort derived from the *interview model* and from the *camera model* (*camera count sub-model* and *proportion fishing sub-model* indices combined) are compared for each region in Figure 28. The long term decline in fishing effort predicted by the *interview model* for East Northland is not predicted by the *camera model* which suggests that there has been no change in the level of effort over time. Both models predict that levels of effort in the Hauraki Gulf have remained relatively static, but in the Bay of Plenty the *camera model* suggests a gradual increase in effort which is not evident in the *interview model* index.

The indices derived from the camera model are thought to be less reliable than those derived from the interview model, however, because web camera data are only available for a relatively short and recent five year period, which provides only limited insight into long term trends.

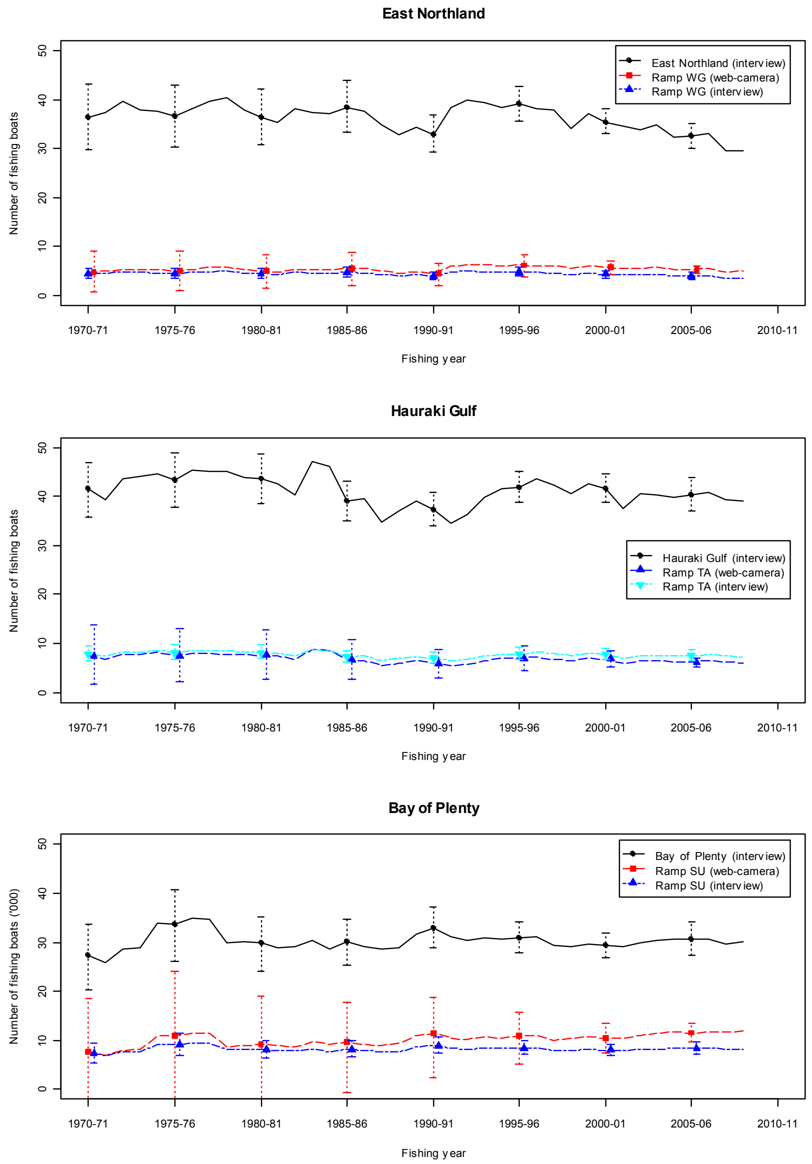


Figure 28: Comparisons of long term recreational fishing effort indices based on projections of effects estimated by the *interview model* and the *camera model*. *Interview model* indices are given for each region and for those boat ramps which are overlooked by web cameras, as the latter should be directly comparable with indices generated by the *camera model*.

4. DISCUSSION

Historical levels of recreational effort and catch in QMA 1 are largely unknown because research on amateur fisheries has been sporadic and variable in extent and purpose. Our current understanding of New Zealand's recreational fisheries is based primarily on data provided by intermittent boat ramp surveys which have followed varying spatial and temporal survey designs. Most of these surveys have focused on describing catch compositions rather than levels of fishing effort, and any collection of effort data was usually incidental to the objective of the survey. Fortunately, most of the boat ramp interview data on fishing effort have been collected in a broadly consistent, if somewhat sporadic, manner and these data are used here to model long-term trends in fishing effort. In this report we have updated and improved a Bayesian hierarchical fishing effort model developed by Watson & Hartill (2005) to include data collected during relatively extensive boat ramp surveys of recreational fishers in QMA 1 that have been conducted since December 2003.

The hierarchical Bayesian approach used by Watson & Hartill (2005) is ideally suited to mixed effects modelling and has several potential advantages over the more commonly used generalised linear modelling approach. Bayesian methods offer a powerful and intuitive means of calculating the extent and distribution of uncertainty associated with any estimated parameters, and information from ancillary data sources can be readily incorporated into the model in the form of a prior. A key advantage of the hierarchical approach is its ability to pool data across similar anticipated effects, thereby improving the precision of the estimates where little data exists for a set of circumstances. Hierarchical methods are therefore, ideally suited to interpreting unbalanced and patchy datasets such as those provided by the disparate boat ramp surveys considered here.

There are several differences between the interview model presented here, and the model developed by Watson & Hartill (2005). A comparison of projected regional indices of recreational fishing effort derived from the two models based on data collected over a common period (December 1990 to April 2003) suggests that the removal of 8 ramps from the data set, the restriction of data to those hours where the boat ramp was observed for a full 60 minutes and the correction for inadvertent double application of regional population growth indices, had little affect on the rate of change in effort over time. However, the inclusion of data from boat ramp surveys conducted between December 2003 and April 2009, an extension of population growth indices out to 2009, the partitioning of the data into 12 month bins (rather than 5 bins), and a redefinition of the year term from the calendar year to the fishing year, have had some affect on regional trends in effort. In East Northland there is further ongoing evidence of a gradual decline in fishing effort since the mid 1990s. In the Hauraki Gulf there is continuing evidence of relatively little change in levels of recreational fishing effort. However in the Bay of Plenty, a declining trend in effort seen in the projection of the 2005 model has been replaced by a relatively static trend in the current model, which is considered more plausible.

The inclusion of data from recent boat ramp surveys has considerably improved the model's ability to estimate temporal and environmental effects that will influence levels of fishing. This is because two recent surveys have been conducted over a full 12 month period, providing observational information on levels of fishing effort throughout the day, on all days of the week, across a wider range of weather conditions. The relative influence of seasonal, diurnal, and environmental effects are intuitively plausible, and the confidence intervals associated with these effects are also reasonably tight.

The reliability of the long term regional indices of recreational fishing effort generated from the projection of these effects back beyond December 1990 (when the first boat ramp interviews were conducted) to 1970 is, however, uncertain. These indices suggest that there has been very little if any change in levels of fishing effort in the Hauraki Gulf and Bay of Plenty, and that there has been a small but gradual decline of effort in East Northland. These trends are also evident in the effects estimated for individual years/surveys. The stable or declining trends in effort estimated by this model suggest that although there has been population growth in all three regions, this growth has been offset by a decline in the per capita tendency to go fishing. Trends in declining recreational fishing effort have been reported in Australia, Canada and the United States of America, which are usually attributed to significant declines in catch rates. There has been no such recorded decline in catch rates for snapper; the species most commonly landed by recreational fishers in QMA 1.

Watson & Hartill (2005) projected estimated effects back to 1970 because the objective of that study was to provide indices of effort for an assessment of the SNA 1 stock over the period 1970 to 2003. Although we have also projected the three regional effort indices back to 1970 in this study for comparative purposes, we suggest that any interpretation of trends before December 1990 should be regarded with caution because there is no quantitative data available on fishing effort before this date. The trajectory of effort indices before 1990 is determined by other related influences, such as regional population growth, the daily incidence of environmental conditions, and the assumption that the annual rate of change in the per capita tendency to go fishing estimated from data collected since 1990 is constant over the period 1970 to 2009. The influence of short term determinants of fishing effort before 1990, such as the oil price shock in the late 1970s is unmeasured and unknown because of the lack of boat ramp data in these early years.

Many assume that levels of recreational catch and effort have increased over recent decades, as disposable incomes have increased and the population of New Zealand has grown, but there is no quantitative evidence of any substantial increase in fishing effort over this period. Anecdotal evidence suggests that boat ramps have become more congested over the last two decades, but some of this increase may be attributable to other forms of recreational boating activity which are not fishing related. A standardised analysis of boat ramp interview data on the proportion of interviewed boats that have been used for fishing suggests, that there has not been any significant increase in the proportion of boats used for purposes other than fishing. The second author of this report was a boat ramp interviewer in 1990–91, and boat ramp traffic rates in Auckland at that time were often considerable.

Any inference on changes in levels of recreational effort over time, based on the recorded rate at which fishing boats return to surveyed ramps, assumes that effort is unconstrained by the capacity of those ramps. It is likely, however, that in some instances the available trailer parking close to a busy ramp becomes saturated, especially on weekend summer days when the weather is favourable for recreational boat based activity. This ramp saturation may lead to fishers using other surveyed or unsurveyed ramps, and in the case of the latter, any increase in effort on these day types over time will go undetected. It is also likely, that some fishers will be put off fishing on these days altogether, because dealing with high volumes of traffic at ramps and on the water defeats the oft stated purpose of going fishing – to get away from it all. To some extent these fishers would switch to other less congested days. It is also possible that interviewers could be overwhelmed when traffic levels peak, and they will fail to observe and record the return of all vessels at these times.

Alternative indices of fishing effort have also been presented here, based on web camera counts of boats returning to four key boat ramps in QMA 1. This data source only provides a crude means of monitoring changes in levels of fishing effort, as an unknown proportion of these boats will have been used for non-fishing purposes, such as water skiing. We also attempted to estimate the proportion of observed boats that would have been used for fishing given a range of temporal and environmental influences, but this proportion appears to be highly variable in space and time. The indices of recreational fishing effort derived from the combined modelling of web camera and fishing activity data are not considered reliable, although the long term trends generated from these data were broadly similar to those estimated from interview data.

An aerial overflight survey is planned for QMA 1 for the 2011–12 fishing year, and counts of recreational fishing vessels made during these flights, and other flights conducted in the western Hauraki Gulf in 1994, in the wider Gulf in 2003–04 and throughout QMA 1 in 2004–05, could be used as another source of information on trends in fishing effort in this region.

We suggest two means of improving the predictive power of an index of fishing effort based on web camera count data. The first suggestion is to wait until data are available for a longer period. These web camera systems have only been in operation for a five year period, which is not long enough to provide any insight into long terms trends in effort. The ongoing maintenance of these web camera systems is warranted because they provide a consistent and cost effective means of measuring changes in general recreational effort. The second suggestion is to conduct boat ramp interviews at the small number of boat ramps overlooked by web cameras on the same days that vessels are counted, in the late afternoon. This hybrid survey approach has two advantages. First, these interviews will provide both a direct measurement of the proportion of boats observed by camera on that day that were used for fishing, albeit for only part of that 24 hour period. Second, information on catch rates could be collected, which could be used to translate indices of fishing effort into indices of catch. Indices of catch are ultimately of more use to fisheries managers than indices of effort, and information on trends in harvest will greatly increase the value of any harvest estimates obtained from infrequent large scale harvest estimation programmes, such as those planned for 2011–12.

5. CONCLUSIONS

The following conclusions are drawn from this research:

- A Bayesian hierarchical model of boat ramp traffic developed by Watson & Hartill in 2005 has been updated to include data provided by several recent large scale surveys of recreational fisheries in QMA 1, and the results obtained are broadly similar to those generated in 2005.
- Weather effects and other factors that may determine levels of fishing effort have been estimated and shown to have a clear and plausible influence on the rate at which recreational fishing vessels returned to surveyed boat ramps between 1991 and 2009.
- There appears to have been a slight but gradual decline in levels of fishing effort in East Northland since the mid 1990s, but there is no evidence of any upward or downward trend in effort in the Hauraki Gulf or Bay of Plenty over the same period. This suggests that any potential increase in fishing effort resulting from regional population growth has been offset by a decline in the per capita tendency to go fishing.
- Although these indices are projected back to 1970, any predictions for the period prior to 1991 should be regarded with greater caution as they are not directly based on any observation of fishing effort during these early years.
- A similar modelling approach was also used to model web camera counts of the number of vessels returning daily to four key boat ramps in QMA 1. The results of this model, and an associated model required to estimate the proportion of these boats that would have been used for fishing, were combined to generate alternative regional indices of change in recreational effort over the same period.
- Although the regional effort indices generated from this combined model were broadly similar to those predicted by the model based on boat ramp traffic data, we suggest that they are less reliable and informative, given the short five year period for which web camera data are available, and the breadth of associated confidence intervals.
- We suggest, however, that the predictive power of data provided by the regular and ongoing operation of the web camera network will be greater than that provided by sporadic boat ramp surveys in the long term, and that further modelling based on these data will be warranted in five years time.
- This modelling has shown that a hybrid survey approach of conducting interviews at the small number of boat ramps overlooked by web cameras would be highly beneficial and cost effective, as it will provide a direct means of determining the proportion of the observed boats that have been used for fishing, albeit for only part of the day.
- Data from these interviews could also be used to provide species specific catch rate data, which could be used to translate any indices of recreational fishing effort into indices of harvest, which are of greater relevance to fisheries managers.

ACKNOWLEDGMENTS

The authors thank Alistair Dunn and members of the Marine Amateur Fisheries Working Group for suggestions made on an earlier draft of this report. Funding for this work was provided by the Ministry of Fisheries as part of MAF-2009/03.

REFERENCES

Armiger, H.; Hartill, B; Rush, N.; Vaughan, M.; Smith, M.; Buckthought, D. (2009). Length and age compositions of recreational landings of kahawai in KAH 1 in January to April 2008 and KAH 8 in January to April 2007. *New Zealand Fisheries Assessment Report 2009/36*. 40 p.

Armiger, H. Hartill, B.; Tasker, R.; Smith, M.; Griggs, L. (2006). Length and age compositions of recreational landings of kahawai in KAH 1 in January to April 2003–04 and 2004–05. *New Zealand Fisheries Assessment Report 2006/57*. 37 p.

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

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

Bradford, E. (1998). Harvest estimates from the 1996 national marine recreational fishing survey. New Zealand Fisheries Assessment Research Document 98/16. 26 p. (Unpublished report held in NIWA library, Wellington).

Francis, R.I.C.C. (1999). The impact of correlations in standardised CPUE indices. New Zealand Fisheries Assessment Research Document 99/42. 30 p. (Unpublished report held in NIWA library, Wellington)

Francis, R.I.C.C. (2006). Assessment of hoki (*Macruronus novaezelandiae*) in 2005. *New Zealand Fisheries Assessment Report 2006/3*. 96 p.

Hartill, B.; Armiger, H.; Tasker, R.; Middleton, C.; Fisher, D. (2007a). 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 Report 2007/6*. 38 p.

Hartill, B.; Armiger, H; Vaughan, M.; Rush, N.; Smith, M.; (2008). Length and age compositions of recreational landings of kahawai in KAH 1 in January to April 2007. *New Zealand Fisheries Assessment Report 2008/63*. 40 p.

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

Hartill, B.; Blackwell, R.; Bradford, E. (1998). Estimation of mean fish weights from the recreational catch landed at boatramps in 1996. *NIWA Technical Report 31*. 40 p.

Hartill, B.; Cryer, M. (2001). Recreational catch and effort in the Ministry of Fisheries North region. *NIWA Technical Report 101*. 64 p.

Hartill, B.; Payne, G.; Reddish, L.; Vaughan, M.; Spong, K.; Buckthought, D. (2007c). Monitoring recreational fishing effort in QMA 1. Final Research Report for Ministry of Fisheries research project REC200506. 18 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Hartill, B.; Rush, N.; Payne, G. (2010). Web camera based indices of recreational fishing effort in QMA 1 and QMA 8. Final Research Report for Ministry of Fisheries research project REC200702. 24 p. (Unpublished report held in NIWA library, Wellington.)

Hartill, B.; Smith, M.; Rush, N.; Vaughan, M.; Armiger, H. (2007d). Length and age compositions of recreational landings of kahawai in KAH 1 in 2005–06. *New Zealand Fisheries Assessment Report 2007/28*. 30 p.

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

Sturtz, S.; Ligges, U.; Gelman, A. (2005). R2WinBUGS: A Package for running WinBUGS. *Journal of Statistical Software*, *12(3)*:1–16.

Sullivan, K.J.; Hore, A.J.; Wilkinson, V.H. (1988). Snapper. *In* Baird, G.G.; McKoy, J.L. (eds) Papers from the workshop to review fish stock assessments for the 1987–88 New Zealand fishing year. pp. 251–275. (Unpublished report, held in NIWA library, Wellington.).

Sylvester, T. (1993). Recreational Fisheries Catch Per Unit Effort Trends in the North Region (1990/91) Northern Fisheries Region Internal Report No. 14. 23 p. (Unpublished report held in NIWA library, Auckland).

Sylvester, T. (1996). A comparison of the Hauraki Gulf recreational snapper catch between the aerial / interview survey and the telephone / diary survey. 22 p. (Unpublished report held in NIWA library, Auckland).

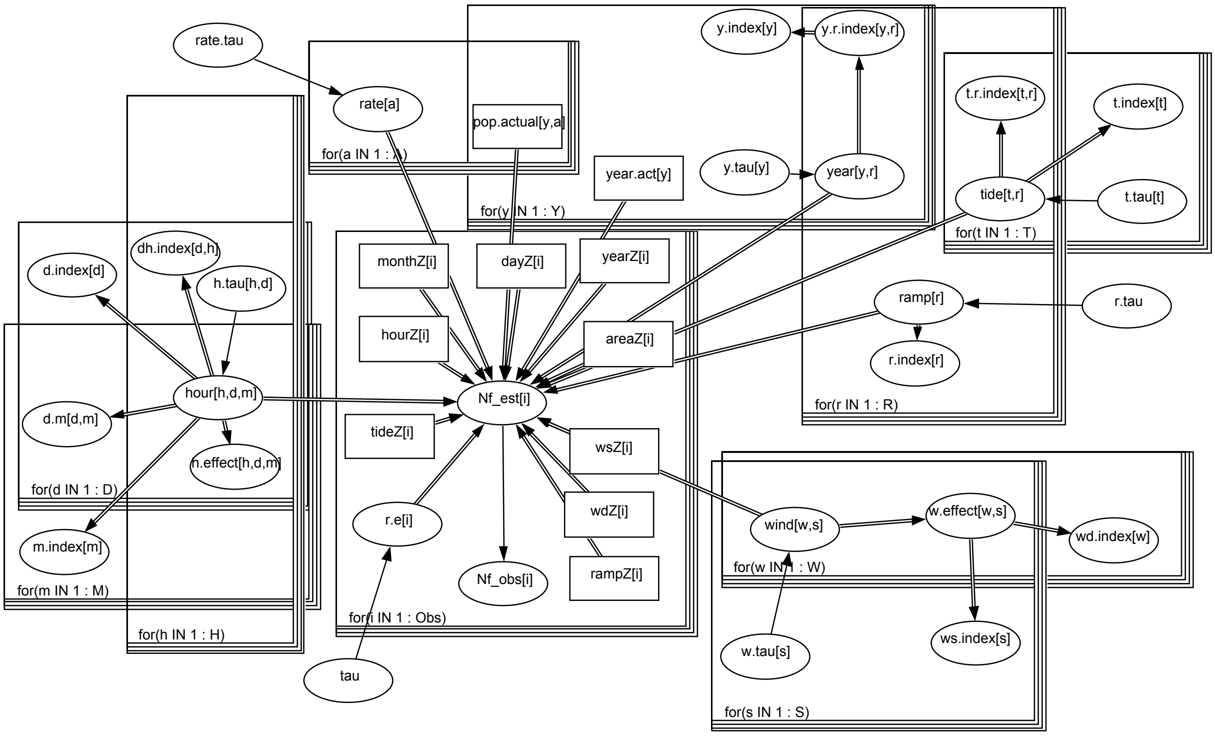
Teirney, L. D., A. R. Kilner, R. B. Millar, E. Bradford, and J. D. Bell. 1997. Estimation of Recreational Harvests from 1991–92 to 1993–94. *New Zealand Fisheries Assessment Research Document 97/15*. 43 p.

Walters, R.A. (1998). A finite element model for tides and currents with field applications. *Communications on Applied Numerical methods 4*: 401–411.

Watson, T.; Hartill, B. (2005). Bayesian modelling of boat ramp traffic in SNA 1 since 1970. *New Zealand Fisheries Assessment Report 2005/033.* 52 p.

APPENDICES

Appendix 1a: Interview model structure and code.

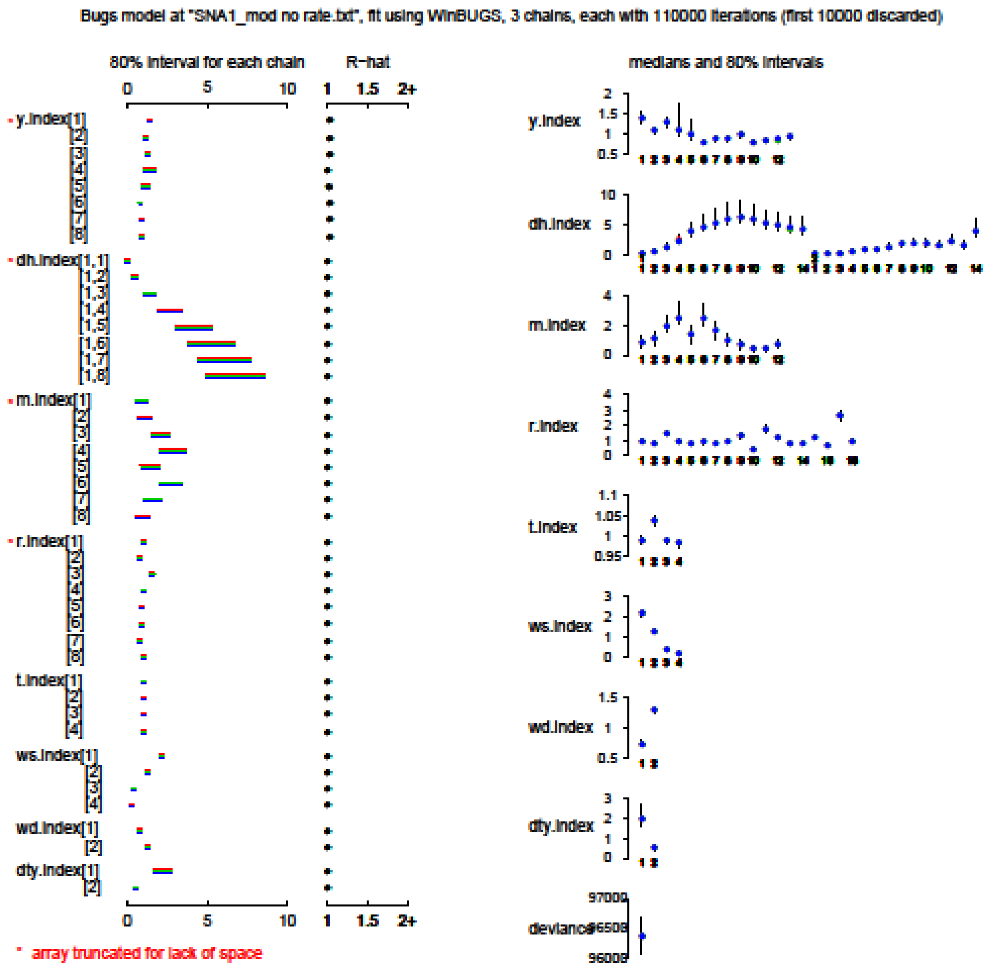



```
model;
{
  #model for fishing boat number
  for( i in 1 : Obs ) {
    Nf_obs[i] ~ dpois(Nf_est[i])
    log(Nf_est[i]) <- year[yearZ[i] , rampZ[i]] + wind[wdZ[i] , wsZ[i]] + hour[hourZ[i] , dayZ[i] , monthZ[i]] +
log(pop.actual[yearZ[i] , areaZ[i]]) + ramp[rampZ[i]] + rate[areaZ[i]] * (year.act[yearZ[i]] - 2008) + tide[tideZ[i] ,
rampZ[i]] + r.e[i]
  }

  #year effects for total number of boats and fishing probability
  for( y in 1 : Y ) {
    for( r in 1 : R ) {
      year[y , r] ~ dnorm(0,y.tau[y])
    }
  }
  for( y in 1 : Y ) {
    y.tau[y] ~ dgamma(0.001,0.001)
  }
  for( y in 1 : Y ) {
    for( r in 1 : R ) {
      log(y.r.index[y , r]) <- year[y , r] - mean(year[ , ])
    }
  }
  for( y in 1 : Y ) {
    log(y.index[y]) <- mean(year[y , ]) - mean(year[ , ])
  }

  #hour effects, and day month effects
  for( d in 1 : D ) {
```

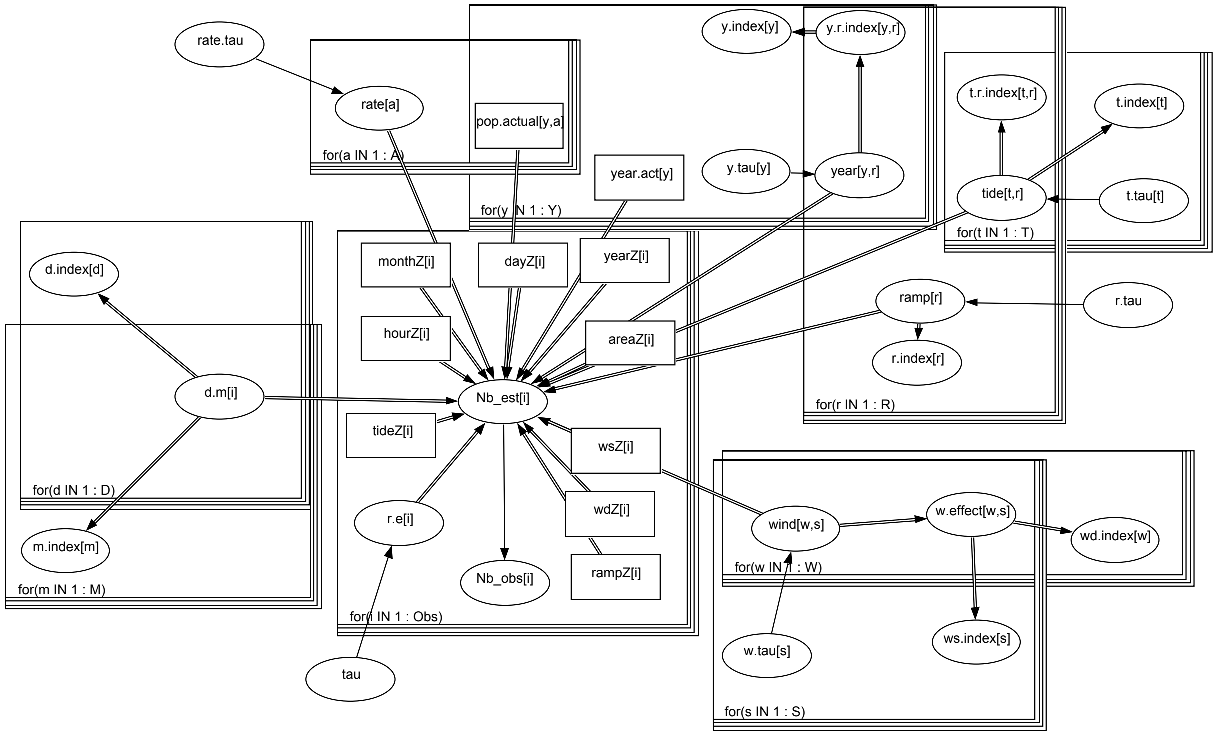
```
  for( m in 1 : M ) {
    for( h in 1 : H ) {
      hour[h , d , m] ~ dnorm( 0.0,h.tau[h , d])I(-100,)
    }
  }
}
for( d in 1 : D ) {
  for( h in 1 : H ) {
    h.tau[h , d] ~ dgamma(0.001,0.001)
  }
}
for( d in 1 : D ) {
  for( m in 1 : M ) {
    for( h in 1 : H ) {
      log(h.effect[h , d , m]) <- hour[h , d , m] - mean(hour[ ,  , ])
    }
  }
}
for( d in 1 : D ) {
  log(d.index[d]) <- mean(hour[ , d , ]) - mean(hour[ ,  , ])
}
for( m in 1 : M ) {
  log(m.index[m]) <- mean(hour[ ,  , m]) - mean(hour[ ,  , ])
}
for( d in 1 : D ) {
  for( h in 1 : H ) {
    log(dh.index[d , h]) <- mean(hour[h , d , ]) - mean(hour[ ,  , ])
    hdm[h,d] <- mean(hour[h, d, ])
  }
}
for( d in 1 : D ) {
  log(ddm.index[d]) <- mean(hdm[ ,d])-mean(hdm[ , ])
}
for( d in 1 : D ) {
  for( m in 1 : M ) {
    d.m[d , m] <- mean(hour[ , d , m])
  }
}

#ramp effects
for( r in 1 : R ) {
  ramp[r] ~ dnorm( 0.0,r.tau)
}
r.tau ~ dgamma(0.001,0.001)
for( r in 1 : R ) {
  log(r.index[r]) <- ramp[r] - mean(ramp[])
}

#rate effects
for( a in 1 : A ) {
  rate[a] ~ dnorm( 0.0,rate.tau)
}
rate.tau ~ dgamma(0.001,0.001)

#tide effects
for( t in 1 : T ) {
  for( r in 1 : R ) {
    tide[t , r] ~ dnorm( 0.0,t.tau[t])
  }
}
for( t in 1 : T ) {
  t.tau[t] ~ dgamma(0.001,0.001)
}
for( t in 1 : T ) {
  log(t.index[t]) <- mean(tide[t , ]) - mean(tide[ , ])
}
for( t in 1 : T ) {
```

```
      for( r in 1 : R ) {
         log(t.r.index[t , r]) <- tide[t , r] - mean(tide[ , ])
      }
   }

   #wind effects
   for( w in 1 : W ) {
      for( s in 1 : S ) {
         wind[w , s] ~ dnorm( 0.0,w.tau[s])I(-100,)
      }
   }
   for( s in 1 : S ) {
      w.tau[s] ~ dgamma(0.001,0.001)
   }
   for( w in 1 : W ) {
      for( s in 1 : S ) {
         log(w.effect[w , s]) <- wind[w , s]
      }
   }
   for( s in 1 : S ) {
      log(ws.index[s]) <- mean(wind[ , s]) - mean(wind[ , ])
   }
   for( w in 1 : W ) {
      log(wd.index[w]) <- mean(wind[w , ]) - mean(wind[ , ])
   }

   #individual observation random effects
   for( i in 1 : Obs ) {
      r.e[i] ~ dnorm( 0.0,tau)
   }
   tau ~ dgamma(0.001,0.001)
}
```

Appendix 1b: Convergence diagnostics for the interview model.



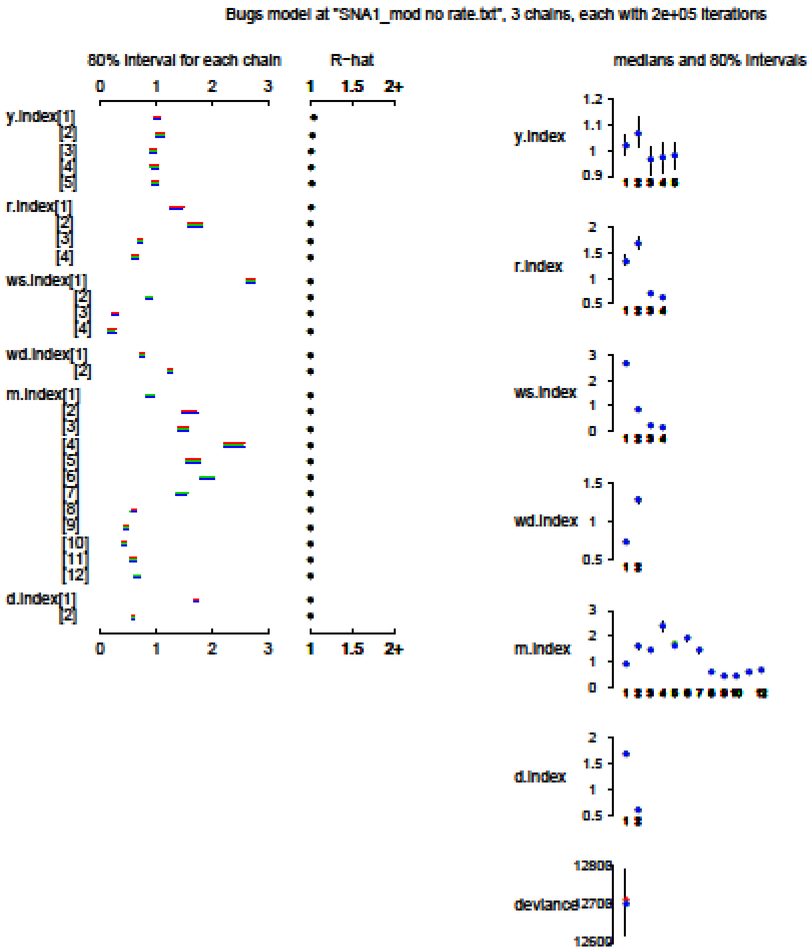
Appendix 2a: Camera count sub-model structure and code.



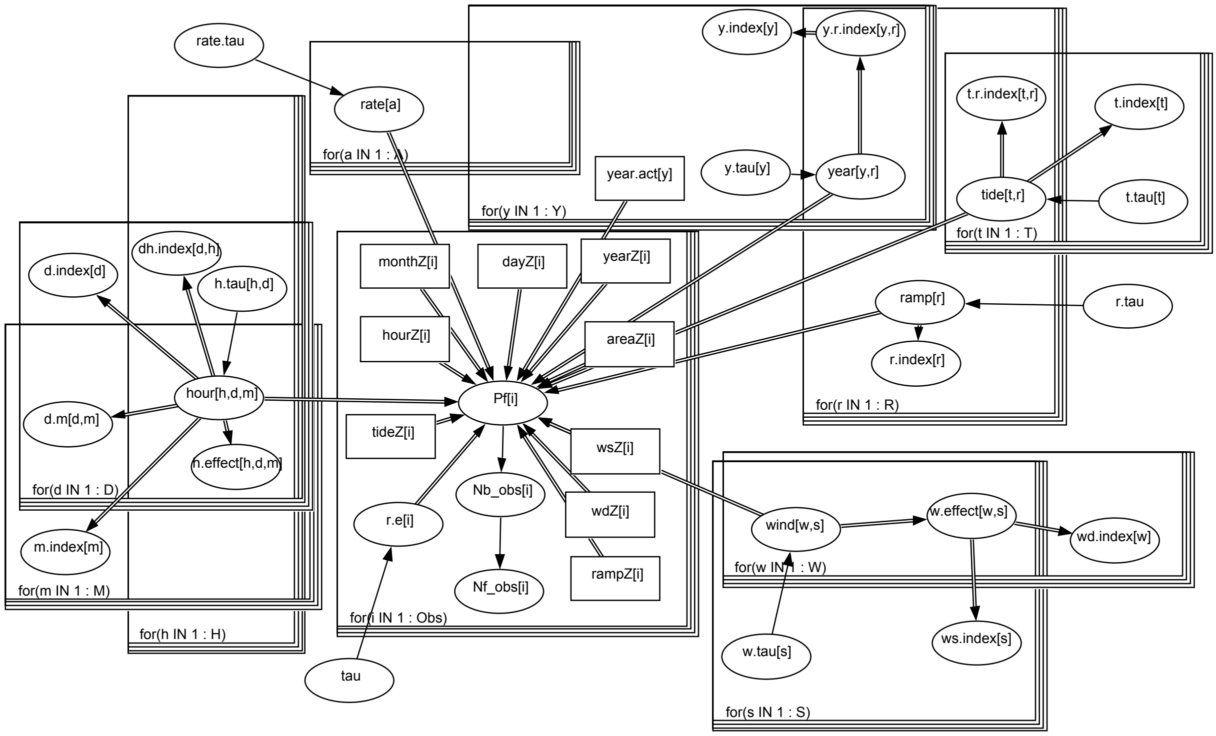

```
model;
{
   #model for total number
   for( i in 1 : Obs ) {
      Nb_obs[i] ~ dpois(NPUE[i])
      log(Nb_est[i]) <- year[yearZ[i] , rampZ[i]] + wind[wdZ[i] , wsZ[i]] + day[dayZ[i] , monthZ[i]] +
log(pop.actual[yearZ[i] , areaZ[i]]) + ramp[rampZ[i]] + rate[areaZ[i]] * (year.act[yearZ[i]] - 2008) +  r.e[i]
   }

   #year effects for total number of boats
   for( y in 1 : Y ) {
      for( r in 1 : R ) {
         year[y , r] ~ dnorm(0,y.tau[y])
      }
   }
   for( y in 1 : Y ) {
      y.tau[y] ~ dgamma(0.001,0.001)
   }
   for( y in 1 : Y ) {
      for( r in 1 : R ) {
         log(y.r.index[y , r]) <- year[y , r] - mean(year[ , ])
      }
   }
   for( y in 1 : Y ) {
      log(y.index[y]) <- mean(year[y , ]) - mean(year[ , ])
   }

   #day and month effects
   for( d in 1 : D ) {
      for( m in 1 : M ) {
         day[d , m] ~ dnorm( 0.0,d.tau[d , m])I(-100,)
      }
   }
   for( d in 1 : D ) {
      for( m in 1 : M ) {
```

```
        d.tau[d , m] ~ dgamma(0.001,0.001)
      }
    }
    for( d in 1 : D ) {
      for( m in 1 : M ) {
        log(d.effect[d , m]) <- day[d , m]
      }
    }
    for( d in 1 : D ) {
      log(d.index[d]) <- mean(day[d, ]) - mean(day[ , ])
    }
    for( m in 1 : M ) {
      log(m.index[m]) <- mean(day[ , m]) - mean(day[ , ])
    }

    #ramp effects
    for( r in 1 : R ) {
      ramp[r] ~ dnorm( 0.0,r.tau)
    }
    r.tau ~ dgamma(0.001,0.001)
    for( r in 1 : R ) {
      log(r.index[r]) <- ramp[r] - mean(ramp[])
    }
    #rate effects
    for( a in 1 : A ) {
      rate[a] ~ dnorm( 0.0,rate.tau)
    }
    rate.tau ~ dgamma(0.001,0.001)


    #wind effects
    for( w in 1 : W ) {
      for( s in 1 : S ) {
        wind[w , s] ~ dnorm( -2.0,w.tau[s])I(-100,)
      }
    }
    for( s in 1 : S ) {
      w.tau[s] ~ dgamma(0.01,0.01)
    }
    for( w in 1 : W ) {
      for( s in 1 : S ) {
        log(w.effect[w , s]) <- wind[w , s]
      }
    }
    for( s in 1 : S ) {
      log(ws.index[s]) <- mean(wind[ , s]) - mean(wind[ , ])
    }
    for( w in 1 : W ) {
      log(wd.index[w]) <- mean(wind[w , ]) - mean(wind[ , ])
    }

    #individual observation random effects
    for( i in 1 : Obs ) {
      r.e[i] ~ dnorm( 0.0,tau)
    }
    tau ~ dgamma(0.001,0.001)
}
```

Appendix 2b: Convergence diagnostics for the camera count sub-model.



Appendix 3a: Proportion fishing sub-model structure and code.




```
model;
{
  #probability of a boat is for fishing. no log(pop.actual)
  for( i in 1 : ObsP ) {
    Nf_obs[i] ~ dbin(Pf[i], Nb_obs[i])
    logit(Pf[i]) <- yearp[yearP[i] , rampP[i]] + windp[wdP[i] , wsP[i]] + hourp[hourP[i] , dayP[i] , monthP[i]] +
rampp[rampP[i]] + ratep[areaP[i]] * (year.act[yearP[i]] - 2008) + tidep[tideP[i] , rampP[i]] + rep[i]     #
  }

  #year effects for total number of boats and fishing probability
  for( y in 1 : Y ) {
    for( r in 1 : R ) {
      yearp[y, r] ~ dnorm(0,yp.tau[y])
    }
  }
  for( y in 1 : Y ) {
    yp.tau[y] ~ dgamma(0.01,0.01)
  }
  for( y in 1 : Y ) {
    logit(yp.index[y]) <- mean(yearp[y,])
  }

  #wind effects
  for( w in 1 : W ) {
    for( s in 1 : S ) {
      windp[w, s] ~ dnorm( 0.0,wp.tau[s])I(-10,10)
    }
  }
  for( s in 1 : S ) {
    wp.tau[s] ~ dgamma(0.01,0.01)
  }
  for( w in 1 : W ) {
    for( s in 1 : S ) {
      logit(wp.effect[w , s]) <- windp[w , s]
```

```
    }
  }
  #need to be corrected to geomean
  for( s in 1 : S ) {
    logit(wsp.index[s]) <- mean(windp[ , s])
  }
  for( w in 1 : W ) {
    logit(wdp.index[w]) <- mean(windp[w , ])
  }

  #hour effects, and day month effects
  for( d in 1 : D ) {
    for( m in 1 : M ) {
      for( h in 1 : H ) {
        hourp[h , d , m] ~ dnorm( 0.0,hp.tau[h , d])I(-10,10)
      }
    }
  }
  for( d in 1 : D ) {
    for( h in 1 : H ) {
      hp.tau[h , d] ~ dgamma(0.01,0.01)
    }
  }
  for( d in 1 : D ) {
    for( m in 1 : M ) {
      for( h in 1 : H ) {
        logit(hp.effect[h , d , m]) <- hourp[h , d , m]
      }
    }
  }
  for( m in 1 : M ) {
    logit(mp.index[m]) <- mean(hourp[ ,  , m])
  }
  for( d in 1 : D ) {
    for( h in 1 : H ) {
      logit(dhp.index[d , h]) <- mean(hourp[h , d , ])
      hdm[h,d] <-mean(hourp[h, d, ])
    }
  }
  for( d in 1 : D ) {
    logit(dp.index[d]) <- mean(hdm[ ,d]) #-mean(hdm[ , ])
  }
  for( d in 1 : D ) {
    for( m in 1 : M ) {
      dmp[d , m] <- mean(hourp[ , d , m])
    }
  }

  #ramp effects
  for( r in 1 : R ) {
    rampp[r] ~ dnorm( 0.0,rp.tau)
  }
  rp.tau ~ dgamma(0.01,0.01)
  for( r in 1 : R ) {
    logit(rp.index[r]) <- rampp[r] #- mean(rampp[])
  }

  #rate effects
  for( a in 1 : A ) {
    ratep[a] ~ dnorm( 0.0,ratep.tau)
  }
  ratep.tau ~ dgamma(0.01,0.01)

  #tide effects
  for( t in 1 : T ) {
    for( r in 1 : R ) {
      tidep[t , r] ~ dnorm( 0.0,tp.tau[t])
```

```
    }
  }
  for( t in 1 : T ) {
    tp.tau[t] ~ dgamma(0.01,0.01)
  }
  for( t in 1 : T ) {
    logit(tp.index[t]) <- mean(tidep[t , ]) #- mean(tidep[ , ])
  }
  for( t in 1 : T ) {
    for( r in 1 : R ) {
      logit(tp.r.index[t , r]) <- tidep[t , r] #- mean(tidep[ , ])
    }
  }

  #individual observation random effects
  for( i in 1 : ObsP ) {
    rep[i] ~ dnorm( 0.0,ptau)
  }
  ptau ~ dgamma(0.01,0.01)
}
```

Appendix 3b: Convergence diagnostics for the proportion fishing sub-model.