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Hector’s dolphin survey after the November 2016 Kaikōura earthquake

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Boat-based surveys for Hector's dolphin (*Cephalorhynchus hectori*) north and south of the Kaikōura Peninsula have been conducted intermittently since 2013. Surveys were being undertaken during the 2016/2017 summer which coincided with the November 2016 earthquake. This project was to conduct surveys in the 2017/2018 summer and use the new and previously collected survey data to assess potential impacts of the earthquake on the abundance and distribution of Hector's dolphin in the Kaikōura region.

Some Hector's dolphins can be individually identified through unique scarring patterns and other natural markings. During surveys, photographs are taken of marked individuals enabling an encounter history to be developed of the sighting frequency of such individuals. In addition, sightings of unmarked individuals along the survey route are recorded. Dolphin abundance can be estimated from both the sighting frequency of marked individuals and number of sightings of unmarked individuals using a mark-resight model. A binomial mark-resight model was used to estimate the abundance of adult Hector's dolphins during periods of surveying between January 2013 and March 2018. The estimates varied depending on which survey periods were used but were consistently in the range of 250–450 adults for most survey periods, except for early 2013 which tended to produce higher estimates. There was no statistically discernible difference in abundance during the two summers after the earthquake.

Potential changes in the spatial distribution of Hector's dolphin were evaluated by analysing the number of sightings of adult dolphins per survey in six distinct regions. A generalised linear model assuming Poisson distributed counts was used to evaluate how the expected number of adults sighted per survey varied spatially and temporally. In particular, survey region, pre-/post-earthquake and survey period were used as potential predictor variables. Different combinations of these variables (including interactions) were used to define models to fit to the data. AIC was used to evaluate the level of support for each model. As the pre-/post-earthquake and survey period variables are partially confounded, they were not both included in the same model. The model with greatest support included an interaction between the survey region and survey period variable, suggesting that there are localised changes in the distribution of dolphins between survey periods, which is operating at a finer time scale than pre-/post-earthquake. Further separation of these effects is not possible with the short time series available.

In summary, the survey results do not indicate there has been a substantial change in the number of Hector's dolphins using the study area, and although there may have been some distributional changes (based on the expected number of adult sightings), it is difficult to discern any lasting effect of the earthquake from more general annual variation at this point.

1. INTRODUCTION

Hector’s dolphins (*Cephalorhynchus hectori*) are a small, coastal species, found only in New Zealand. They have high site fidelity and small home ranges (about 30–50 km alongshore) (Bräger et al. 2003, Rayment et al. 2010) and tend to be encountered in shallow waters with poor water clarity, often near river mouths (Dawson & Slooten 1988, Bräger & Schneider 1998, Bräger et al. 2002, Weir & Sagnol 2015). Hector’s dolphins are classified as Endangered nationally and internationally by the International Union for Conservation of Nature.

On November 14, 2016 a 7.8 magnitude Kaikōura earthquake caused considerable changes to the marine environment along the coast where Hector’s dolphins have been the focus of a monitoring programme since 2013. Due to the significant uplift along the coast and increased sedimentation from landslides and via rivers, there was concern for the marine species utilising this environment. The Kaikōura earthquake recovery package was put in place to assess the short-term ecological impact of the earthquake on particular species and habitats, including the Hector’s dolphin, and to inform management options for recovery.

1.1 Background

Since 2013, three separate studies employing three different methods (photo-identification/mark rate, aerial surveys and fine-scale genetic sampling) have provided estimates of the abundance of Hector’s dolphins using the Kaikōura area. Using boat-based photo-identification methods and mark rate (the proportion of individuals with obvious and distinct markings), Weir & Sagnol (2015) estimated 304 individuals (95% CI = 211 – 542) were using the study area between Haumuri Bluffs and the Hapuku River in 2013. Because identifiable individuals photographed south of the Kaikōura Canyon were never identified north of the Kaikōura Canyon and vice versa, they predicted that this estimate might include subsets of both a southern and a northern population (Weir & Sagnol 2015).

During roughly the same timeframe, MacKenzie & Clement (2014) employed aerial survey methodology to estimate the abundance of Hector’s dolphins along the East Coast South Island (ECSI) in summer 2012 – 2013 and winter 2013. The Kaikōura study area, which was larger than the study area used by Weir & Sagnol (2015) and included the Clarence coastline, included 358 individuals (95% CI = 129 – 995) in summer and 216 individuals (95% CI = 50 – 935) in winter respectively (MacKenzie & Clement 2014).

In 2014 and 2015, biopsy samples were collected from individual Hector’s dolphins between Point Gibson to the south and Ward Beach to the north, to estimate abundance and assess whether there were indeed genetically distinct populations north and south of the Kaikōura Canyon (Hamner et al. 2016). The subsequent ‘capture-recapture’ analysis provided an estimate of 314 individuals (95% CL = 216 – 483) for the northern population (Kaikōura-North) and 102 individuals (95% CL = 68 – 175) for the southern population (Kaikōura-South). This study also confirmed that the two populations were both demographically and genetically distinct from one another (Hamner et al. 2016).

Two of the above studies (MacKenzie & Clement 2014, Weir & Sagnol 2015) also examined some aspects of distribution.

1.2 Scope

Since 2013, the Kaikōura Ocean Research Institute (KORI) has conducted boat-based surveys for Hector’s dolphins along the Kaikōura coastline between Hapuku River and Haumuri Bluffs. The 48 surveys from January to December 2013 were funded by the Department of Conservation and by Encounter Foundation and were spread evenly throughout the entire year. The results of these surveys were published by Weir & Sagnol (2015). Subsequent surveys conducted from December 2014 to

March 2017 were only partially funded and conducted during restricted and often opportunistic times of the year.

In July 2017, the Kaikōura Ocean Research Institute (KORI), in conjunction with Proteus Wildlife Research Consultants, were contracted by the Ministry for Primary Industries (MPI) to conduct new surveys (between November 2017 and March 2018) and analyse these and historic (2013 – 2017) Hector's dolphin surveys conducted by KORI along coastal Kaikōura.

The objectives of this programme are outlined as follows:

Overall objective:

To conduct and analyse Hector's dolphin surveys along coastal Kaikōura.

Specific objectives:

1. To survey Hector's dolphins along coastal Kaikōura in 2017/2018 in a manner consistent with previous surveys (Weir & Sagnol 2015).
   Planned survey time periods:
      November 1–15, 2017; 8 surveys (4 north and 4 south)
      December 22, 2017–January 5, 2018; 8 surveys (4 north and 4 south)
      March 1– 5, 2018; 8 surveys (4 north and 4 south)
2. To analyse historical and 2017/2018 Hector's dolphin survey information to characterise any impact of the 2016 Kaikōura earthquakes.

2. METHODS

2.1 Study area and survey design

From January 2013 to March 2018, boat-based surveys were conducted to the north of the Kaikōura Peninsula (42°30' S, 173°32' E) to the Hapuku River and south of the Kaikōura Peninsula to Haumuri Bluffs (Figure 1). In June 2013, the survey route was expanded slightly to cover slightly more area further from shore and closer to the coast between Haumuri Bluffs and Oaro. After December 2013, the original survey was resumed with the added section closer to the coast between Haumuri Bluffs and Oaro maintained. It is important to note that the survey route was originally chosen to focus on areas where Hector's dolphins were most frequently encountered (Bräger et al. 2003), to minimise travel time and costs when photographing individuals to determine identity for estimating mark rate and abundance.

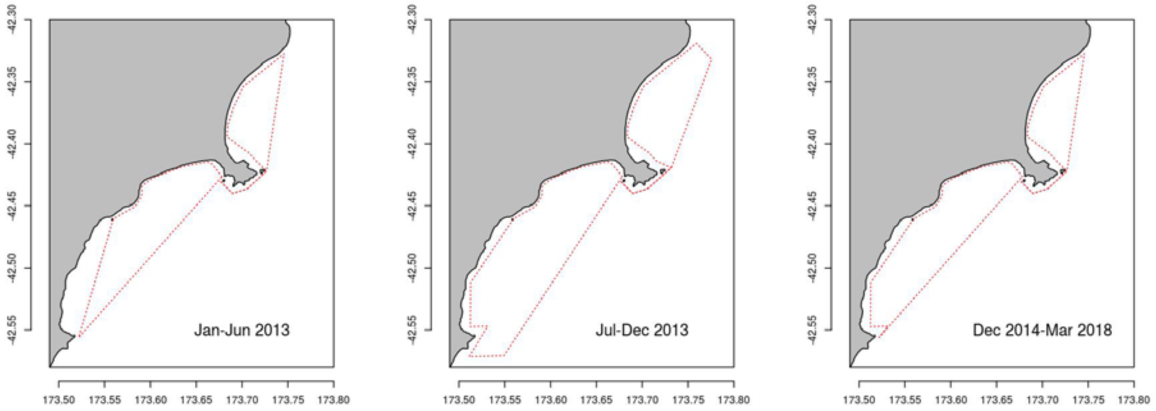

Figure 1: Planned survey routes used between January 2013 and March 2018.

2.2 Field work and data collection

Boat-based surveys were conducted between January 2013 and March 2018, when funding and sea conditions allowed (Table 1).

Table 1: Number of surveys of southern (Sth) and northern (Nth) rate in each month during the survey period.

	2013		2014		2015		2016		2017		2018	
Month	Sth	Nth	Sth	Nth	Sth	Nth	Sth	Nth	Sth	Nth	Sth	Nth
January	2	2			2	2			2	0	3	4
February	3	2			2	2						
March	1	2			2	2	0	1	4	3	6	5
April	4	3					1	0				
May	1	1										
June	1	2										
July	1	2										
August	2	3										
September	2	1										
October	3	3										
November	0	1					3	3	5	5		
December	3	1	4	5	4	3	1	2	2	1		

Surveys in January 2013 – August 2013 were conducted from a 5.5-m rigid-hull inflatable vessel with an 80-hp 4-stroke outboard engine. From September 2013 to March 2018, a similar but slightly larger (5.8 m) vessel with a 100-hp 4-stroke outboard engine was used. On each survey day, the route, which had been programmed into a handheld Garmin 76 GPS unit, was followed at a speed of 10 – 20 knots until a Hector's dolphin group was sighted. This speed was selected because it usually prevented dolphins from following the research vessel and therefore could help prevent repeat sightings of the same individual within a survey (Bräger et al. 2003). When it was suspected that individuals from a previous group had possibly joined the 'new' group, this was noted on the data sheets and these data were not used for abundance estimates.

The following data were collected for each encounter with Hector's dolphins:

1. Time and GPS location at the start of the encounter using a handheld GPS unit
2. Environmental variables including sea state, swell height, cloud cover and water clarity (using a Secchi disc)
3. The maximum number of dolphins (adults, juveniles, and calves) counted at one time during the encounter was recorded as the group size at the end of each encounter
4. Photographs of individual dolphins were taken using a high-speed digital SLR camera (either a Nikon D90 with vibration reduction and 70 – 300 mm lens or a Nikon D800 with vibration reduction and 80 – 400 mm lens). Mark rate was determined in 2013 as 0.15 (Weir & Sagnol 2015) and was not reassessed again.

Information from data sheets was entered into Excel worksheets for subsequent analysis. Note that there was some deviation from the planned survey route, although the actual route was not recorded.

2.3 Processing of photographs

Photographs were processed manually in Adobe Photoshop Lightroom CC Version 1.2. After the initial import, photos were sorted by quality and assigned keywords (labels) based on the type of marking on the dolphin's dorsal fin. Only high-quality photographs that included individuals with obvious and distinctive markings were included in this analysis (488 photographs). Photo-identification matching revealed 80 individuals that were photographed on survey 2013 – 2018.

2.4 Data analysis

Three different configurations of the sighting data were investigated for the purpose of the abundance and distribution analyses, using different definitions of the survey periods (Table 2). The first definition allocated surveys into six distinct time periods, based on the timing and location of the survey effort. In 2013, different survey waypoints were used in each half of the year, but consistent survey waypoints were used from December 2014 onwards. Under this definition, the surveys conducted in the two weeks immediately prior to the earthquake on 14 November 2016 are combined with the surveys in the remainder of the 2016/2017 summer survey period. In the second definition, the surveys conducted immediately prior to the earthquake were ignored, hence the first four survey periods are all pre-earthquake and the final two are post-earthquake. The final definition of the survey periods that was considered uses the data that were collected at similar times of year. This results in four survey periods where data were consistently collected over the summer months. Data collected over the summer of 2015/2016 were not used because the survey effort only consisted of multiple surveys in late December 2015, and one survey in each of March and April 2016.

Table 2: Survey period configurations used.

	Configuration		
Period	1	2	3
1	Jan-Jun 2013	Jan-Jun 2013	Jan-Mar 2013
2	Jul-Dec 2013	Jul-Dec 2013	Dec 2014-Mar 2015
3	Dec 2014-Mar 2015	Dec 2014-Mar 2015	Dec 2016-Mar 2017
4	Dec 2015-Apr 2016	Dec 2015-Apr 2016	Nov 2017-Mar 2018
5	Nov 2016-Mar 2017	Dec 2016-Mar 2017	
6	Nov 2017-Mar 2018	Nov 2017-Mar 2018	

Abundance estimation

The Hector's dolphin population consists of some individuals with marks (primarily scarring or damage to the dorsal fin) that allow individuals to be identified on each survey and individuals with no identifiable marks. Over the course of multiple surveys, an encounter history can be developed for those animals that are individually identifiable which denotes the time and location at which each individual was observed. This information can be used to perform a mark-recapture analysis to estimate the number of marked individuals in the population. To obtain an estimate of the total population, one approach is to then make a secondary correction to the estimated abundance of marked individuals by a 'mark rate' (e.g., Weir & Sagnol 2015). A different approach, with a similar intent, is to conduct a mark-resight analysis (e.g., McClintock et al. 2009) that explicitly utilises the sighting information from the marked and unmarked individuals in a single analysis. This latter approach has been used here. Note that typically only adult Hector's dolphins carry identifiable marks, hence the abundance estimates relate to only adults. Furthermore, the survey region is not geographically closed, meaning that individuals may move in and out of the survey area; hence the abundance estimates apply to an unknown area that is larger than the region that was surveyed.

There is a range of specific methods available for mark-resight analyses, with a main distinction being whether the number of marked individuals in the population is known (e.g., when marks are applied to captured individuals) or unknown. One approach for when the number of marked individuals is unknown, is the Poisson-log normal mark-resight model (McClintock et al. 2009). This model assumes that the total number of sightings per individual per period can be well described by the Poisson distribution. The Poisson distribution is reasonable when resightings may be made continuously during the survey period, or it is a suitable approximation when the number of sighting opportunities is relatively large and the probability of resighting per occasion is small.

When the number of survey opportunities is small, as in this study, the Poisson approximation will no longer be appropriate and the number of sightings per individual will be better described by the binomial distribution (McClintock et al. 2009). This assumes that each individual is sighted once per survey occasion (i.e., once per day), irrespective of whether they are marked or unmarked. Implementation of this mark-resight model required development of custom code for the analysis using the software package R.

The key data requirements for this method are the total number of times each marked adult was sighted within a defined survey period and the total number of sightings of unmarked adults within that period. Heuristically, information on the number of sightings per marked adult is used to estimate the expected number of sightings per individual, which is then used to back calculate the number of unmarked adults from the total number of sightings of unmarked adults. In using a single analytic framework, the uncertainty and correlation between parameters can be appropriately accounted for. The key parameters in the model are:

- p_t = probability of sighting an adult in a survey in period t
- U_t = number of unmarked adults in period t

Analyses were conducted using custom-written R code. Two models were fitted to the data where p_t was assumed to be different for each period, or constant for all periods. The number of unmarked adults was always estimated as different for each period. Total abundance of adults in survey period t was estimated as:

$$\hat{N}_t = \hat{U}_t + \frac{n_t}{\hat{p}_t^*}$$

where n_t is the number of unique marked adults sighted during the period and $\hat{p}_t^*$ is the estimated probability of a marked adult being sighted at least once during the k_t surveys (i.e., $\hat{p}_t^* = 1-(1-\hat{p}_t)^{k_t}$. Essentially, $n_t \big/ \hat{p}_t^*$ is the Huggins estimator of population size. The standard error of $\hat{N}_t$ was calculated using the delta method, and log-normal based 95% confidence interval estimates were used. The two models that were fitted to the data were compared using AIC, and model averaging was used to account for any model selection uncertainty.

Note that in some periods a different number of surveys were conducted in the northern and southern portion of the study area; for these periods, the maximum of the two values was used for the analysis because individuals are not confined to just one area. See Discussion for comments on the sensitivity of the results to use of the maximum.

Spatial distribution

The original study design was not intended to examine the spatial distribution of Hector’s dolphin in the study region, and some aspects of the design limit what can be done. In particular, the actual route surveyed was not recorded for each survey hence accurate information on the location of the survey effort is not available. Therefore, potential changes in the spatial distribution of Hector’s dolphin has only been evaluated at a relatively broad scale.

The study area was divided into six regions (Figure 2), and the number of adults sighted per survey in each region was analysed using a generalised linear model (GLM) to assess whether the number of adults in each region changed after the earthquake. GLMs were fitted to the data where region and pre-/post-earthquake were considered as potential predictor variables. The interaction between these two predictor variables was also considered in the GLM to account for localised changes in the distribution of Hector's dolphin within the study area (e.g., increases in some areas, and declines in others). To provide context to any apparent change post-earthquake with respect to broader-scale temporal variation, survey period was also considered as a predictor variable, where periods were defined according to the third configuration of the data used in the abundance analysis (Table 2). GLMs were not considered with both the pre-/post-earthquake and survey period predictor variables, because these variables are partially confounded. Models were fitted to the data and compared on the basis of AIC.

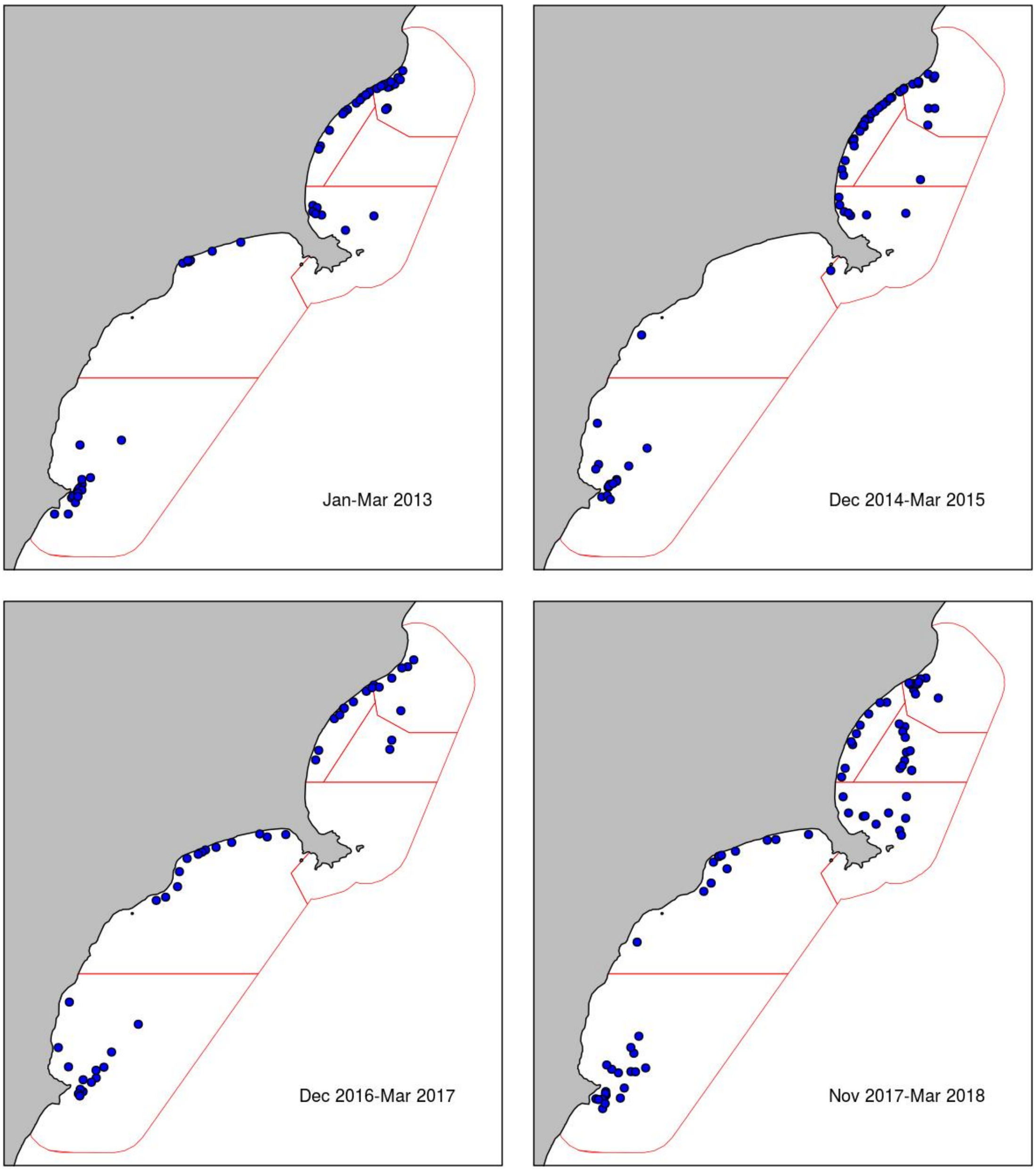

Figure 2: **Six general regions used to assess changes in distribution of Hector's dolphin within the study area. The locations of sightings between January 2013 and March 2018 used in the analysis are also indicated.**

Because the location of the along-shore effort was reasonably consistent over the entire period, the relative frequency of sightings along the coastline was also visually assessed for changes post-quake. The distance along the coastline (from a point approximately 6 km north of Hapuku River mouth) was determined for all sightings recorded as within 1.5 km of the coastline. The relative frequency of the sightings along the coastline within a period was smoothed with a Gaussian kernel and a bandwidth of 1 km, using the *density* function in R. The relative frequencies are standardised to sum to 1.0. The third data configuration was used to define the survey periods.

3. RESULTS

3.1 Abundance estimation

Tables 3–5 present a summary of the sighting data for each configuration of the sighting data, indicating the number of sighting records, the number of individuals sighted (unique individuals per sighting), and the mean and standard deviation of the number of individuals per sighting. Tables 6–8 contain a summary of the sighting information for marked individuals and the number of surveys conducted in the northern and southern portions of the study area.

Table 3: Sighting data summary using the first configuration of survey periods: the total number of sightings in each period and total number of individuals of each class (unique individuals per sighting). Mean and standard deviation of the number of individuals per sighting are given.

		Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Nov 2016-Mar 2017	Nov 2017-Mar 2018
	Sightings	102	60	62	18	56	72
Adults	Individuals	525	282	294	97	245	399
	Mean	5.15	4.70	4.74	5.39	4.38	5.54
	SD	3.83	3.52	3.64	3.73	3.84	5.50
Juveniles	Individuals	37	22	15	6	11	16
	Mean	0.36	0.37	0.24	0.33	0.20	0.22
	SD	0.66	0.71	0.50	0.59	0.40	0.51
Calves	Individuals	19	3	20	1	18	7
	Mean	0.19	0.05	0.32	0.06	0.32	0.10
	SD	0.61	0.22	0.72	0.24	0.79	0.42
Total	Individuals	581	307	328	104	274	422
	Mean	5.70	5.12	5.29	5.78	4.89	5.86
	SD	4.12	3.71	3.79	3.84	4.11	5.62

Table 4: Sighting data summary using the second configuration of survey periods: the total number of sightings in each period and total number of individuals of each class (unique individuals per sighting). Mean and standard deviation of the number of individuals per sighting are given.

		Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Dec 2016-Mar 2017	Nov 2017-Mar 2018
	Sightings	102	60	62	18	46	72
Adults	Individuals	525	282	294	97	194	399
	Mean	5.15	4.70	4.74	5.39	4.22	5.54
	SD	3.83	3.52	3.64	3.73	3.35	5.50
Juveniles	Individuals	37	22	15	6	9	16
	Mean	0.36	0.37	0.24	0.33	0.20	0.22
	SD	0.66	0.71	0.50	0.59	0.40	0.51
Calves	Individuals	19	3	20	1	18	7
	Mean	0.19	0.05	0.32	0.06	0.39	0.10
	SD	0.61	0.22	0.72	0.24	0.86	0.42
Total	Individuals	581	307	328	104	221	422
	Mean	5.70	5.12	5.29	5.78	4.80	5.86
	SD	4.12	3.71	3.79	3.84	3.60	5.62

Table 5: Sighting data summary using the third configuration of survey periods: the total number of sightings in each period and total number of individuals of each class (unique individuals per sighting). Mean and standard deviation of the number of individuals per sighting are given.

		Jan-Mar 2013	Dec 2014-Mar 2015	Dec 2016-Mar 2017	Nov 2017-Mar 2018
	Sightings	55	62	46	72
Adults	Individuals	253	294	194	399
	Mean	4.60	4.74	4.22	5.54
	SD	3.15	3.64	3.35	5.50
Juveniles	Individuals	14	15	9	16
	Mean	0.25	0.24	0.20	0.22
	SD	0.48	0.50	0.40	0.51
Calves	Individuals	17	20	18	7
	Mean	0.31	0.32	0.39	0.10
	SD	0.79	0.72	0.86	0.42
Total	Individuals	284	328	221	422
	Mean	5.16	5.29	4.80	5.86
	SD	3.58	3.79	3.60	5.62

Table 6: Summary of data used in the mark-resight analysis for abundance estimation, using the first configuration of survey periods: the number of unique marked adults sighted, total number of sightings of marked adults, number of sightings of unmarked adults, and number of surveys conducted.

	Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Nov 2016-Mar 2017	Nov 2017-Mar 2018
Marked adults	46	23	19	9	9	25
Marked sightings	69	33	25	10	10	40
Unmarked sightings	456	249	269	87	235	359
Northern surveys	12	11	11	4	8	15
Southern surveys	12	11	10	5	10	16

Table 7: Summary of data used in the mark-resight analysis for abundance estimation, using the second configuration of survey periods: the number of unique marked adults sighted, total number of sightings of marked adults, number of sightings of unmarked adults, and number of surveys conducted.

	Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Dec 2016-Mar 2017	Nov 2017-Mar 2018
Marked adults	46	23	19	9	9	25
Marked sightings	69	33	25	10	10	40
Unmarked sightings	456	249	269	87	184	359
Northern surveys	12	11	11	4	5	15
Southern surveys	12	11	10	5	7	16

Table 8: Summary of data used in the mark-resight analysis for abundance estimation, using the third configuration of survey periods: the number of unique marked adults sighted, total number of sightings of marked adults, number of sightings of unmarked adults, and number of surveys conducted.

	Jan-Jun 2013	Dec 2014-Mar 2015	Nov 2016-Mar 2017	Nov 2017-Mar 2018
Marked adults	21	19	9	25
Marked sightings	23	25	10	40
Unmarked sightings	230	269	184	359
Northern surveys	6	11	5	15
Southern surveys	6	10	7	16

For all data configurations, the model that assumed constant per-survey sighting probability had much stronger support (Table 9). The AIC weight for the constant model was 0.98, 0.99, and 0.93 for data configurations 1, 2, and 3, respectively. Resulting model-averaged estimates of adult abundance using each data configuration are given in Tables 10–12 and Figures 3–5. Results using the first two configurations are very similar and excluding the early November 2016 sightings leads to estimates with less uncertainty, but the estimates themselves are not substantially different. This will be due to the fact that no marked adults were sighted in early November 2016 and only sightings of unmarked individuals have been excluded. Using the third configuration, estimates have much greater uncertainty and are approximately 60–100 adults greater than using the other two configurations. The probability of an adult being sighted during a survey trip from the top ranked model was estimated to be 0.073 (SE = 0.009), 0.075 (0.009), and 0.063 (0.012) from the three data configurations, respectively.

Table 9: Model selection summary for binomial mark-resight analysis for the data for each configuration of the sighting data. The model with constant sighting probability across survey periods is denoted as *p*(.) and *p*(period) denotes the model with period-specific sighting probability. The table gives the relative difference in AIC (ΔAIC), AIC model weight (*w*), number of parameters (NPar), and twice the negative log-likelihood value (-2*ll*).

Configuration	Model	ΔAIC	*w*	NPar	-2*ll*
1	*p*(.)	0.00	0.98	7	1211.33
	p(period)	7.36	0.02	12	1208.69
2	*p*(.)	0.00	0.99	7	1207.63
	p(period)	8.73	0.01	12	1206.35
3	*p*(.)	0.00	0.93	5	650.37
	p(period)	5.24	0.07	8	649.61

Table 10: Estimated abundance of adult Hector's dolphins in each survey period using first data configuration, from each mark-resight model fitted to the data. The model with constant sighting probability across survey periods is denoted as *p*(.) and *p*(period) denotes the model with period-specific sighting probability. MA is the model averaged estimates using the AIC model weights (*w*). Standard error and CV are given in parentheses.

Model	*w*	Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Nov 2016-Mar 2017	Nov 2017-Mar 2018
p(.)	0.98	594	348	366	264	336	341
		(68; 11%)	(40; 12%)	(43; 12%)	(32; 12%)	(40; 12%)	(39; 11%)
p(period)	0.02	528	315	434	286	929	354
		(92; 17%)	(85; 27%)	(158; 36%)	(261; 91%)	(890; 96%)	(78; 22%)
MA		592	348	368	265	351	341
		(68; 11%)	(42; 12%)	(48; 13%)	(52; 20%)	(112; 32%)	(40; 12%)

Table 11: **Estimated abundance of adult Hector's dolphins in each survey period using the second data configuration, from each mark-resight model fitted to the data. The model with constant sighting probability across survey periods is denoted as *p*(.) and *p*(period) for the model with period-specific sighting probability. MA is the model averaged estimates using the AIC model weights (*w*). Standard error and CV are given in parentheses.**

Model	*w*	Jan-Jun 2013	Jul-Dec 2013	Dec 2014-Mar 2015	Dec 2015-Apr 2016	Dec 2016-Mar 2017	Nov 2017-Mar 2018
p(.)	0.99	583	342	359	259	372	335
		(66; 11%)	(39; 12%)	(42; 12%)	(31; 12%)	(45; 12%)	(38; 11%)
p(period)	0.01	528	315	434	286	665	354
		(92; 17%)	(85; 27%)	(158; 36%)	(261; 91%)	(627; 94%)	(78; 22%)
MA		583	342	360	260	376	335
		(66; 11%)	(40; 12%)	(44; 12%)	(43; 16%)	(76; 20%)	(39; 12%)

Table 12: **Estimated abundance of adult Hector's dolphins in each survey period using the third data configuration, from each mark-resight model fitted to the data. The model with constant sighting probability across survey periods is denoted as *p*(.), and *p*(period) for the model with period-specific sighting probability; MA is the model averaged estimates using the AIC model weights (*w*). Standard error and CV given in parentheses.**

Model	*w*	Jan-Mar 2013	Dec 2014-Mar 2015	Dec 2016-Mar 2017	Nov 2017-Mar 2018
p(.)	0.93	667	421	437	391
		(122; 18%)	(76; 18%)	(81; 18%)	(70; 18%)
p(period)	0.07	945	434	665	354
		(627; 66%)	(158; 36%)	(627; 94%)	(78; 22%)
MA		686	422	453	389
		(189; 28%)	(84; 20%)	(172; 38%)	(69; 18%)

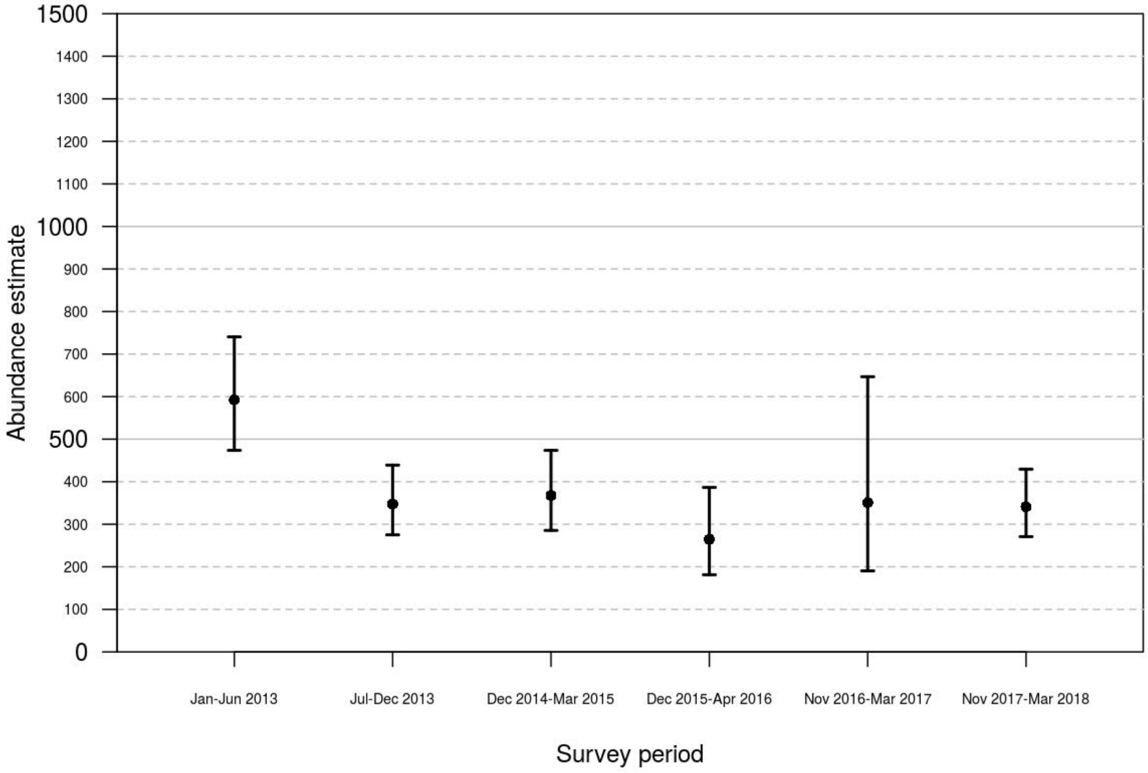

Figure 3: **Model-averaged estimates (with 95% confidence intervals) of adult Hector's dolphins in each survey period using the first data configuration.**

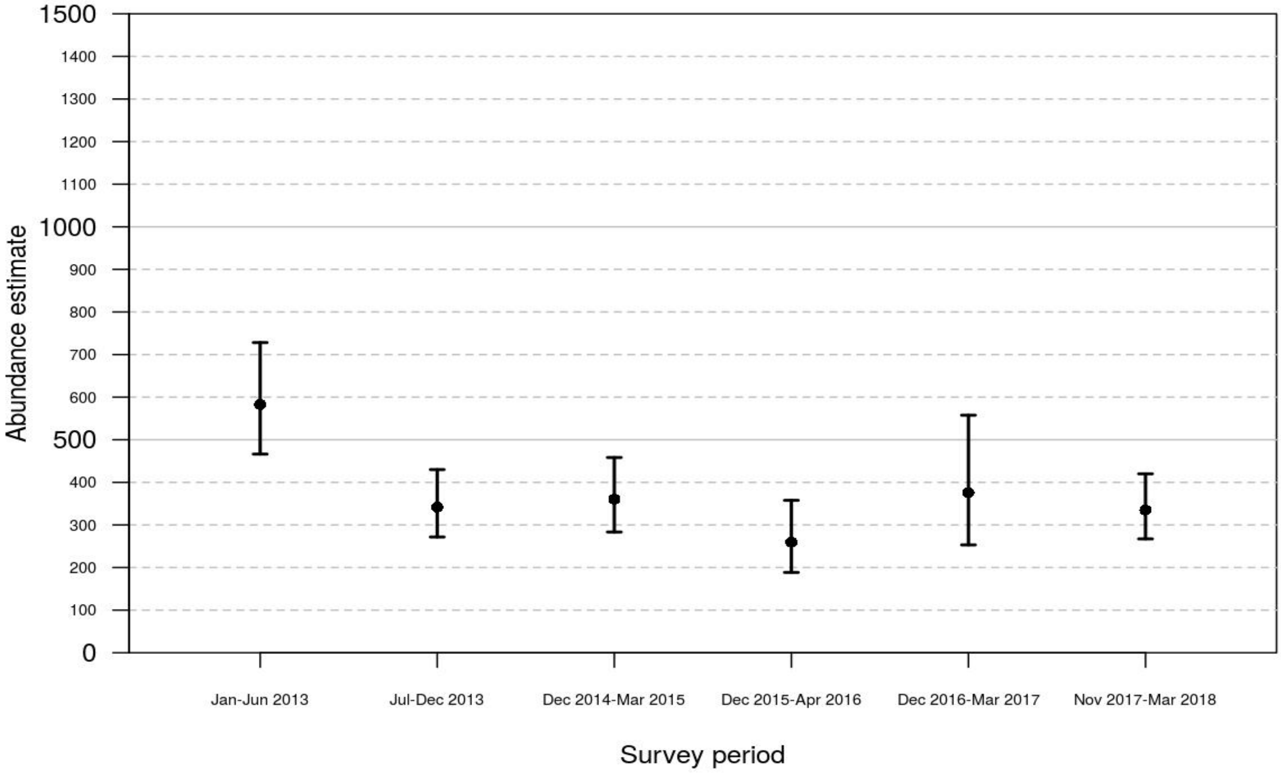

Figure 4: **Model-averaged estimates (with 95% confidence intervals) of adult Hector's dolphins in each survey period using the second data configuration.**

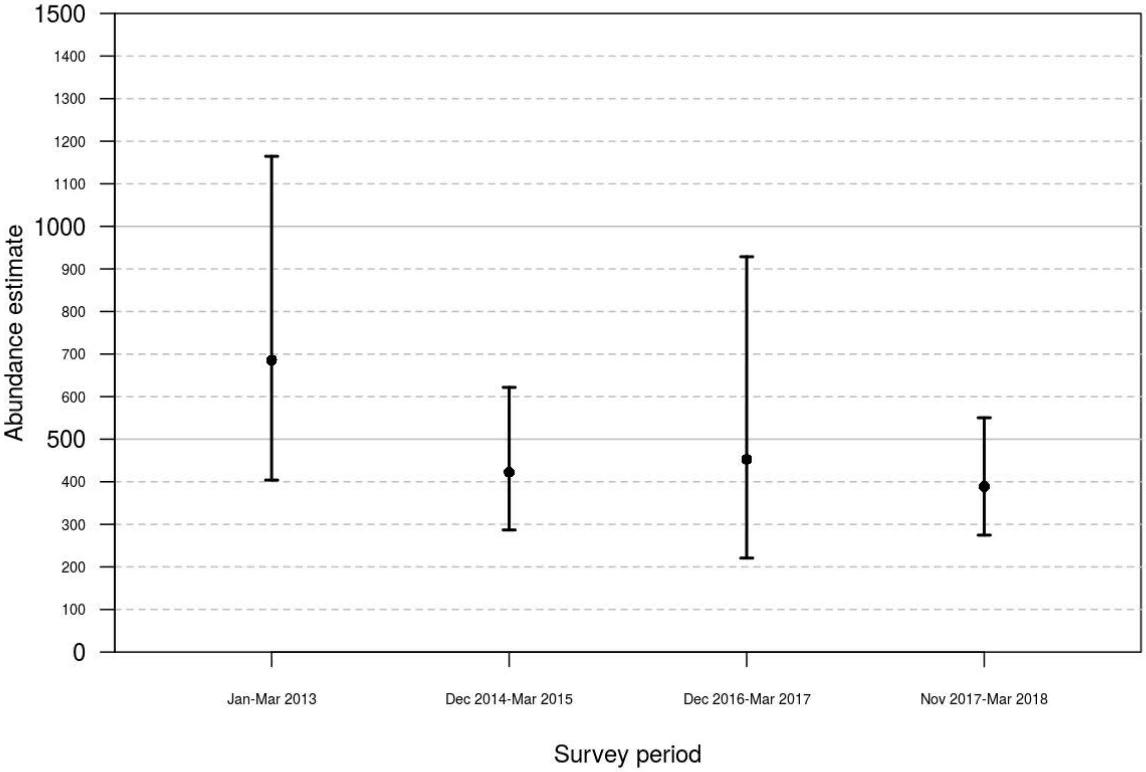

Figure 5: **Model-averaged estimates (with 95% confidence intervals) of adult Hector's dolphins in each survey period using the third data configuration.**

3.2 Spatial distribution

A summary of the number of adults sighted in each region is given in Table 13, with further detail in Figure 6. Table 14 contains a list of the GLMs that were fitted to the data, and the results of comparing them on the basis of AIC. Although there is strong evidence of localised changes in the expected number of adults that would be sighted in a region during a survey, after the earthquake (because the model that includes the ‘region by quake’ interaction is highly ranked), there is even stronger evidence for ongoing localised changes at the temporal scale of the survey period. Hence, any apparent change in the expected number of adults sighted after the earthquake, may be a reflection of general temporal changes rather than a change due to the actual earthquake.

Table 13: Summary of the number of adult Hector’s dolphins sighted per survey in each of the six regions in each of the periods used to assess changes in spatial distribution: the mean, standard deviation, and range of the counts, and the number of surveys conducted.

Region	Statistic	Jan-Mar 2013	Dec 2014-Mar 2015	Dec 2016-Mar 2017	Nov 2017-Mar 2018
Hapuku	Mean (SD)	12.67 (6.53)	7.18 (9.45)	5.60 (8.85)	3.67 (3.77)
	Range	6 – 24	0 – 31	0 – 21	0 – 12
	# Surveys	6	11	5	15
Nth Onshore	Mean (SD)	9.33 (9.22)	8.55 (4.80)	5.20 (4.44)	2.33 (2.79)
	Range	0 – 23	1 – 14	0 – 12	0 – 7
	# Surveys	6	11	5	15
Nth Offshore	Mean (SD)	0.00 (0.00)	0.36 (1.21)	2.00 (4.47)	3.53 (6.13)
	Range	0 – 0	0 – 4	0 – 10	0 – 23
	# Surveys	6	11	5	15
Peninsula	Mean (SD)	6.67 (5.89)	2.64 (2.87)	0.00 (0.00)	2.33 (3.42)
	Range	0 – 14	0 – 8	0 – 0	0 – 10
	# Surveys	6	11	5	15
Airport	Mean (SD)	2.33 (2.25)	0.20 (0.63)	7.29 (8.77)	2.13 (2.60)
	Range	0 – 5	0 – 2	1 – 25	0 – 8
	# Surveys	6	10	7	16
Haumuri	Mean (SD)	11.17 (4.22)	8.60 (10.16)	11.29 (9.50)	11.69 (10.84)
	Range	5 – 17	0 – 27	0 – 27	0 – 28
	# Surveys	6	10	7	16

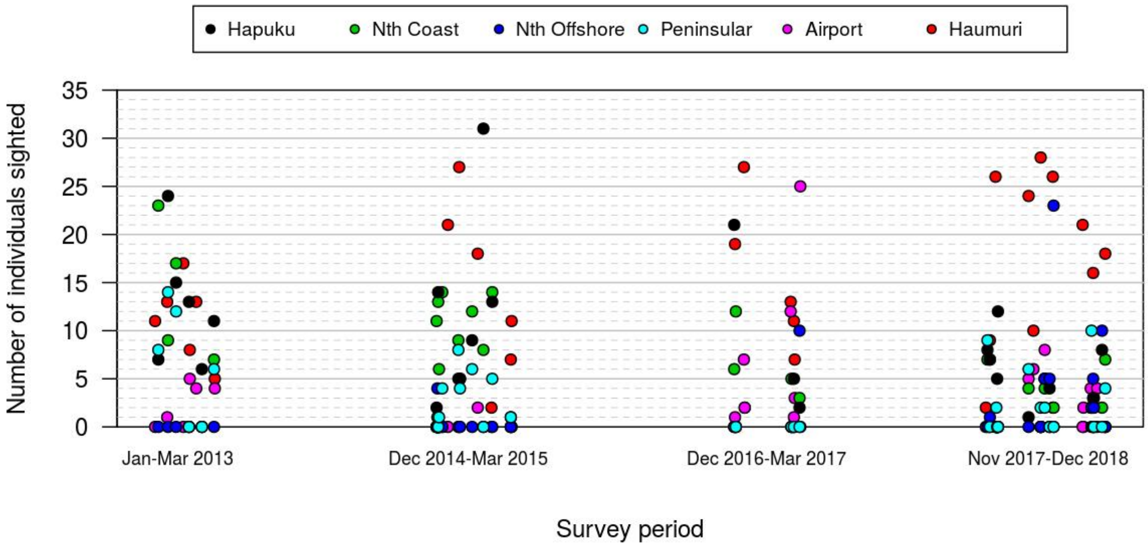

Figure 6: Number of adults counted per survey in each region.

Table 14: Model selection summary for generalised linear models fit to the number of adults sighted per survey in each region, assuming counts are Poisson distributed. Models are denoted by the predictor variables in each model, where '*' indicates an interaction between those variables. Given is the relative difference in AIC (□AIC), AIC model weight (*w*), number of parameters (NPar) and twice the negative log-likelihood value (-2*ll*).

Model	□AIC	*w*	NPar	-2*ll*
Period*Region	0.00	1.00	24	1699.48
Quake*Region	93.56	0.00	12	1817.04
Period+Region	243.14	0.00	9	1972.62
Quake+Region	269.63	0.00	7	2003.10
Region	276.09	0.00	6	2011.58
Period	639.52	0.00	4	2379.00
Quake	669.16	0.00	2	2412.64
Constant	673.58	0	1	2419.06

Figure 7 illustrates the relative frequency of sightings along the coastline for each period. Clearly there are some areas that consistently have a greater proportion of the sightings, but there is no obvious, consistent change in the level of use (assuming consistent alongshore effort) post-earthquake.

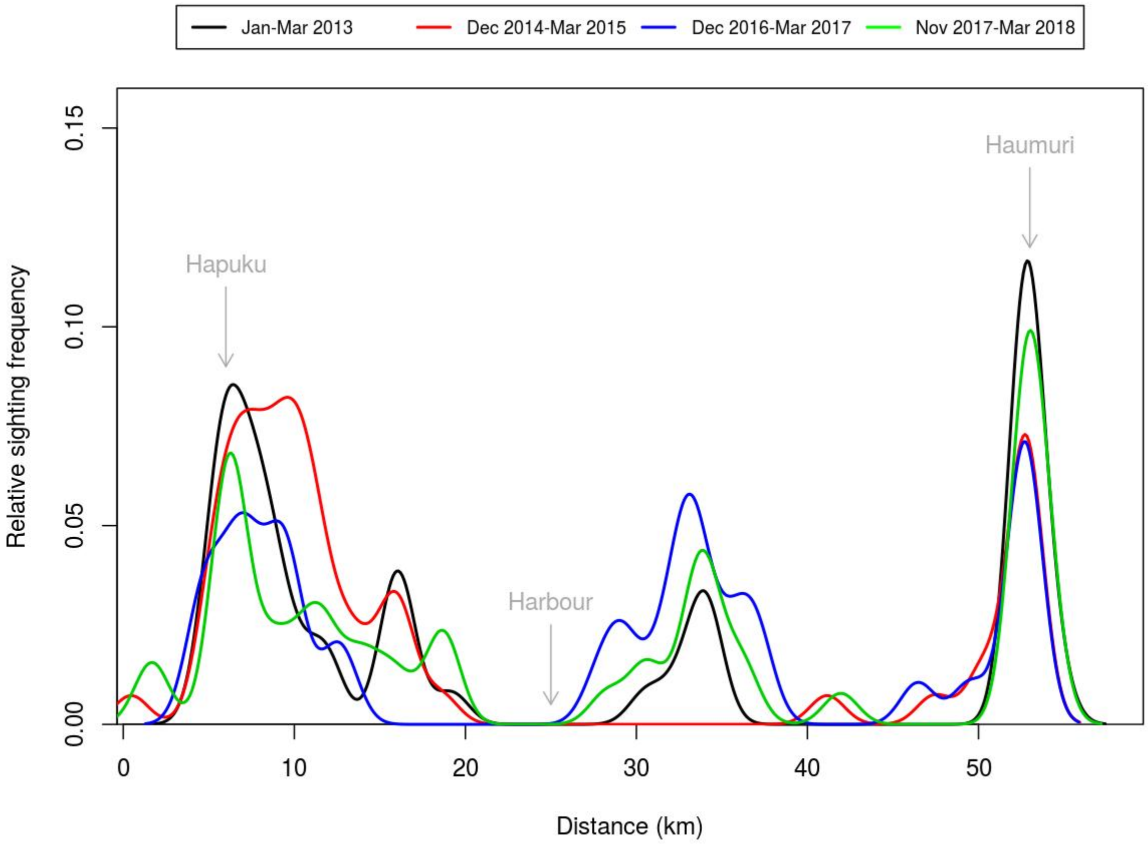

Figure 7: Relative frequency of Hector's dolphin sightings along the coastline near Kaikōura, in each survey period. Only sightings recorded within 1.5 km of the coast are represented here.

4. DISCUSSION

The estimated abundance of adult Hector's dolphin in the survey area does not appear to have substantially changed since the November 2016 earthquake. Regardless of which data configuration is used, the abundance estimates for the 2016/2017 and 2017/2018 survey periods are very comparable with those for earlier periods, particularly late 2013 and 2014/2015. A consistent feature of all analyses is the much higher estimated abundance in early 2013, during which period the number of sightings per survey were greater than in latter periods. The low abundance estimate for 2015/2016 is likely to be due to the low and intermittent survey effort.

Abundance estimates obtained from the binomial mark-resight analysis for June 2013 onwards are broadly comparable to estimates obtained by others using a range of methods along a similar stretch of coastline (e.g., MacKenzie & Clement 2014, Weir & Sagnol 2015, Hamner et al. 2016). However, we stress that the estimates from other studies are not directly comparable because different study areas have been used. Because individuals may move outside the study area between surveys, the estimates of abundance obtained here will apply to an area larger than the nominal study area. Given the spatial allocation of the survey effort, it is difficult to ascertain how large that area may be.

The degree to which the survey area overlaps with the home range of different dolphins will be different. The individuals whose home range overlaps with the survey area more fully will have a higher probability of being sighted during a survey than those that have little overlap. This is a form of heterogeneity which can cause abundance to be underestimated if unaccounted for. The binomial mark-resight model does not account for individual heterogeneity; however, preliminary analyses of the mark-resight data were conducted using Program MARK which assumes a Poisson mark-resight model (i.e., the number of sightings follows a Poisson rather than a binomial distribution). Program MARK has been programmed to allow the option of incorporating for heterogeneity, and, when such models were fitted, abundance estimates were approximately 20–30 higher than from those models with no heterogeneity. This difference is small relative to the standard errors of the estimates, hence had little practical influence on final inferences. Therefore, comparable models for the binomial mark-resight models were not developed. The Poisson mark-resight models were not used for the final analysis because the binomial distribution is a fundamentally better representation of the survey process.

Incorporation of spatial information was considered for abundance estimation (e.g., spatially explicit mark-recapture methods), but not used. With relatively few repeat sightings of the same individual in the same period (i.e., lots of single sightings), and for those individuals that were sighted repeatedly, some were seen in similar locations, whereas others were sighted at opposite ends of the study area. This paucity of spatial recapture information in combination with the large variation in where individuals were sighted would suggest that parameters associated with the spatial movement of individuals would be difficult to estimate. Furthermore, the actual survey track was not recorded for each survey and reliable information on the spatial location of the survey effort is required for these methods to work well.

In the analysis, the larger of the number of surveys conducted in either the northern or southern region was used as the number of surveys conducted in that period. Using the minimum value instead increased the estimated abundance for some periods and decreased the estimate in others. However, the magnitude of the change was small relative to the uncertainty in the estimates, hence only the single sets of results (using the maximum number of surveys) are presented here. An integer value is required which precludes the use of the average.

Although there is some indication of potential changes in the spatial distribution of adult Hector's dolphins since the November 2016 earthquake, this is against a backdrop of ongoing annual variation in the locations used. Without the benefit of longer time series, it is difficult to separate out changes potentially due to the earthquake from more general annual variation. One should also be mindful of the potential for changes in other environmental factors that are confounded with the timing of the 2016 earthquake.

The results of a number of alternative analyses of both the mark-resight and distribution data are not reported here, because the results were not considered reliable. In particular, analyses were attempted to estimate adult survival from the mark-resight data because some individuals were sighted in multiple time periods. However, such attempts resulted in survival estimates that were much lower than what would be expected for Hector's dolphin. This may be due to a range of factors, individually or in combination, including the relatively short time series, small number of adults sighted in multiple years, heterogeneous sighting probabilities, or 'permanent' movement out of the study area (where 'permanent' is relative to the duration of the study, e.g., Williams et al. 2002). Dolphin movements that are at a spatial scale comparable with the size of the mark-resight study area may lead to either heterogeneous sighting probabilities or 'permanent' emigration (or both), depending on the nature of the movements and position of a dolphin's home range relative to the study area. This, in turn, will lead to adult survival being underestimated. A range of analyses using different methods (e.g., GAMs and occupancy models) were attempted to estimate a smooth surface for dolphin distribution using bivariate splines, similar to the density surface models of MacKenzie & Clement (2014). These attempts were not successful because the results tended to be very sensitive to the degrees of freedom defined for the bivariate spline. This is likely to be due to the spatial resolution of the survey data, which is primarily linear along the coastline, i.e., there is limited 2-dimensional information for the bivariate spline to utilise when fitting models.

Where transects met, or at other corners within the survey route, there were times when a group that had been recorded was seen again (due to the close proximity of the route in some areas). In these instances, it was almost always clear to the researchers aboard the vessel whether or not they were seeing the same group they had just documented previously and every effort was made to not repeat sightings of the same groups (i.e., dolphin groups that had previously been recorded were not recorded again). hWen it was questionable if a group had already been recorded, the group was not recorded as a new sighting.

The same survey design was maintained for the 2017/2018 surveys as was used previously. This was done to provide consistency for the purpose of investigating potential impacts of the November 2016 earthquake on the abundance and distribution of Hector's dolphins in the Kaikōura region. However, there are aspects of the design that could be improved from the perspective of obtaining good information on the abundance and distribution of Hector's dolphins. These aspects include:

- automatic logging of survey route
- electronic recording of GPS locations to avoid transcription errors
- spatial allocation of survey effort that is most conducive to primary objectives.
- continuing to record environmental conditions (e.g., water clarity) at regular intervals along the survey transect including where dolphins are not sighted, in addition to recording conditions at sightings locations.

Careful thought must also be given to the likely methods of analysis, particularly with respect to collection of auxiliary information (e.g., potential predictor variables) to ensure that such information is collected at an appropriate spatial and temporal scale. It should be noted that the present survey was not designed specifically for the purposes for which the data have been used in this project.

5. MANAGEMENT IMPLICATIONS

These results do not indicate a substantial change in abundance in the two summers after the November 2016 earthquake, although there may be some localised changes in distribution. Whether these changes are the result of changes in the ecosystem following the earthquake, or simply more general annual fluctuations due to other factors, is difficult to ascertain at this point. It is also not clear whether these changes will be lasting or not.

If ongoing monitoring of Hector’s dolphins in this region is to be initiated to evaluate long-term impacts of the earthquake, then refinement of the current survey methodology may be required, depending on the management objectives.

6. ACKNOWLEDGMENTS

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APPENDIX 1: Locations of sightings of marked individuals

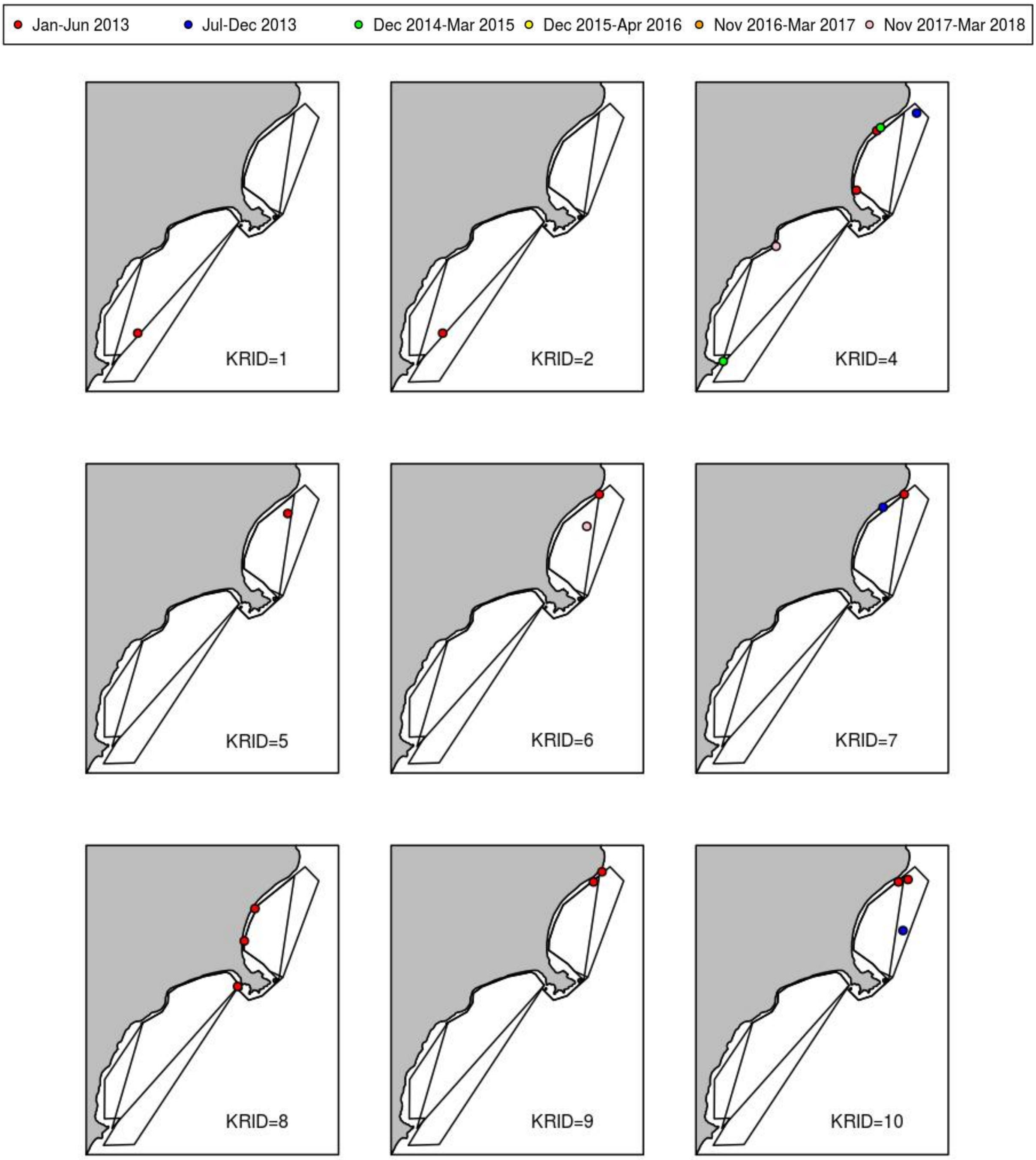
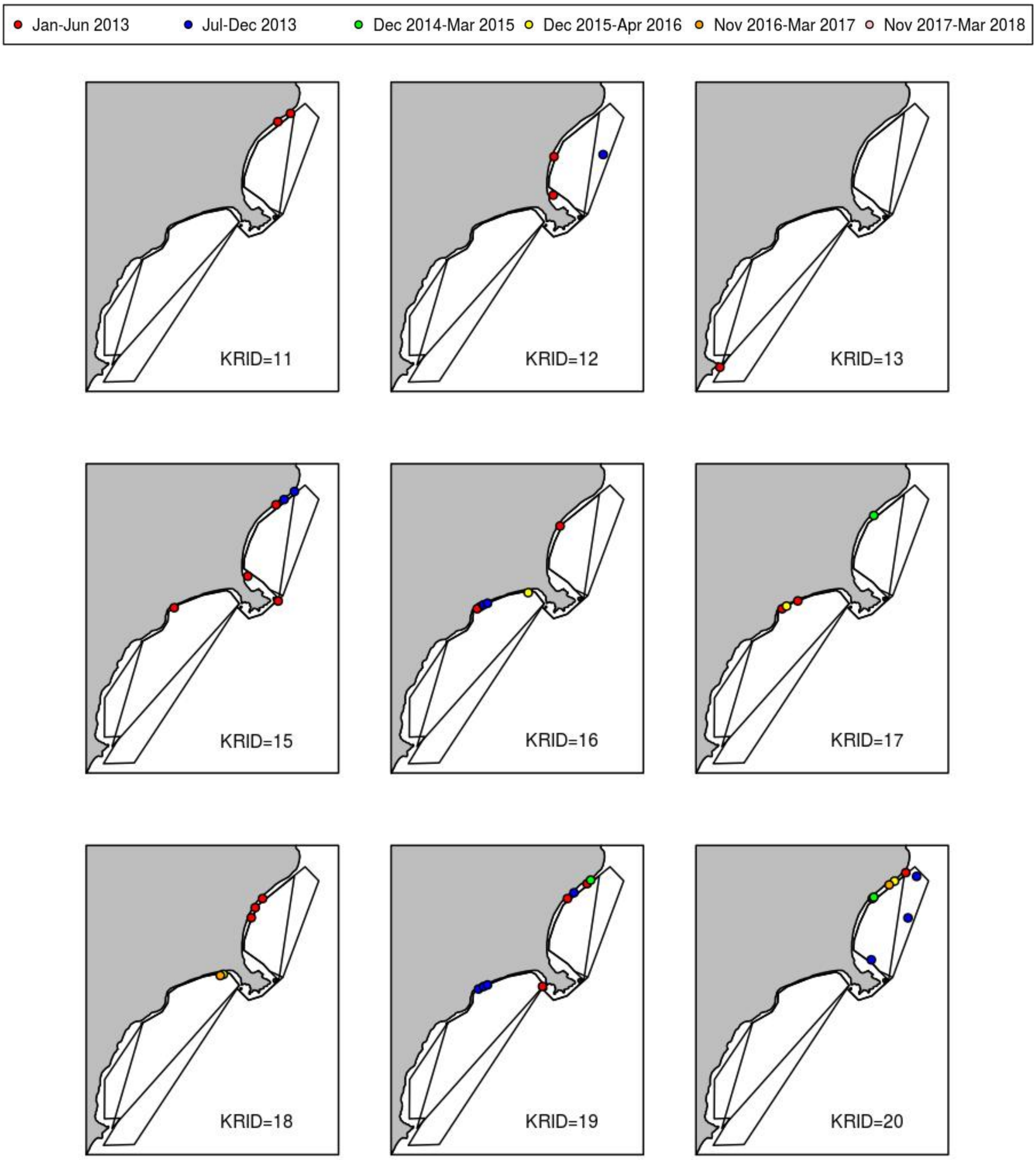


Figure A1: Sighting location of marked individuals.



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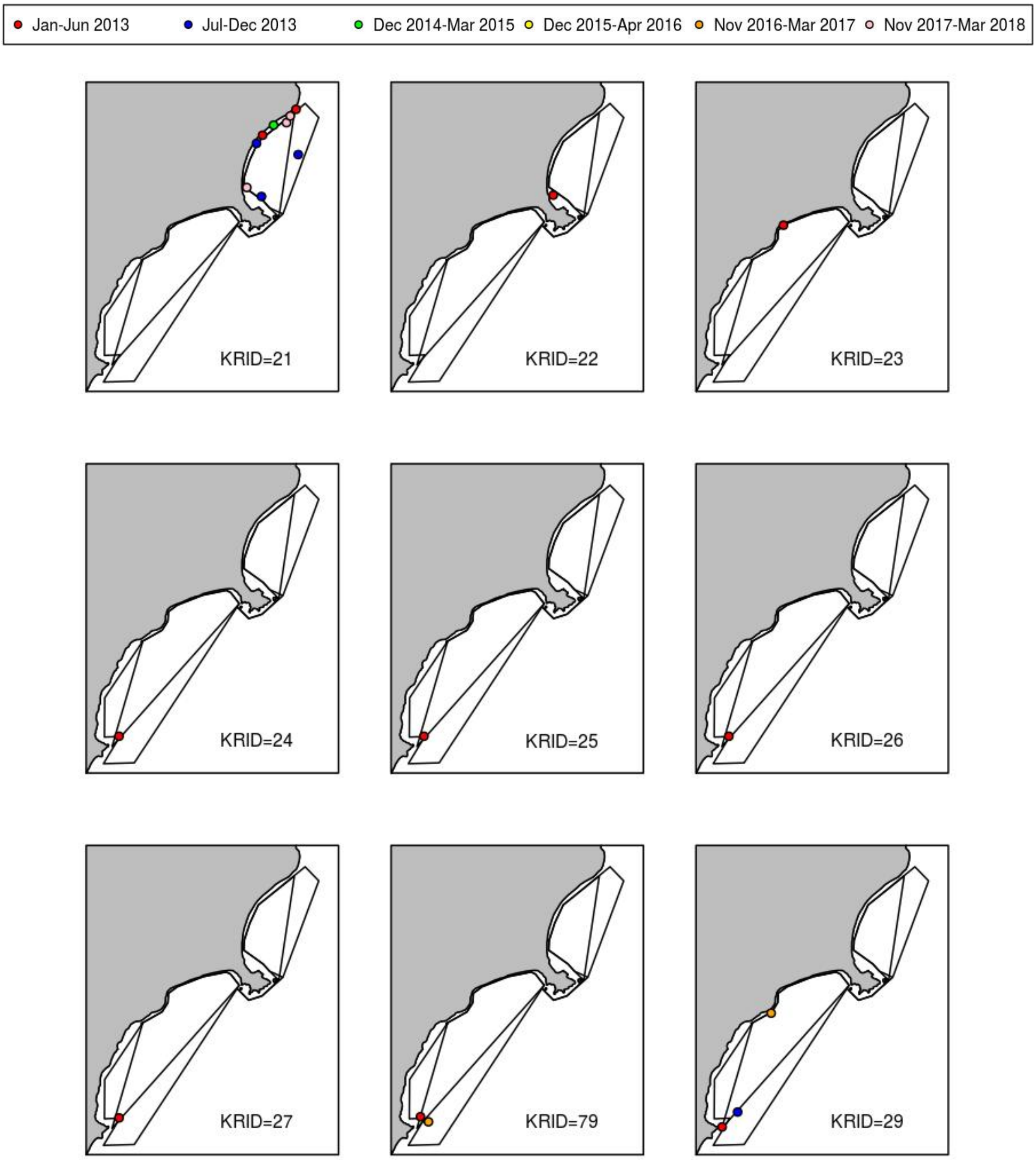

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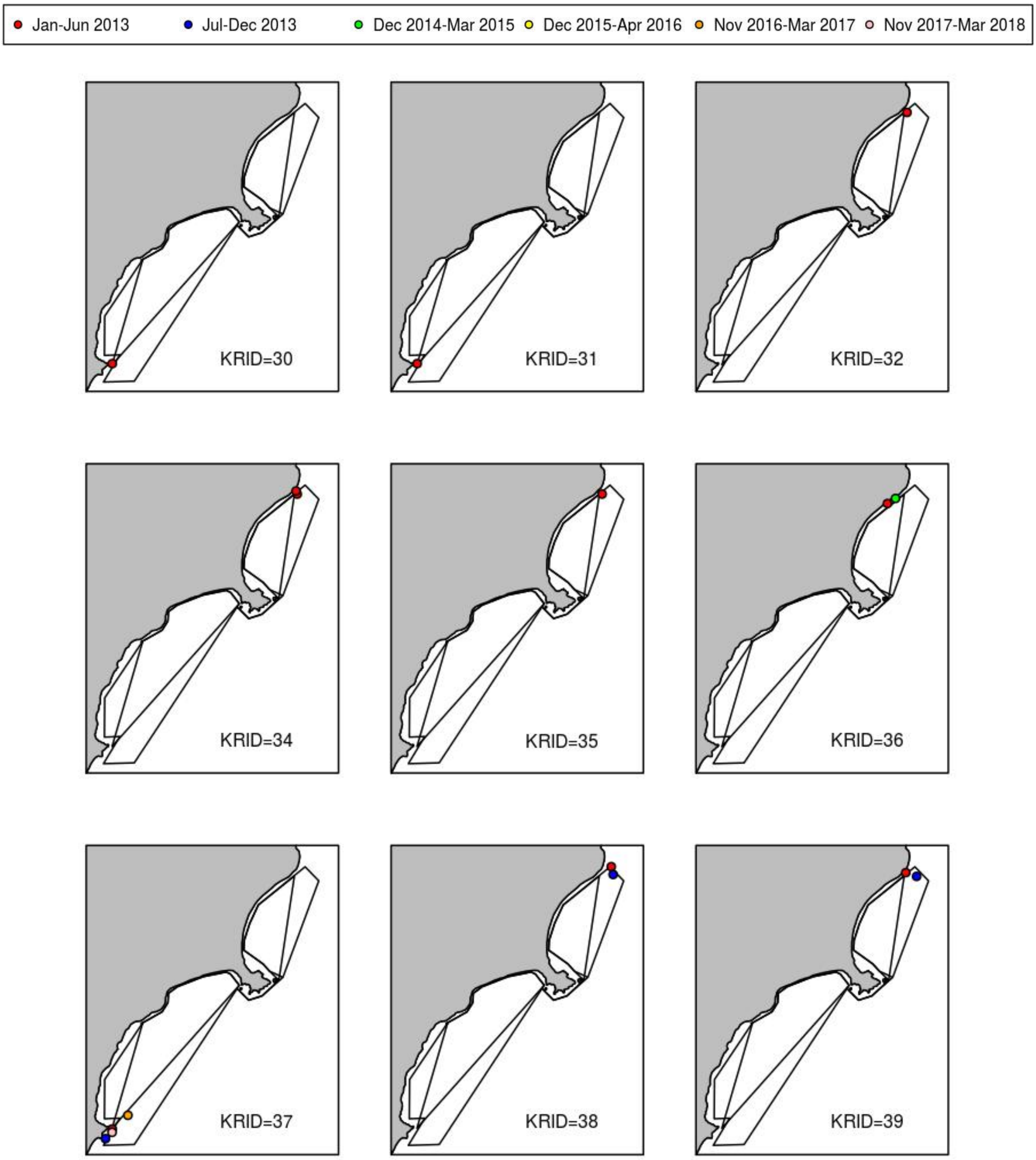

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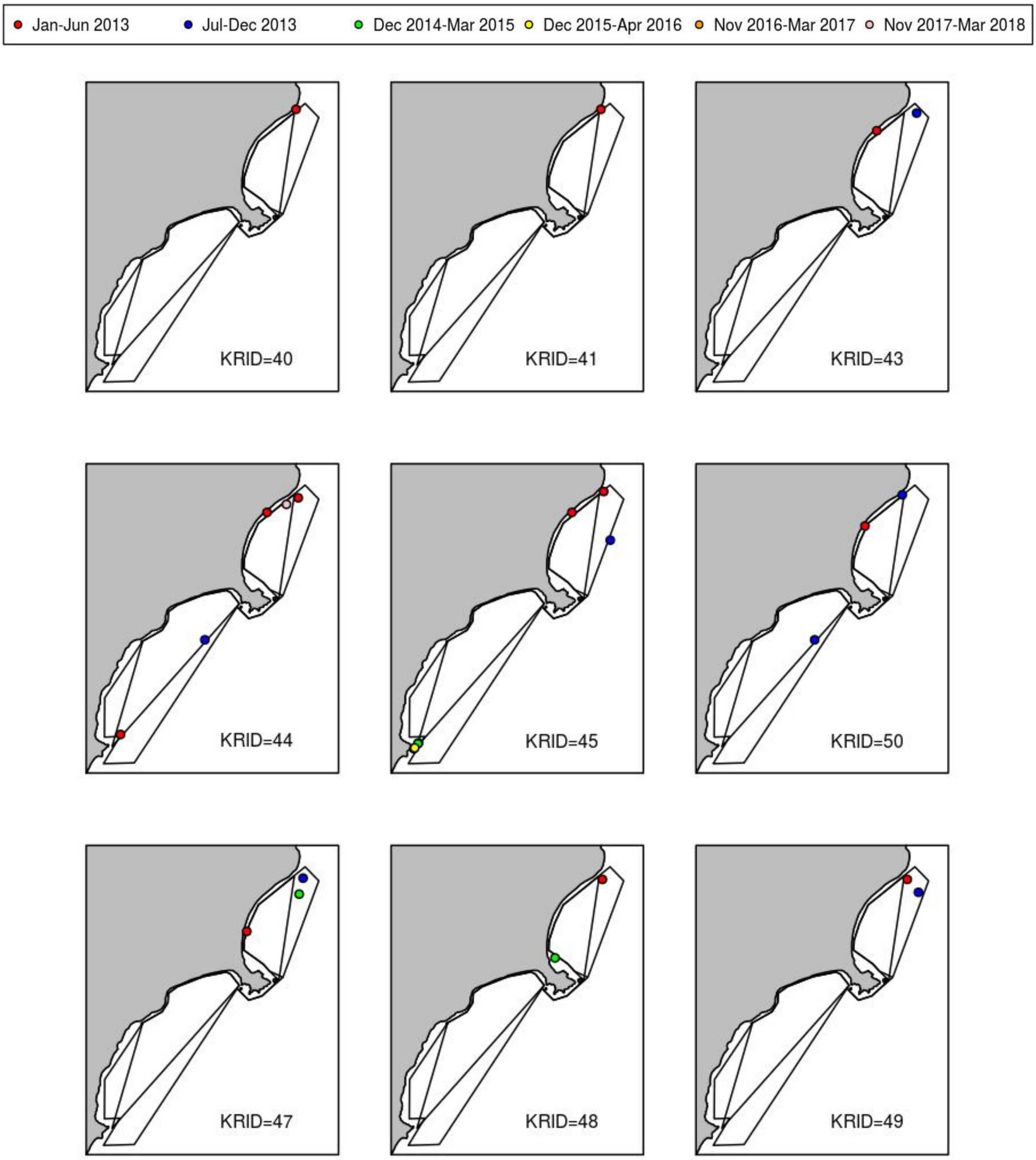

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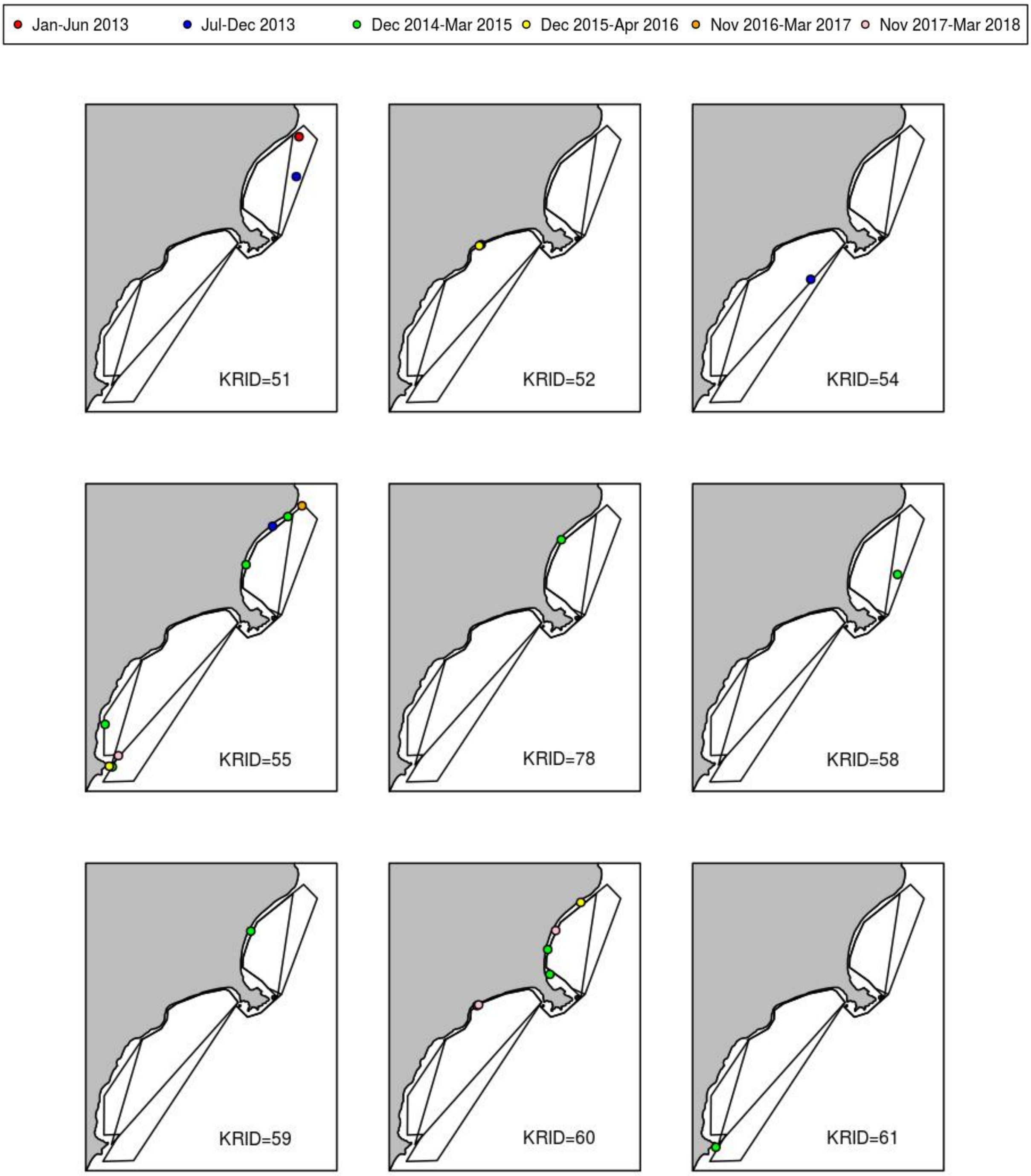

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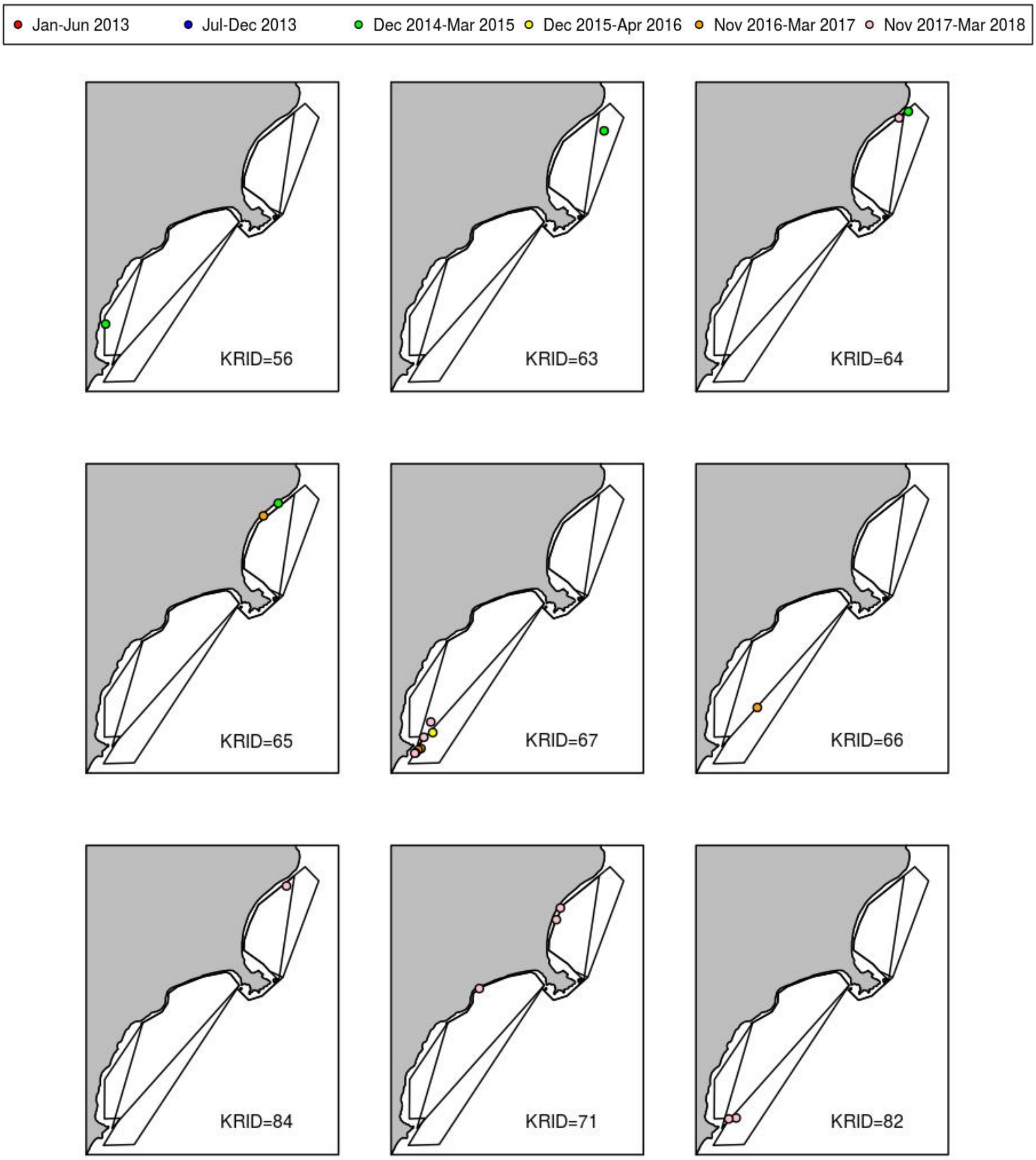

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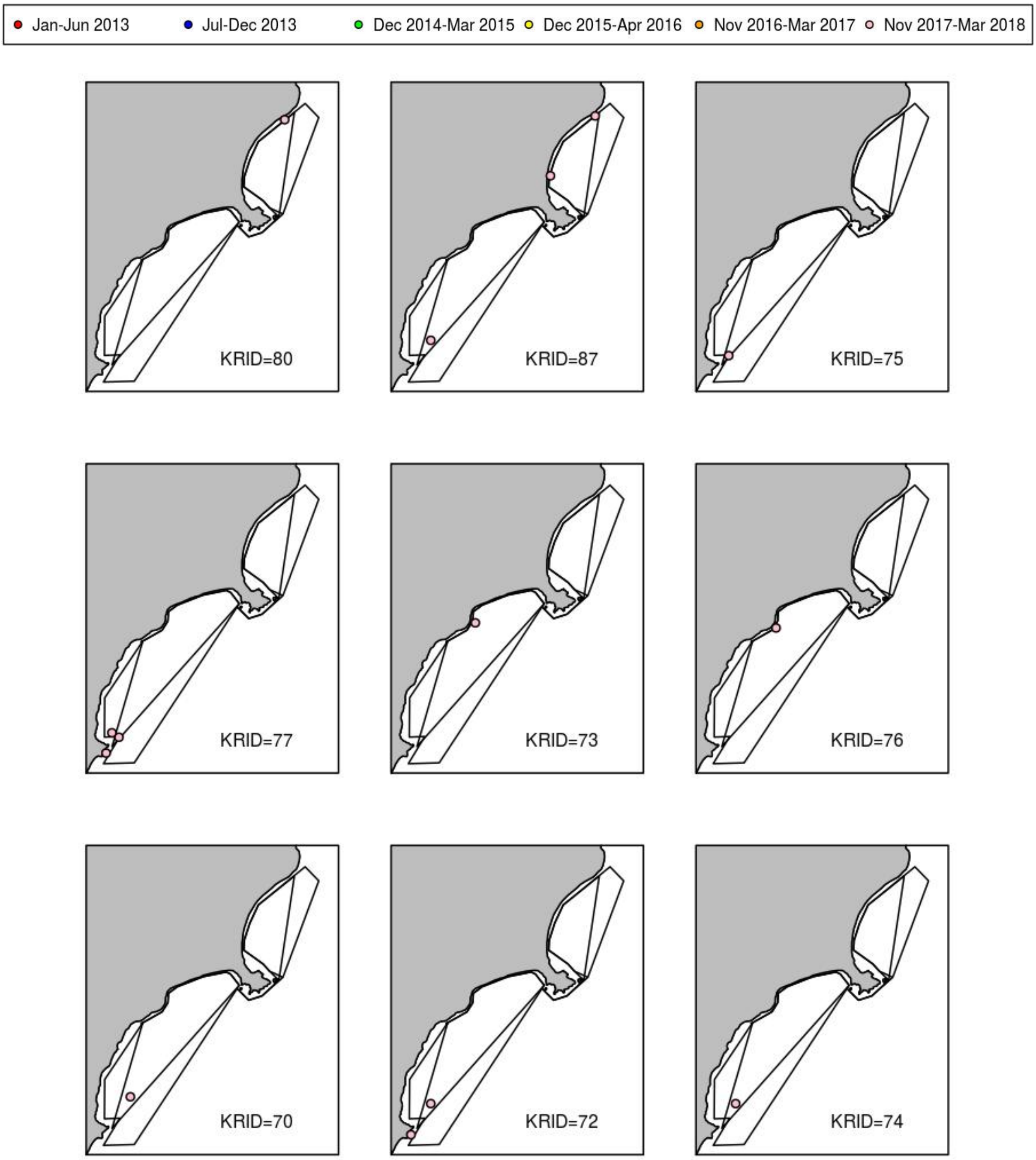

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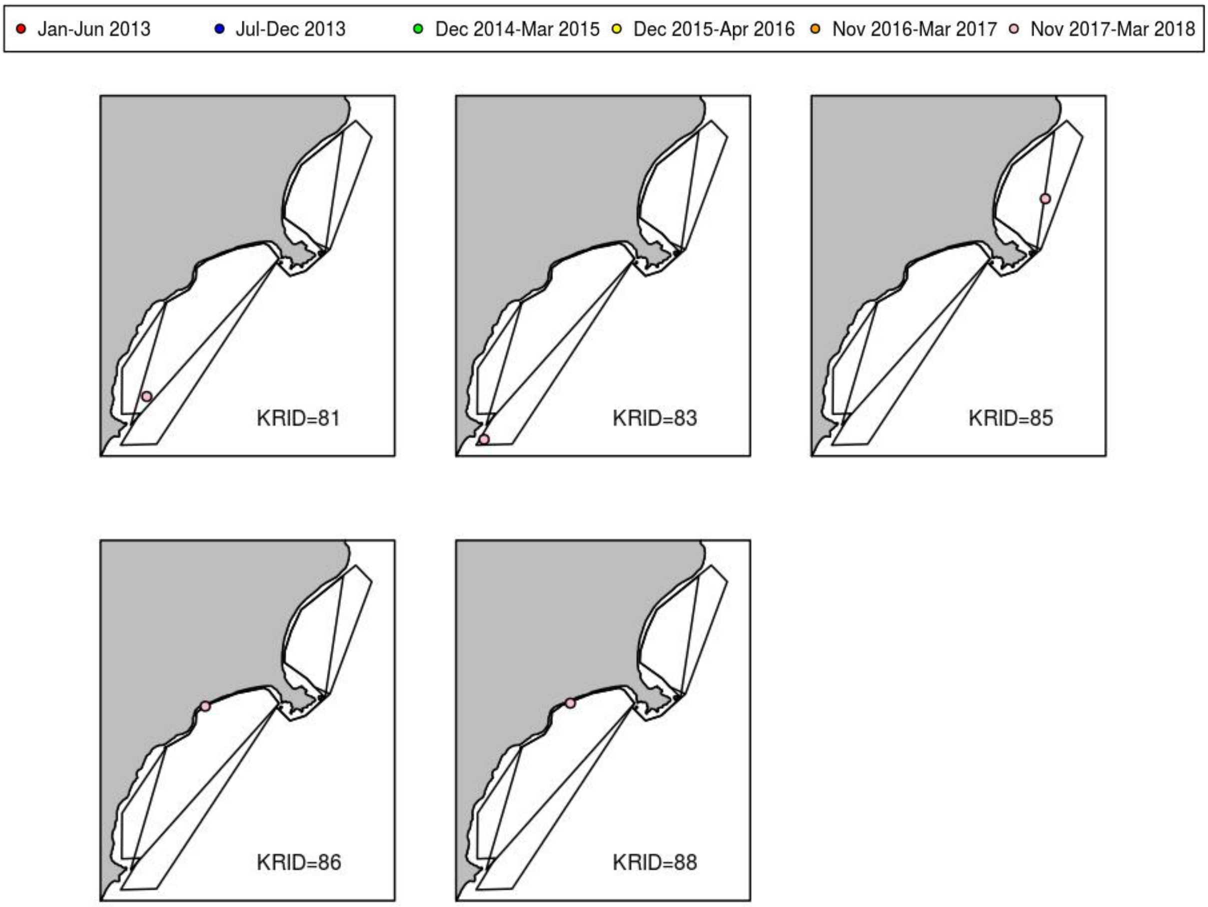

Figure A1 (cont): Sighting location of marked individuals.