POP2018-02

Hoiho population and tracking

Filling data gaps in yellow-eyed penguin marine habitat use

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Introduction

Background/context

Hoiho/yellow-eyed penguins (*Megadyptes antipodes*) are listed as 'endangered' in both the NZ threat classification (Robertson et al., 2017) and the IUCN red list (BirdLife International, 2016). On the mainland, the species has been undergoing a substantial decline starting in the mid-1990s and significantly accelerating since 2008. Ocean warming and associated changes in the marine environment have been identified as an important factor putting pressure on the species, although these effects only partially explain the observed reduction of penguin numbers (Mattern et al., 2017).

Besides climate change, hoiho face a range of threats both at sea and on land, and recent poor breeding success and disease events across most of the species mainland range have highlighted the precarious nature of hoiho (Webster, 2018; Mattern & Wilson, 2019). Direct fishing mortality, particularly in setnets (Darby & Dawson, 2000; Crawford et al., 2017), along with indirect effects of habitat modification (Mattern, Ellenberg & Davis, 2007; Mattern et al., 2013) and reduction of prey availability (Browne et al., 2011; Mattern & Ellenberg, 2018) adversely affect hoiho, particularly on the mainland, Rakiura/Stewart Island Whenua Hou/Codfish Island populations.

Since climate change related, ecosystem-wide changes are difficult to manage on a local scale, it is imperative to ease pressure imposed on the species by other threats to increase its resilience to a changing environment. Whereas conservation of hoiho on land has advanced significantly in recent years, with the ramping up of rehabilitation efforts and measures to control disease outbreaks (Hoiho Recovery Partnership, 2019), key knowledge gaps were identified in their marine habitat, especially lack of representative tracking data over the species entire mainland range to better identify marine habitat use, foraging hotspots and fisheries overlap.

Previous tracking work mainly focussed on hoiho from the Otago Peninsula (e.g. Moore, 1999; Ellenberg & Mattern, 2012; Mattern et al., 2013, 2018) with some limited tracking data available for Oamaru, North Otago (Mattern et al., 2007) as well as the northeast coast of Stewart Island/Rakiura (Mattern, 2006). Most of these data were recorded during the early chick-rearing phase of breeding (i.e. November & December) which may not be representative of the penguins' at-sea distribution outside the breeding season. Once chicks have fledged, adult penguins are no longer bound to nesting duties and can venture further afield.

Thus, to accurately quantify the risk associated with anthropogenic activities at sea obtaining information about the penguins' foraging ecology and their utilization of the marine habitat throughout their annual cycle is key.

Objectives

To fill important knowledge gaps about hoiho distribution at sea, a 20-months long, comprehensive tracking project of hoiho across their mainland range was initiated. Focus of tracking activities was on the regions north of the Otago Peninsula (Aramoana to Oamaru), the Eastern Catlins (Nugget Point, Penguin Bay and Hinahina Cove), Western Catlins (Te Rere), and Rakiura/Stewart Island. Using GPS dive loggers, the penguins' foraging movements and diving behaviour were to be determined in each the principal breeding and life-history stages, i.e. chick guard, early post-guard, late post-guard, pre-moult, winter dispersal, and concluding with incubation. Each site was to be sampled approximately five times although the feasibility of this was dependent on penguin abundance and logistics.

Methods

GPS dive loggers

Two types of GPS dive loggers were used over the course of this study (Figure 1).

Initially, a combination of **i-gotU GPS loggers** (GT-600, Mobile Action, Taiwan; water and pressure proofed using epoxy resin) and **Axy4** time depth recorders (TechnoSmart, Italy). Both devices were taped together into a single, streamlined package (dimensions WxHxL: 40 mm x 15 mm x 65 mm). Many of these devices were lost during initial deployments as the start of the study coincided with a particularly poor breeding season for the mainland hoiho population (2018/19) which resulted in nest abandonments. Several penguins that remained active breeders managed to preen off devices, further contributing to device loss. Some units malfunctioned or leaked water further limiting the pool of available i-gotUs.

In 2019, **AxyTrek** (TechnoSmart, Italy) GPS dive loggers equipped with 1600mAh batteries were introduced as main device to track foraging movements and dive behaviour in hoiho. Shape and size of these devices was identical to the initial i-gotU/TDR packages.

Figure 1. *GPS dive loggers used in this study. AxyTrek (left) and combination of epoxy-encased i-gotU GT-600 and Axy4 TDR (right); SD card shown for scale.*

All devices were programmed to record GPS fixes every 1.5 minutes and sample water depth at 1 second intervals (1 Hz). Using these settings, battery life for each deployment ranged between 5-10 days. Hence, recovery attempts of devices commenced 5-7 days after deployment. All devices had to be recovered to access data; device loss also resulted in data loss.

Device recovery proved to extremely challenging during the winter period when penguins only infrequently returned to their breeding colonies. The birds' unpredictability posed a substantial additional risk for device and data loss.

To overcome this issue, two other device types were trialled, both of which had transmitting functionality, so that the units frequently broadcasted a penguin's location. It was hoped that transmitted data could be used to determine when and where penguins made landfall to recover the devices.

GPS-GSM dive transmitters

OrniTrack-25 solar powered GPS-GSM transmitters (Ornitela, Lithuania; dimensions WxHxL: 32 mm x 20 mm x 62 mm; Figure 2) were trialled on two hoiho. The devices recorded similar data to the GPS dive loggers described above (i.e. GPS location and dive depth) at programmable intervals. However, although all data is also stored in onboard memory, it is also frequently submitted wirelessly through the mobile phone network.

Energy requirements for data transmission is high. To increase operation time, the transmitters are fitted with solar panels that trickle charge the unit whenever the device is exposed to light. If battery voltage falls below certain thresholds, data recording frequency is reduced and ultimately stopped until the device has recharged sufficiently to resume normal operation.

The use of GPS-GSM dive transmitters is only feasible in areas that have adequate mobile phone coverage, which limited their use to North Otago.

Satellite transmitters

Satellite transmitters were used to track two hoiho from the Catlins where patchy mobile phone coverage prevented the use of GPS-GSM dive transmitters. SPOT-275 satellite transmitters (Wildlife Computers, USA; dimensions WxHxL: 17 mm x 20 mm x 86 mm; Figure 2) that remained unused from a winter tracking study on Fiordland penguins/tawaki (Mattern

& Ellenberg, 2020) were used; data transmission costs were kindly covered by the Antarctic Research Trust.

The transmitters operate through the ARGOS satellite network and were programmed to broadcast their location 30 times per hour. However, location fix frequency was dependent on whether ARGOS satellites were in view of the signal. Moreover, fix accuracy varied with the number of transmitter broadcasts received by a satellite. On average, the transmitted locations fell within an error range of 250 m to 1500 m.

In addition to the satellite transmitter, an Axy4 time depth recorder (TechnoSmart, Italy; dimensions WxHxL: 15 mm x 9 mm x 34 mm) was also fitted to the birds; the unit was attached directly behind the satellite transmitter.

Figure 2. *Transmitting devices used during four deployments in this study. Ornitrack-25, GPS-GSM dive transmitter (left) and Wildlife Computers SPOT-275 satellite transmitter (right); SD card shown for scale. Note that the Ornitrack-25 is sitting on a magnetized base plate that keeps the unit in sleep mode; the unit is deployed without this base.*

Camera loggers

To get insights into the penguins' feeding habits, i.e. their prey composition, pursuit behaviour and prey capture rates, novel animal-borne camera loggers (PenguCam, Eudyptes Ltd, New Zealand; dimensions WxHxL: 35mm x 20 mm x 85 mm; Figure 3) were deployed on 10 occasions. These devices record continuous full HD video footage and have an operating time of 2-3 hours. Hence, camera deployments were only conducted when short foraging trips were predictable (i.e. during chick-guard stage) so that the units could be recovered after a single foraging trip. The devices are equipped with a salt-water switch that triggers preprogrammable delayed start of the video recording, allowing it to focus on the penguins' active foraging period. Devices were set-up to start recording four hours after the penguin had entered the water when penguins had reached their foraging destinations. Cameras were deployed in conjunction with GPS dive loggers, so that foraging tracks and dive data were recorded as well.

While cameras were recovered after one foraging trips, GPS dive loggers remained on the penguins for 5-7 days. Results of the camera deployments have been described in monthly reports for November and December 2019.

Figure 3. *Animal-borne camera logger deployed on some hoiho during the course of this project. SD card shown for scale.*

Device attachment

All devices were attached using the established "Tesa-tape" method (Wilson et al., 1997) which uses adhesive tape threaded under rows of feathers and then wrapped around the device (Figure 4). This method is fully reversible and does not cause damage to the plumage when devices are recovered.

The devices were attached to the birds' lower backs so that the units would sit behind the penguin's arched back which significantly reduces drag (Bannasch, Wilson & Culik, 1994). When attaching the units, special care was taken to not obstruct the bird's access to the preening gland.

Figure 4. Melanie Young in the process of threading adhesive tape into a hoiho's plumage to attach a GPS dive logger. Long Point, Catlins, 4 January 2019.

After several penguins managed to preen off devices while at sea, cable ties were used in the same fashion as the tape (i.e. threaded under feathers) and tightened around the device using a cable tie gun. While the rate of device loss was lowered after cable ties were added to the attachment procedure, it still could not prevent device loss when birds were determined to preen off their devices. This only occurred outside the breeding period, when the penguins did not have to worry about nesting duties and had more time to work on removing devices.

Figure 5. GPS dive loggers attached with tape and a cable tie to the lower back of a hoiho.

Study sites, timing & number of deployments

This study coincided with two poor breeding seasons for mainland hoiho. Numbers of breeding pairs were low so that further locations were added to the sites outlined in the original project objectives. Device deployments (n=73) were conducted at a total of 12 different study sites between North Otago and Rakiura/Stewart Island during 2018 and 2020 (Table 1, Figure 6). North Otago, the Catlins and the northern Otago Peninsula were covered during all important stages of the hoiho annual cycle, the exception being the incubation phase. In the face of poor breeding performance it was decided to not risk interfering with the birds during the incubation stage when they are particularly sensitive to human disturbance (Ellenberg et al., 2007; Ellenberg, Mattern & Seddon, 2013). Working with an endangered species requires minimising the risk of nest abandonment, especially when environmental conditions appear not to be favourable.

Table 1. *Study sites of the hoiho tracking study conducted between December 2018 and August 2020.*

Region	Site	Stage*	Deployments [n]
North Otago	Bushy Beach *-45.12223,170.97951*	PM	2
North Otago	Bobby's Head *-45.53037,170.75947*	PG, PM, WI	8
North Otago	Aramoana *-45.77105,170.70017*	IN, CG, PM	10
Otago Peninsula	Papanui *-45.86587,170.74188*	PG, PM, WI	14
Otago Peninsula	Cicely Beach *-45.87384,170.70729*	PG, PM, WI	2
Catlins	Nugget Point *-46.44647,169.80372*	CG, PG, WI	8
Catlins	Penguin Bay *-46.50823,169.69541*	PG, WI	5
Catlins	Long Point *-46.57693,169.58516*	CG, PG, WI	8
Catlins	Haywards Point *-46.56265,169.56538*	PM, WI	3
Catlins	Mahaka *-46.57499,169.47120*	CG	1
Catlins	Te Rere *-46.64739,169.22207*	PG, WI	6
Rakiura/Stewart Is.	Bravo Group *-46.95410,168.13698*	CG	6

** IN – Incubation, CG – Chick-guard, PG – Post-guard, PM – Pre-moult, WI - winter*

Figure 6. *Overview of the study sites, timing and number of deployments*

Data handling & analysis

Raw GPS data was uploaded to the Movebank tracking data repository after device recovery (Movebank ID: 610046035, URL: https://bit.ly/hoihotracking2020).

Dive data was processed using custom analysis scripts programmed in Matlab (Mathworks, Inc., USA). Dive events were identified and dive phases determined following methods outlined in Mattern et al. (2007). Main dive parameters determined were

- **surface time**, time spent at the sea surface prior to each dive
- **dive time**, time spent underwater before resurfacing
- **descent duration**, time spent descending to depth from the surface
- **bottom time**, time spent after the descent and before ascending again
- **bottom start depth**, depth at which the bottom phase started
- **bottom end depth**, depth at which bottom phase ended
- **max dive depth**, dive depth reached during each dive
- **ascent duration**, time spent ascending back to the surface after conclusion of bottom phase
- **diving efficiency**, ratio of dive time to duration of a full dive cycle, i.e. dive time / (surface time + dive time)
- **foraging effort**, ratio of bottom time to duration of full dive cycle, i.e. bottom time/ (surface time + dive time)
- **benthic dive**, binary parameter indicating if the dive was pelagic (0) or benthic (1)

The benthic dive parameter is an important metric in hoiho due to their predominantly benthic foraging strategy (Mattern et al., 2007). Benthic dives were identified by their characteristic dive profile, which resembles a square wave with a linear descent, followed by a bottom phase with little to no vertical undulations, and concluded by a linear ascent (Figure 7). Benthic dives often occur in sequences during which the penguin reaches similar depths of previous dives; sequences of pelagic dives generally vary in the maximum depth reached.

See also monthly report for April 2020 for further details about the dive analysis process (DOI: https://doi.org/10.6084/m9.figshare.12203168).

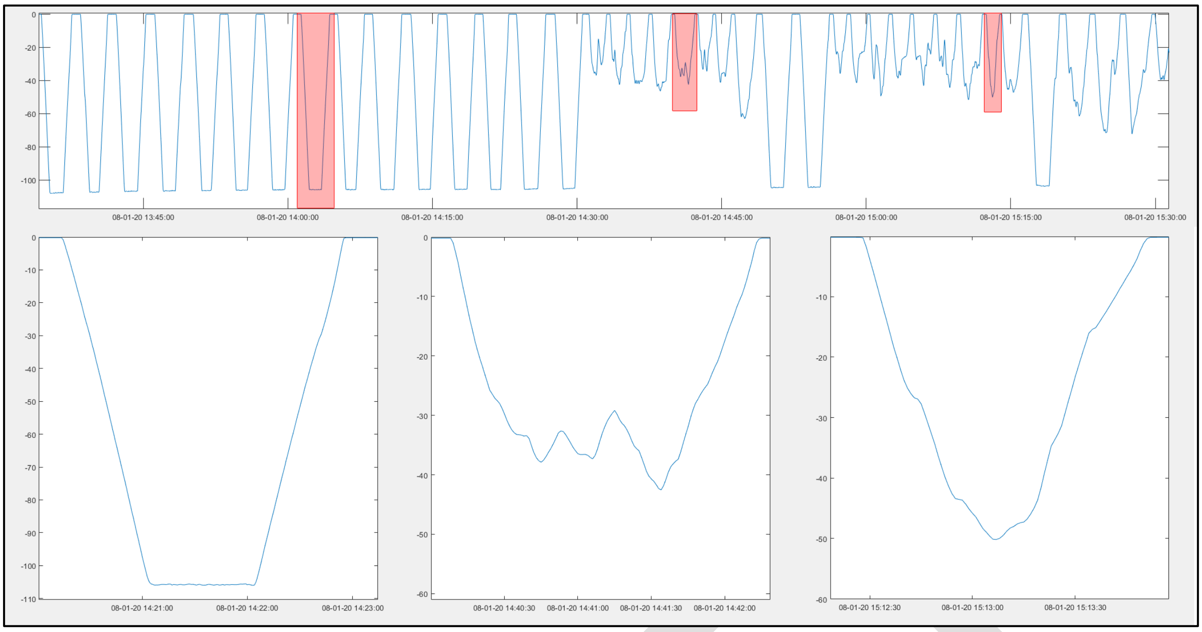

Figure 7. *Dive profile characteristics of benthic dives (lower left panel) and pelagic dives (centre and right panel).*

Dive analysis results were combined with recorded GPS data, by matching GPS timestamps with those of dive events. The last GPS fix recorded during the surface period prior to a dive was used as the geographic location for that dive. If no GPS fix was recorded during the surface period, the approximate location was calculated as linear interpolation of the last GPS fix prior to and the first GPS fix after the dive in question. For each interpolated dive, the time-to-fix (TTF, in seconds) was calculated which specifies how close temporally the interpolated fix is to a true GPS fix. The TTF provides a measure of accuracy, with interpolated fixes with a short TTF generally being more likely to be an acceptable estimate of a dive location (e.g. Tremblay et al., 2006). For spatial analysis only fixes with TTF < 600 (i.e. within 10 minutes of a true GPS fix) were accepted. To provide a basic spatial overview of the marine habitat utilization by hoiho, kernel density (KD) analysis was performed on accepted dive locations. KD analysis was carried out using the Geospatial Modelling Environment (GME, Beyer, 2012) and ArcGIS (ESRI, USA).

Results

Of the 73 deployments of tracking devices conducted over the course of 20 months, 11 units could not be recovered because penguins managed to preen off the devices before they could be recaptured. Five deployments yielded no or severely fragmented data due to device malfunction.The remaining 57 deployments yielded foraging data from 42 different penguins. Nine birds were fitted with devices twice and another four birds carried trackers on three occasions during different life history stages; the remaining 29 birds carried tracking device for a single deployment period.

GPS dive loggers remained on the birds for a mean 9.3±3.6 days (range: 1.9-33 days); recoveries that occurred >10 days after deployment were delayed because of penguins eluding recapture. The two birds from Bushy Beach that carried GPRS GSM Loggers could only be recaptured 21 and 45 days after deployment. The two penguins from Penguin Bay in the Catlins carrying satellite transmitters proved to be even more difficult to recapture and devices could only be recovered 51 and 121 days after deployment; the latter recovery was only possible after the bird had settled to breed.

A total of 33,290 at-sea locations were determined directly from device sensors (i.e. GPS or satellite transmission, Figure 8.) from which of 370 individual foraging trips could be reconstructed representing a total of 6,417.1 at-sea hours. Foraging trip duration ranged between 0.6 hours during chick-guard (mean: 10.7±3.4 hrs) to 13.3 days (mean: 1.6±0.6 days) during the pre-moult period (Table 2).

Table 2. *Overview of foraging trip durations in the different hoiho life-cycle stages.*

Stage	Foraging trip duration		
	Min	**Max**	**Mean ± SD**
Incubation	11.1 hrs	12.2	11.8±0.3 hrs
Chick-guard	0.6 hrs	12.0 hrs	10.7±3.4 hrs
Post guard	0.7 hrs	59.9 hrs	12.9±4.2 hrs
Pre-moult	4.6 hrs	319.4 hrs	37.3±14.8 hrs
Winter	1.7 hrs	228.0 hrs	15.2±26.0 hrs

Between 2003 and 2016, GPS tracking studies carried out by University of Otago researchers recorded comprehensive tracking data on hoiho from the southern Otago Peninsula (Boulder Beach; Mattern et al., 2013, 2018, Mattern et al. unpublished data) as well as northern Stewart Island and Whenua Hou/Codfish Island (Mattern, 2006; Seed et al., 2018, Mattern et al. unpublished data). This project focussed on the Catlins and North Otago. While it would have been desirable to track hoiho at Katiki Point (North Otago), the data recorded at other North Otago sites is likely adequate to develop habitat models for the region. Without access to Foveaux Strait islands occupied by hoiho, data recorded in the southern Catlins (Te Rere Reserve) may serve to improve habitat models for the Foveaux Strait area. However, a sharp drop in penguin numbers before tracking commenced meant that only rudimentary tracking data could be recorded in the Catlins. Tracking work on Rakiura/Stewart Island was limited to a few deployments in Paterson Inlet in December 2019. There are no inshore set netting restrictions around Rakiura and its outliers, so it is crucial to obtain additional hoiho tracking data to develop adequate habitat models and improve marine conservation of hoiho. A follow-up study (POP2020-05) commencing in November 2020 will address this.

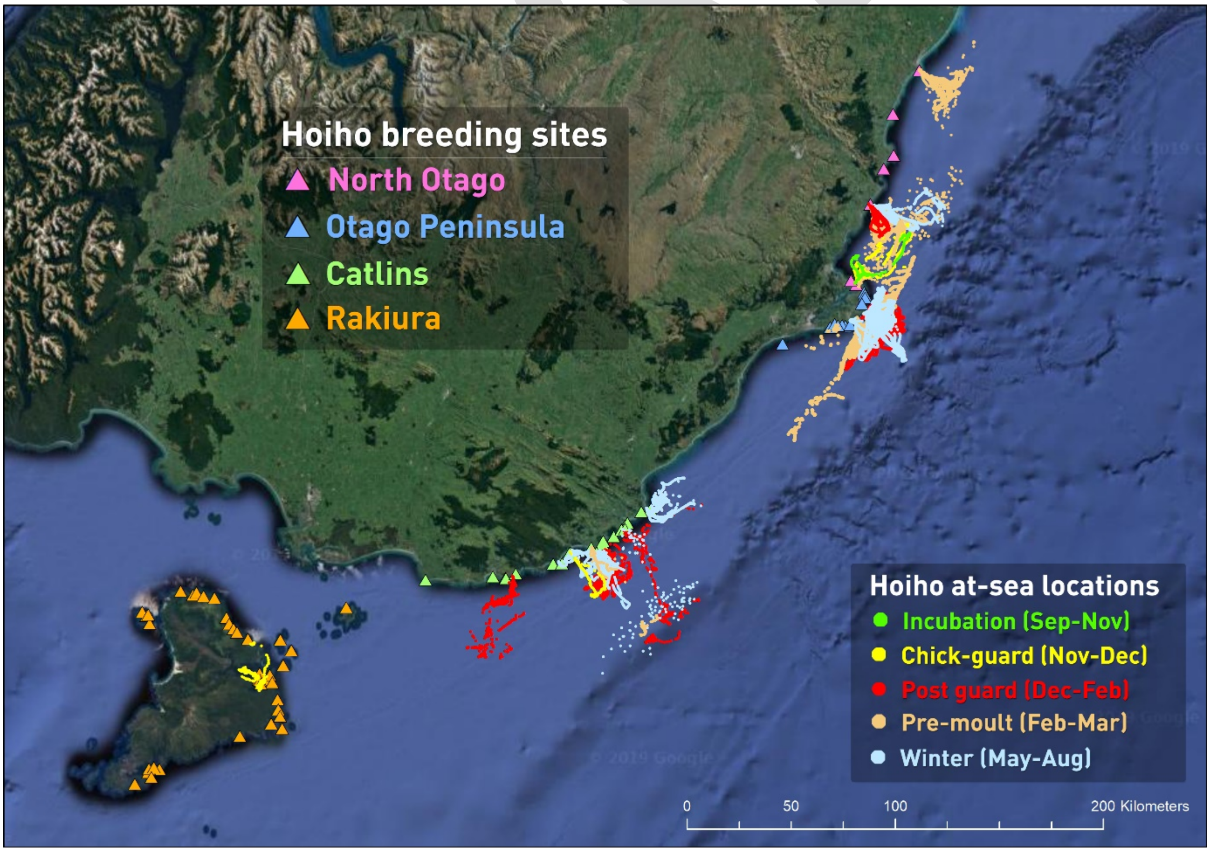

Figure 8. *Tracking data recorded during this project in relation to breeding locations of hoiho along the South Island coastlines. Hoiho colony data derived from 1984-2015 records in the YEP database.*

Diving behaviour

A total of 118,698 dive events were determined from the depth data recorded during the deployments. Core dive parameters differed between the regions, especially dive depths with penguins from the Catlins and the Otago Peninsula diving deeper that birds from North Otago and Rakiura. Conversely, the penguins from these two regions exhibited a greater affinity to dive to the seafloor (Table 3, Figures 9a-d). In North Otago, a mean 62% of all dives were benthic, at Rakiura the rate of benthic dives was 69%, while these dives made up 55% and 27% of all dives at the Otago Peninsula and in the Catlins, respectively. Within regions, dive behaviour remained consistent between the different life cycle stages, the exception being the winter period in North Otago and the Otago Peninsula when fewer benthic dives were undertaken.

Table 3. *Summary of core dive parameters recorded in the different regions through the penguins' annual life-cycle stages.*

Region	Stage*	Birds	Dives	Benthic dives		Dive time	Max depth	Mean depth
		n	*n*	*n*	*%*	*s*	*m*	*m*
North Otago	*IN*	2	1,616	1,182	73.1	105±43	58.2	27.4±15.4
	CG	3	4,589	2,951	64.3	96±46	81.3	22.5±14.3
	PG	1	1,126	876	77.8	110±47	38.0	24.9±13.5
	PM	8	36,291	25,905	71.4	122±48	105.0	28.8±16.3
	WI	2	4,202	958	22.8	70±48	76.2	15.3±16.7
Otago Peninsula	*PG*	5	10,923	6,216	56.9	114±55	129.1	44.5±31.3
	PM	5	9,325	6,306	67.6	128±57	86.5	39.8±24.8
	WI	5	10,458	4,115	39.4	93±58	131.0	29.5±33.3
Catlins	*CG*	1	323	36	11.1	123±55	112.8	46.7±30.6
	PG	7	14,307	4,145	29.0	122±60	145.1	48.0±36.4
	PM	2	2,509	961	38.3	122±70	126.9	51.8±48.4
	WI	8	19,543	5,680	29.1	88±65	137.2	27.4±39.4
Rakiura	*CG*	5	3,486	2,418	69.4	93±32	38.1	16.9±8.4

** IN – Incubation, CG – Chick-guard, PG – Post-guard, PM – Pre-moult, WI - winter*

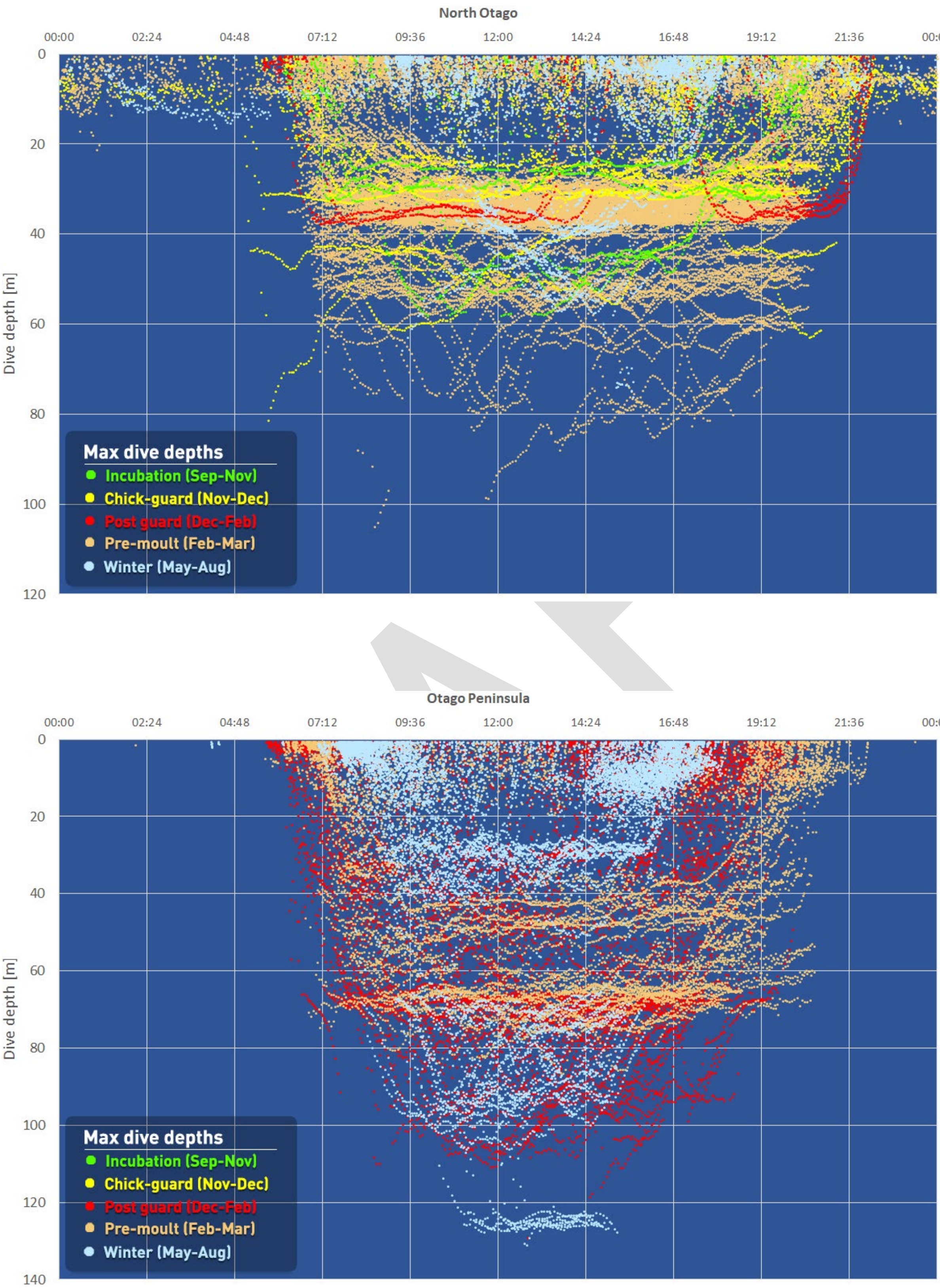

Figure 9a&b. *Diurnal maximum dive depths recorded – North Otago (n=47,824 dives) & Otago Peninsula (n=30,706).*

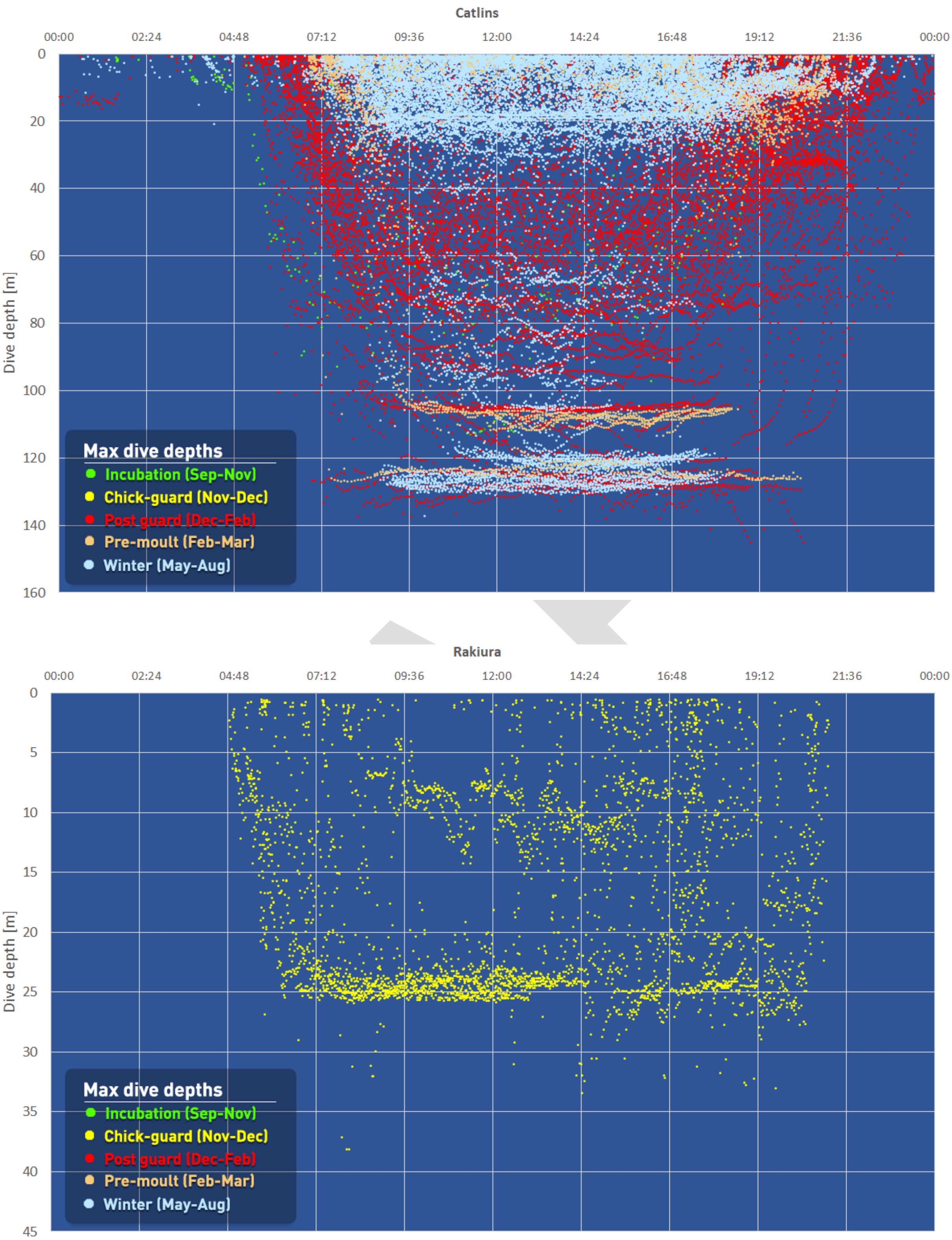

Figure 9c&d. *Diurnal maximum dive depths recorded o – Catlins (n=36,682) & Rakiura (n=3,486).*

Foraging ranges – North Otago

The at-sea movements of hoiho breeding along the North Otago coastline are confined to the continental shelf. Most dives occur 5-25 km from the mainland. Trips to the shelf edge were limited to the pre-moult and winter periods, although one penguin performed a single trip to the shelf-edge during the post guard stage (Figure 10a).

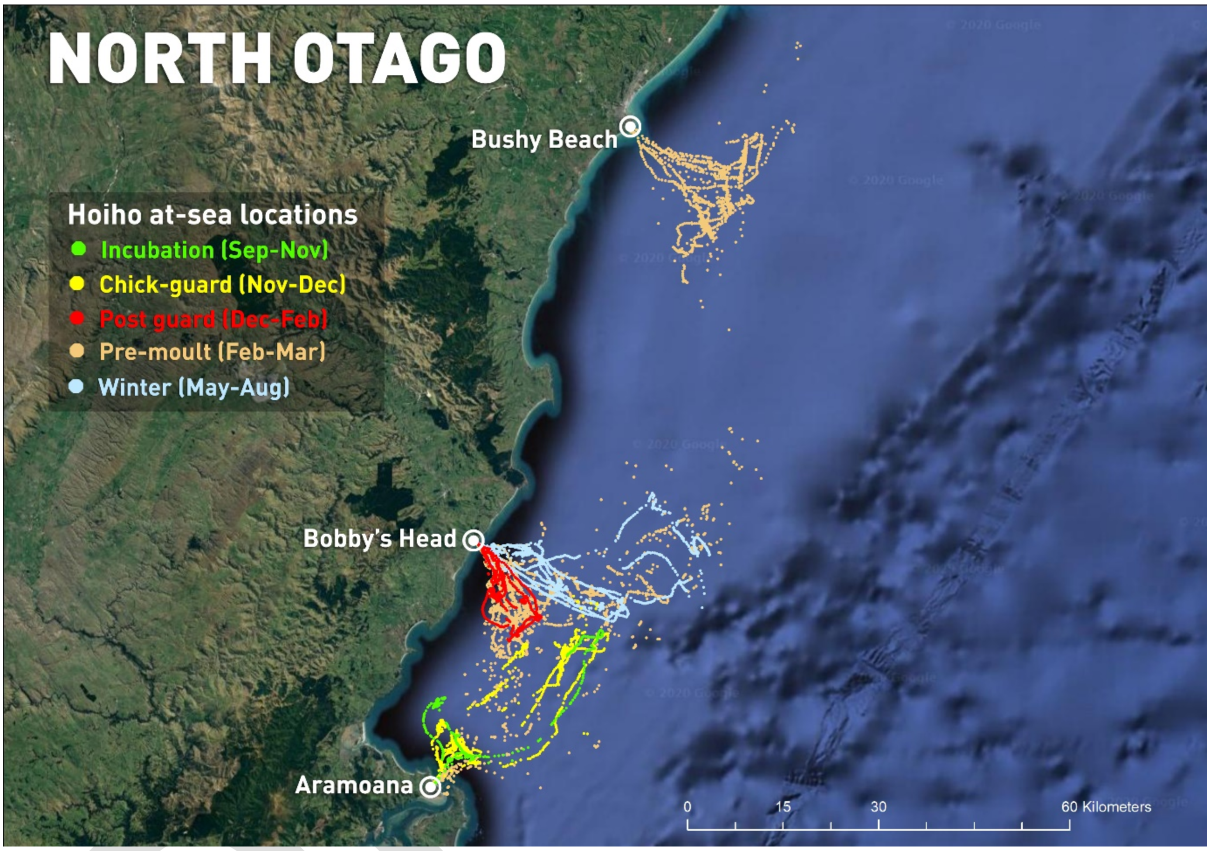

Figure 10a. *GPS fixes of foraging hoiho in North Otago between 17 Feb 2019 and 04 Jul 2020.*

Foraging ranges of hoiho from the two North Otago sites Aramoana and Bobby's Head overlapped, particularly during the non-breeding season. Penguins from Bushy Beach foraged in the same general areas as previously reported for that site (Mattern et al., 2007) although the individual birds spread out further along trajectories parallel to the coast.

At-sea distribution throughout all breeding stages is consistent (Figure 10b). The birds travel further afield during the pre-moult stage and over winter, although the areas utilized during the breeding season remain important foraging habitat in the non-breeding season as well. 80% of yellow-eyed penguin foraging areas are located outside the 4 nm set net restriction zone. Sections of the KDE areas within the ban zone represent the outgoing and incoming corridors of penguins travelling to and from the main foraging habitats further offshore.

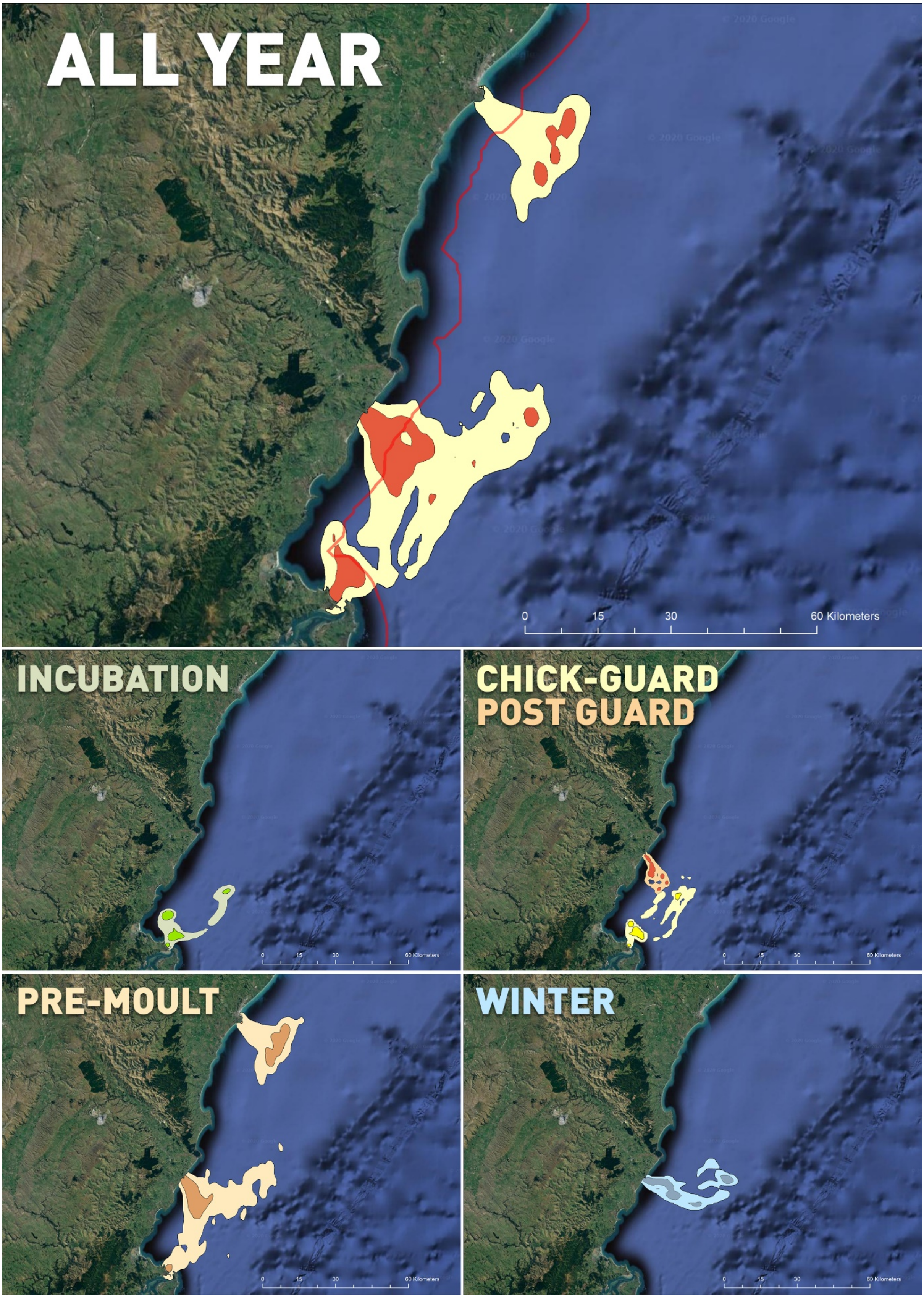

Figure 10b. *Distributions of hoiho GPS fixes along the North Otago coastline. Light coloured polygons represent 95% fixed Kernel Density Estimate (KDE), strong coloured polygons the 50% KDE regions. Red line in main graph indicates approximate boundary of the 4nm inshore set net restriction zone.*

Foraging ranges – Otago Peninsula

Hoiho from Papanui Beach generally distributed themselves within the 70-100 m depth range and stayed within 15 km of the peninsula's east coast (Figure 11a). The exception was one penguin that travelled to the shelf-edge during winter foraging trips (which also accounted for the deepest dives recorded in Otago Peninsula penguins, i.e. >120 m, see Figure 9b). Greatest foraging ranges were recorded during the pre-moult period where one bird foraged in areas utilized by North Otago penguins (compare Figures 10a and 11a) and another penguin travelled 70 km towards the Catlins in the Southwest.

Overall, distribution of GPS fixes suggests that the sea region south off Cape Sounders is of particular relevance, especially during the breeding and pre-moult period (Figure 11b). The southern extremes of the distribution overlap with the areas identified as important foraging grounds for hoiho from Boulder Beach (Ellenberg & Mattern, 2012; Mattern et al., 2013). The dive depths recorded in this region (60-80 m, see Figure 9b) also correspond to diving behaviour observed in Boulder Beach birds. During the pre-moult and winter stages individual birds ventured north and/or further offshore (reaching dive depths of >130m). 75% of the 95%KDE, and 35% of the 50%KDE are located outside the 4nm set net restriction zone.

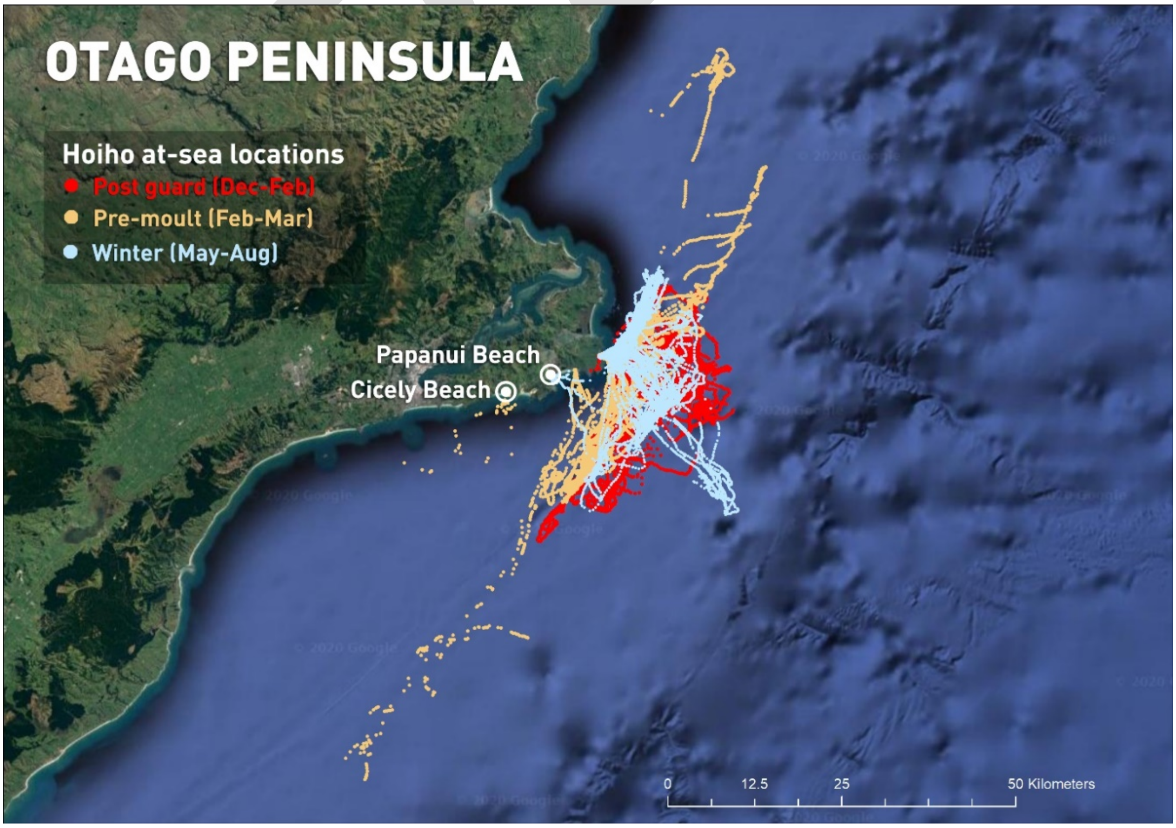

Figure 11a. *GPS fixes of foraging hoiho at Otago Peninsula between 12 Feb 2019 and 29 May 2020.*

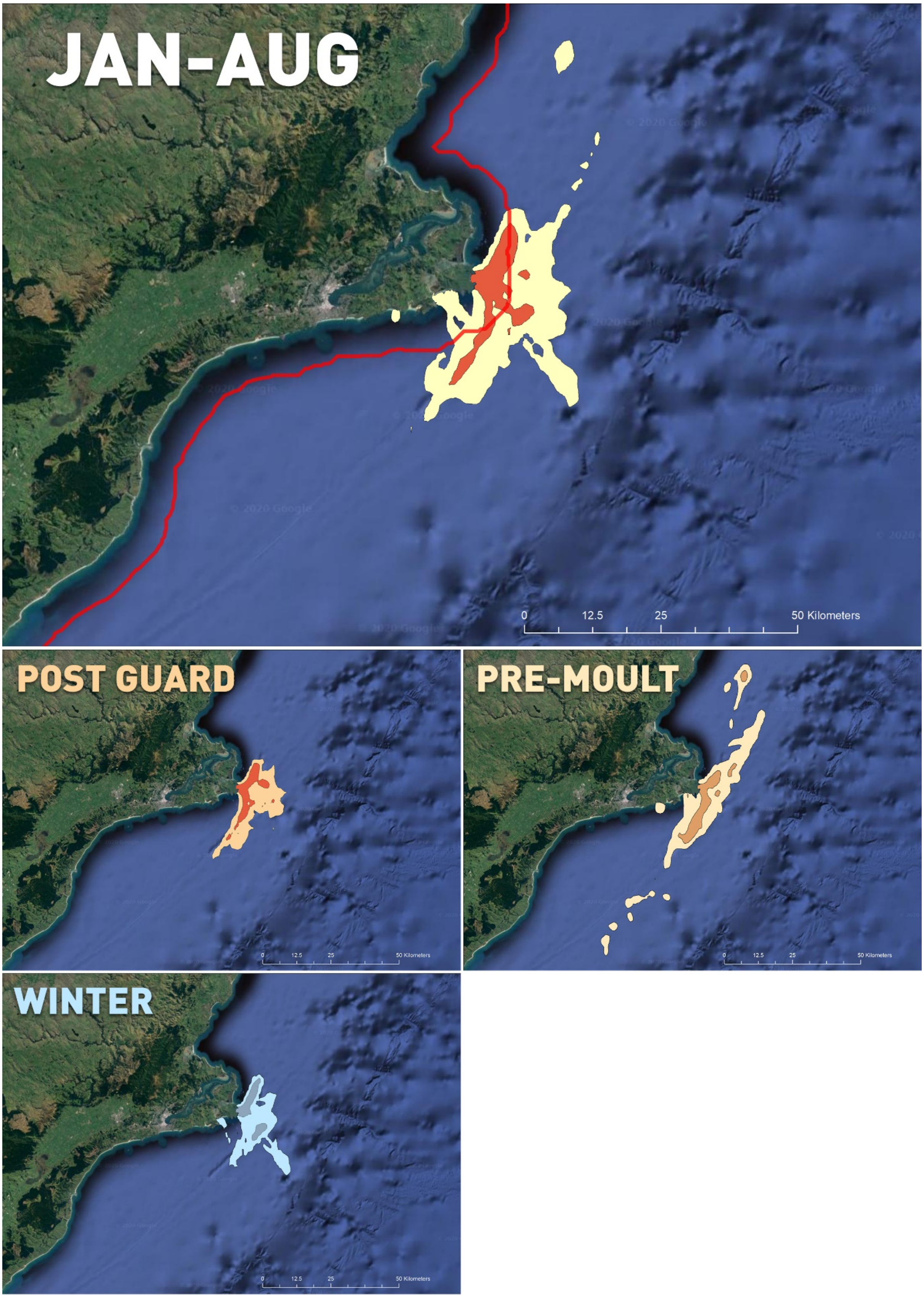

Figure 11b. *Distributions of hoiho GPS fixes off the central Otago Peninsula. Light coloured polygons represent 95% fixed Kernel Density Estimate (KDE), strong coloured polygons the 50% KDE regions. Red line in main graph indicates approximate boundary of the 4nm inshore set net restriction zone.*

Foraging ranges – Catlins

Recorded GPS data provide a good overview of the at-sea distribution for the northern and central Catlins (Figure 12a). Foraging ranges during the post guard stage of breeding and in winter are comparable. Overall, the penguins tended to remain within a 20 km radius from their colonies, with birds from Nugget Point foraging in the southern reaches of Molyneux Bay (a behaviour previously recorded in chick rearing birds from the same site also, Mattern et al, unpubl. data), while penguins from other Catlins sites generally headed southeast towards the central continental shelf. Despite the reasonably short foraging ranges, dive depths associated with foraging behaviour regularly exceeded 100 m owing to the local bathymetry, indicating a higher foraging effort required by the penguins in the Catlins. Birds from Penguin Bay travelled further away from the coast during breeding as well as over the winter months, which may indicate poor foraging conditions closer to the shore.

Kernel densities estimate show that most of the hoiho activity concentrates on sea regions outside the 4nm set net restriction zone which applies to all stages of the penguins' annual life cycle (Figure 12b).

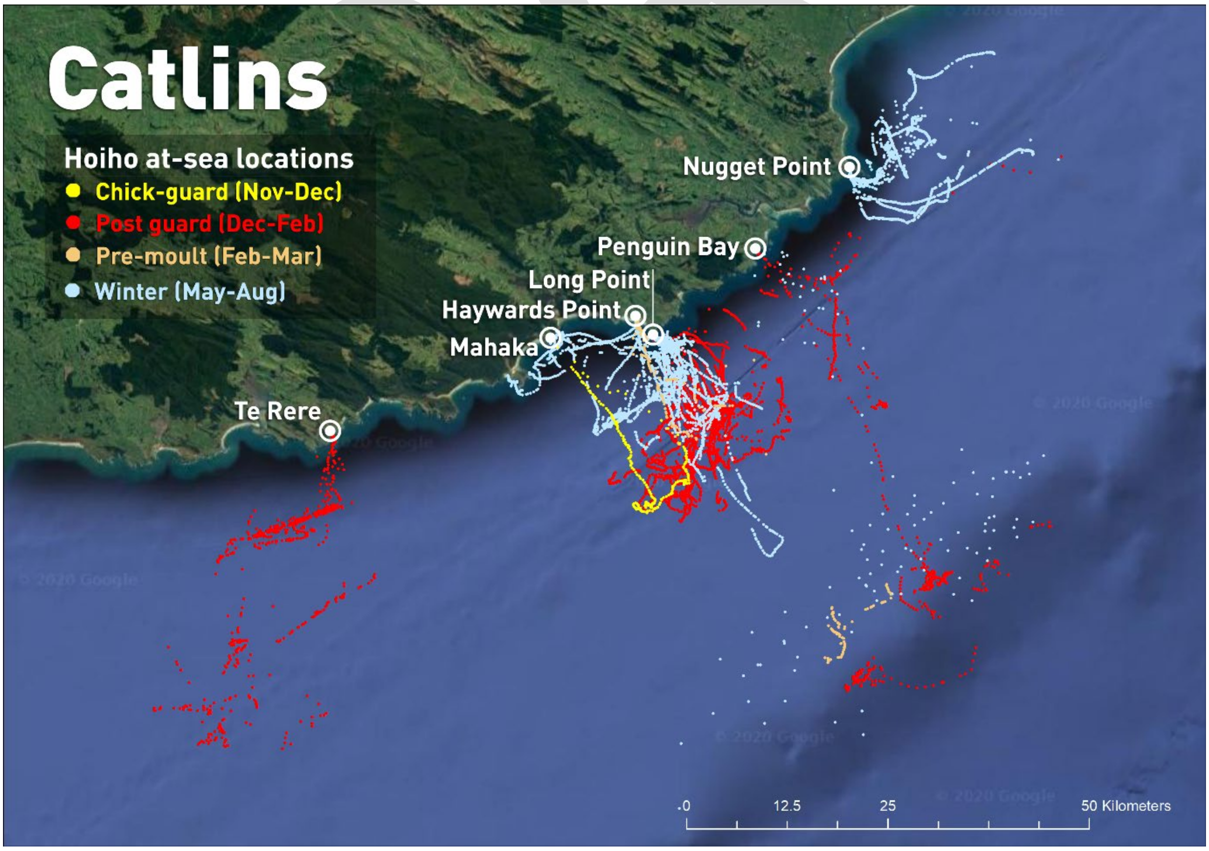

Figure 12a. *GPS fixes of foraging hoiho from the Catlins between 16 Dec 2018 and 24 Aug 2020.*

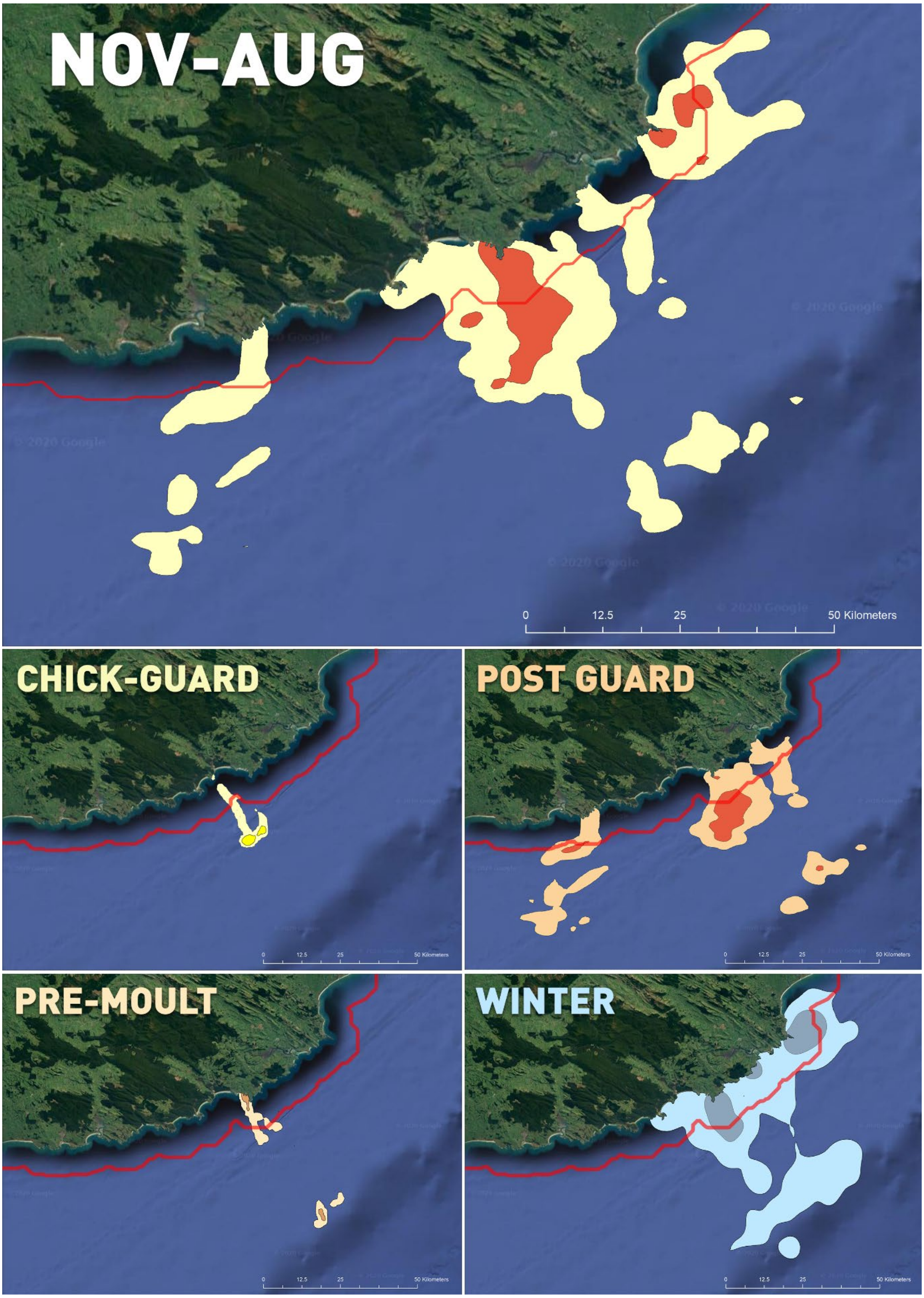

Figure 12b. *Distributions of hoiho GPS fixes along the Catlins coast. Light coloured polygons represent 95% fixed Kernel Density Estimate (KDE), strong coloured polygons the 50% KDE regions. Red line indicates approximate boundary of the 4nm inshore set net restriction zone.*

Foraging ranges – Rakiura

The data recorded for Rakiura can be considered a pilot study and is limited to six deployments on birds breeding on the islands of the Bravo Group in Paterson Inlet. Of the six birds, three showed a strong affinity to forage within Big Glory Bay, where the presence of salmon and mussel farms appear to create unique foraging opportunities for the penguins (see monthly report for December 2019, https://ndownloader.figshare.com/files/22394391). One penguin left Paterson Inlet and, thus, left the set net prohibition zone within the inlet. To which extent this behaviour is common in other penguin requires further investigation.

Currently, the data set is too limited to allow more generalized conclusions about the penguins' utilization of the marine habitat beyond individual preferences for foraging in Big Glory Bay. Both GPS and video logger data showed that in Big Glory Bay penguins foraged primarily near mussel lines, although the fact that none of the penguins travelled further than 3 km into the bay may indicate an indirect influence of the salmon farms on their distribution.

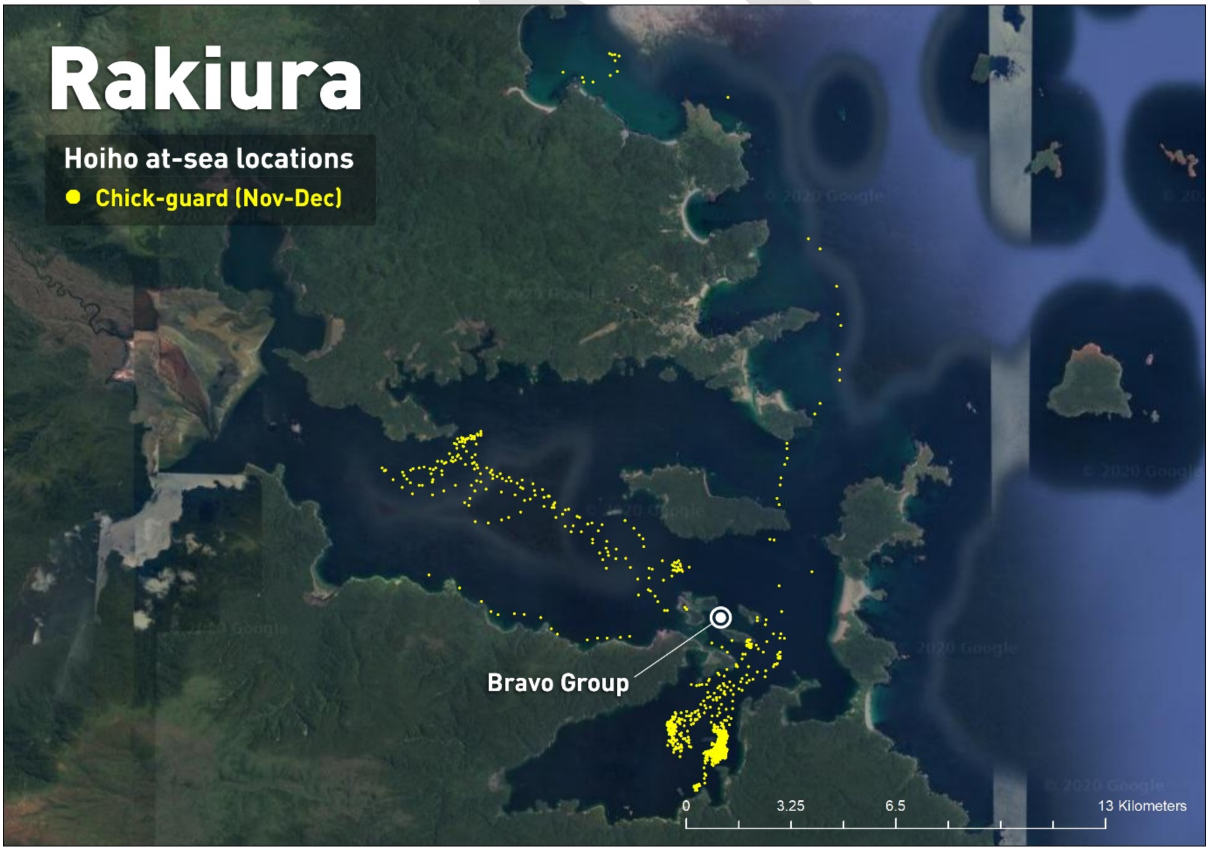

Figure 13a. *GPS fixes of foraging hoiho from the Bravo Group, Rakiura between 30 Nov 2019 and 11 Dec 2019.*

Figure 13b. *GPS fixes of foraging hoiho from the Bravo Group, Rakiura between 30 Nov 2019 and 11 Dec 2019.*

Discussion

Closing of data gaps

GPS and dive data recorded over the course of this project complement data recorded by studies using similar methodologies carried out between 2003 and 2018 (e.g. Mattern, 2006; Mattern et al., 2007, 2013, 2018; Seed et al., 2018). Yet despite best efforts, it was not possible to close all data gaps. Especially the species' southern mainland ranges remain underrepresented.

At Te Rere in the southern Catlins, data from only two birds could be recorded, primarily due to the low number of breeding pairs at that site over the course of this project. At the same time, the data recorded from these birds indicate that the hoiho population in the region may be influenced significantly by fisheries activities. The linear foraging components apparent in the data suggest that the birds' behaviour is likely influenced by bottom fisheries similar to what has previously been reported from the Otago Peninsula (Mattern et al., 2013). Nest numbers at Te Rere appear to be recovering slowly, so that further tracking work in the southern Catlins will be possible and is advisable. Penguins from Te Rere could also act as stand-ins for conspecifics breeding on islands in the Foveaux Strait, which remain largely inaccessible for research. Data from Te Rere seems to indicate that the penguins from that site forage to the South and West and may reach the eastern Foveaux Strait region during the non-breeding period.

Hoiho from Rakiura/Stewart Island are similarly underrepresented. While there are data sets for yellow-eyed penguins from the North Anglem coast and Whenua Hou/Codfish Island (Mattern, 2006), these data only cover the chick-guard stages and provide little information about the penguins use of the local marine habitat outside of the breeding period. The diving behaviour of hoiho from Port Pegasus/Pikihatiti has been studied once before (Chilvers, Dobbins & Edmonds, 2014), but the study did not record their at-sea movements. Dive profiles recorded suggest that the penguins forage outside of and to the East of Port Pegasus, although sequences of shallower benthic dives may indicate that the birds sometimes may visit the confines of South Arm. Tracking work scheduled for November/December 2020 (POP2020-05) should provide further information and data for this region.

Hoiho marine habitat utilization and set netting

The hoiho at-sea distributions determined in this project, in combination with previously recorded information, will provide a solid basis for the development of advanced habitat preference models. These models will be essential to quantify the potential and actual impact of set net fishing practices, a fishery that is known to contribute significantly to hoiho mortality along the New Zealand mainland (Darby & Dawson, 2000; Crawford et al., 2017).

The summarized data presented here, indicate that the existing 4 nautical mile set net restrictions introduced principally to protect inshore dwelling dolphin species (Hectors and Maui Dolphins) is only marginal beneficial for hoiho. In all regions, large portions of the marine habitat utilized by hoiho are located outside of the set net restriction zone (i.e. further than 4 nm/7.4 km) from the shore. Especially hoiho populations in North Otago and the Foveaux Strait area seem to be exposed to substantial set netting activity (Figure 14).

It is likely that the introduction of the set net restrictions around the South Island in 2008 (Crawford et al., 2017) concentrated set net fishing efforts further offshore so that the risk of entanglement in the penguins' main foraging regions may have increased since then.

In this context, it is also important to point out that hoiho densities within the 4 nm zone are likely biased by the penguins' need to commute between breeding site and foraging area daily during the breeding season. This effectively creates penguin approach corridors that are evident in the Kernel Density Estimates presented in figures 10b-12b. These inshore areas are mainly utilized by the birds while commuting in the early morning and in the late afternoon and evening at least during the breeding season. Even when not breeding, i.e. during pre-moult and winter, the average trip lengths (Table 2) suggest that the penguins return to their breeding colonies frequently, yet departure and return times are less predictable.

Set net restrictions around the mainland essentially eliminate the risk of nets inadvertently being set in a penguin colonies' approach corridor. This, however, remains a substantial risk for hoiho from Rakiura/Stewart Island and its outliers as well as the Foveaux Strait islands (e.g. Ruapuke Is.) where no set net restrictions are in effect, the exception being Paterson Inlet. Set net activity around Rakiura seems to concentrate in areas where hoiho are present, i.e. the northern coastlines as well as the South Cape/Port Pegasus/Pikihatiti regions (Figure

14), which underlines the importance to obtain additional data to adequately represent hoiho at-sea distribution to inform marine planners and decision makers.

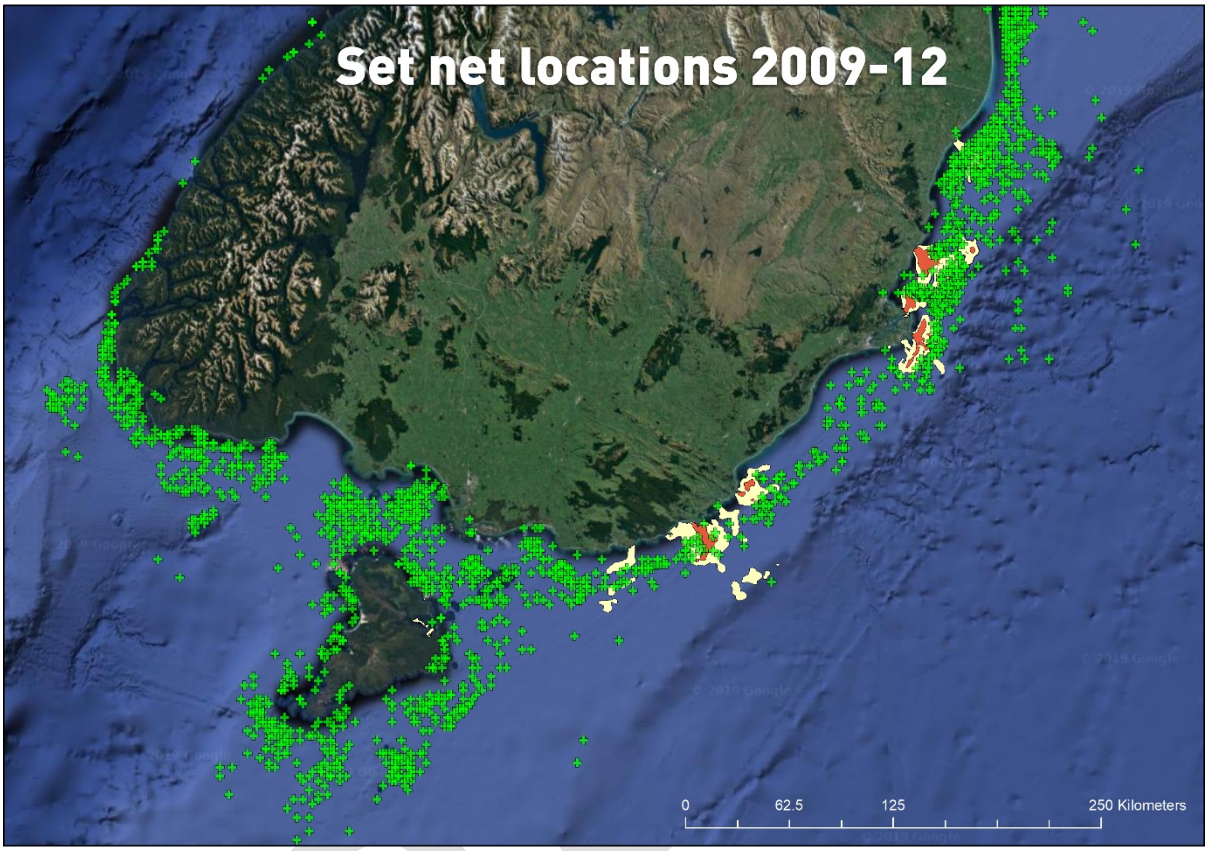

Figure 14. *Set net locations 2009-2012 (obtained via OIA21_357) in relation to the kernel density estimates determined for hoiho tracking data.*

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Appendix - Monthly report summaries

1. 21 November – 20 December 2018

DOI: 10.6084/m9.figshare.12179043

Between 12 and 19 December, five data logger deployments on four different birds. One bird at Nugget Point was fitted with camera & GPS dive loggers but lost both devices over night and was refitted with a new GPS dive logger. The device was recovered five days later but had not left its nest during the deployment period. Three birds at Te Rere were fitted with GPS dive loggers; device recovery is scheduled for Boxing Day. At all Catlins sites, most nests have already entered post-guard despite chicks still being rather small (2-3 weeks old) indicating poor foraging conditions. Nest numbers are down at all sites.

Full report: https://ndownloader.figshare.com/files/22394268

2. 21 December 2018 – 20 January 2019

DOI: 10.6084/m9.figshare.12179058

Between 21 December 2018 and 4 January 2019, a total of six breeding hoiho carried GPS dive loggers. Of these, only three devices could be recovered. One penguin managed to preen off the device while at sea shortly after deployment. Two devices were lost because recapture of the penguins proved very difficult. As a result, deployment periods were extended by more than a week facilitating device loss. Of the three recovered devices, the GPS unit of one device was destroyed as the penguin pierced the casing causing leakage; this did not affect dive data, though. The other units yielded full GPS and data sets. Tracking data from Penguin Bay, highlight increased foraging effort with the penguin performing several overnight trips during which it visited the edge of the continental shelf. At Te Rere, the situation was markedly different with birds performing one-day and short-term trips. GPS data indicates interaction with inshore fisheries, as the penguin performed several trips during which it exhibited linear foraging which is generally associated with bottom trawl fisheries.

Full report: https://ndownloader.figshare.com/files/22394289

3. **21 January – 20 February 2019** DOI: 10.6084/m9.figshare.12179070

Another push to deploy GPS dive loggers on Yellow-eyed penguins from the Catlins was made in late January. The dire situation of breeding birds in the region turned out to be a major stumbling block for this endeavour as many of the nests intended for deployment at Hinahina Cove had failed so that only a single deployment was made on one of the last two remaining breeding females on 22 January 2019. Recovery of the device was attempted between 6pm and 11pm each day from 29 January and 5 February 2019. However, the penguin did not return on any of these days. On 30 January, the two remaining nests at Hinahina Cove dissolved when all chicks – grossly underweight – were transferred to Dunedin for rehab. There is still hope that the device can be recovered when the bird returns to Hinahina Cove to moult. At Te Rere, on the 22 January 2019 a GPS dive logger and camera logger were deployed on the penguin that had exhibited linear foraging in December. Both its chicks are in good conditions and belong to the very small group of chicks not transferred to rehab. Recovery attempts began on 23 January 2019; the bird was recaptured, and devices were recovered on 25 January 2019. The bird had spent three days out at sea foraging in a region some 25 km from Te Rere consistently diving to 90-100m depths. The camera logger only yielded poor video data as the device's lens cap leaked water which compromised image quality and destroyed the image sensor 35 minutes after recording had started. After these deployments it was decided to cease activities in the Catlins for the time being and instead focus on hoiho from the Otago Peninsula and Aramoana. On 11 and 12 February, two female hoiho were captured and fitted with a GPS dive logger at Cicely Beach (Otapahi). On 16 and 17 February, a total of five penguins were fitted with devices at Aramoana.

Full report: https://ndownloader.figshare.com/files/22394313

4. **21 February – 20 March 2019** DOI: 10.6084/m9.figshare.12179082

Due to unpredictability of behaviour of hoiho from the Catlins, the tracking efforts for the pre-moult period were shifted in the second half of February northwards to the Otago Peninsula and Aramoana. Between 11 February and 17 February 2019, a total of seven adult penguins were fitted with GPS dive loggers. Devices were programmed to record up to 20 days' worth of data in case recovery of the birds proved as difficult as in the Catlins leading to delays. As birds from the Catlins repeatedly managed to preen off devices, we now secured devices with two cable ties in addition to cloth tape. The cable ties were threaded under the device after it had been fitted using the Tesa-tape method. A cable tie gun that ensured that the cable ties were tightened strongly around device and the underlying feathers and cleanly cut off the part of tie protruding from the head. This set-up proved to be highly effective. Only one device was lost which was due to the penguin's plumage already being compromised by the onset of moult while still at sea. The device fell off before the bird made landfall. The remaining six devices were recovered successfully and all yielded GPS and dive data sets. Due to the volume of the dive data resulting from prolonged deployment periods (average 34.4 million data points per deployment) not all dive data has been processed at this stage. This means that unlike in the previous reports, dive profiles are only included for some of the penguins. This will be rectified in next month's report when all data collected so far will have been fully processed and analysed.

Full report: https://ndownloader.figshare.com/files/22394328

5. 21 February – 20 March 2019

DOI: 10.6084/m9.figshare.12179082

Due to unpredictability of behaviour of hoiho from the Catlins, the tracking efforts for the pre-moult period were shifted in the second half of February northwards to the Otago Peninsula and Aramoana. Between 11 February and 17 February 2019, a total of seven adult penguins were fitted with GPS dive loggers. Devices were programmed to record up to 20 days' worth of data in case recovery of the birds proved as difficult as in the Catlins leading to delays. As birds from the Catlins repeatedly managed to preen off devices, we now secured devices with two cable ties in addition to cloth tape. The cable ties were threaded under the device after it had been fitted using the Tesa-tape method. A cable tie gun that ensured that the cable ties were tightened strongly around device and the underlying feathers and cleanly cut off the part of tie protruding from the head. This set-up proved to be highly effective. Only one device was lost which was due to the penguin's plumage already being compromised by the onset of moult while still at sea. The device fell off before the bird made landfall. The remaining six devices were recovered successfully and all yielded GPS and dive data sets. Due to the volume of the dive data resulting from prolonged deployment periods (average 34.4 million data points per deployment) not all dive data has been processed at this stage. This means that unlike in the previous reports, dive profiles are only included for some of the penguins. This will be rectified in next month's report when all data collected so far will have been fully processed and analysed.

Full report: https://ndownloader.figshare.com/files/22394328

6. 21 March – 20 April 2019

DOI: 10.6084/m9.figshare.12179094

As penguins all entered the moult phase, no logger deployments occurred in the past month; next deployments are scheduled for the first week of May. The downtime was used to run comprehensive analyses of the recorded data. The post-guard stage of the season 2018/19 started already in early December so that no chick-guard data could be obtained when field work commenced. The data outcome was very limited due to the problems with device recovery and damage as outlined in previous reports. GPS data was obtained for two penguins from the Catlins, one each from Te Rere and Penguin Bay. Foraging ranges between Te Rere and Penguin Bay differed (15.3 km vs 31.0 km) as did foraging trip durations (16.6 hrs vs 32.7 hrs). Dive data was recorded for three birds (2x Te Rere, 1x Penguin Bay). One of the Te Rere birds performed short, evening trips and showed high dive rates (no GPS data recorded); dive profiles suggest that foraged pelagically on 8 of its 9 trips. The other penguin fitted with a device at the same time left on one day trips (16.6 hrs) and foraged predominantly at the seafloor (70% of all dives benthic) which correlates with linear foraging observed (see January 2019 report). The Penguin Bay penguin predominantly foraged pelagically (65%) on its first trip while subsequent trips were characterized by benthic foraging again (see graphs on page 2). During the pre-moult, device deployments occurred at Otapahi, Otago Peninsula (2 birds) and Aramoana (5 birds); except for one of the Aramoana penguins which lost its device package, all loggers were successfully recovered and yielded GPS and dive data. Trip durations differed significantly with Aramoana birds staying at sea for 2-13 days (mean 4.7 days), whereas Otapahi penguins stayed at sea for no longer than three days at a time (mean 1.0 day). This also reflected in foraging ranges (mean foraging range; Aramoana: 33.6 km, Otapahi: 19.2 km). While the overall data outcome from Otapahi was too limited to draw general conclusions, the data sets of pre-moult movements of hoiho from Aramoana provided valuable, new insights. The combined GPS and dive data were used to model the penguins' habitat use utilizing procedures developed for a comprehensive spatial analysis recently conducted for MPI. Hoiho from Aramoana foraged predominantly over sandy sediment at water depths of <70m (mean water depth: 35 m) between 5 and 30 km from the coast. A particularly frequent area lay 6-12 km off the coast of Karitane and Waikouaiti. Habitat use model indicate an area with a circumference of ca 200 km and an area of 1,750 km² ranging from the tip of the Otago Peninsula to the southern end of Barracouta Bay to be particularly suitable for hoiho foraging. Positions of set net operations between 2009 and 2012 available for this analysis shows a significant overlap with hoiho penguin habitat. Hence, the risk of interactions between fisheries and penguins is substantially higher north of the Otago Peninsula than in South Otago and the northern Catlins and comparable with that of the Foveaux Strait.

Full report: https://ndownloader.figshare.com/files/22394331

7. 21 April – 20 May 2019

DOI: 10.6084/m9.figshare.12179100

Following the conclusion of the annual Yellow-eyed penguin moult in late April, tracking work resumed in the first week of May in the Catlins. Between 1 and 10 May 2019, a total of 7 penguins were fitted with GPS dive loggers. Four birds from Nugget Point were fitted with devices, at Penguin Bay one bird was tagged and a further two birds are currently being tracked at Te Rere. At the time of this writing, one bird at the Nugget Point has been recaptured.

Full report: https://ndownloader.figshare.com/files/22394340

8. 21 May – 20 June 2019

DOI: 10.6084/m9.figshare.12179106

Tracking of hoiho during the winter months remains extremely difficult. Of the seven hoiho fitted with GPS dive loggers between 1 and 10 May 2019 at Nugget Point, Penguin Bay and Te Rere, four birds could be recaptured to date. Three birds have remained elusive. The greatest challenge are the unpredictable landing patterns and long foraging trips of penguins. Particularly Te Rere has proved to be very difficult to work at as hoiho at that site return as late as 1am in the morning. The ca. 200 observer-hours invested by PIs and volunteers in the past four weeks led to only 3 recaptures; on many nights, no penguin movements were observed at some of the sites. We propose trialling new GPRS/GSM data loggers that transmit data through mobile phone networks to see if this is a viable option to reduce the issues, we are having with traditional data loggers.

Full report: https://ndownloader.figshare.com/files/22394343

9. 21 June – 20 July 2019

DOI: 10.6084/m9.figshare.12179115

Despite repeated efforts to recapture the remaining three hoiho fitted with GPS dive loggers this has not been achieved to date. Due to the unpredictability of recapture, we decided against deploying archival tags until the penguins re-engage in breeding activities in August (pair-bonding). In the meantime, we are trialling alternative methods of tracking to improve data outcome in the coming winter. Besides having ordered to trail units of data loggers that transmit data through the cell phone network, we deployed satellite tags on a penguin from Penguin Bay in the Catlins. The detail of the tracking data was initially not satisfactory so that the device was recovered, and the bird fitted with another transmitter set-up with a different transmission programme. The satellite data recorded so far suggest that the bird is utilizing the same ocean region for foraging as during the chick rearing period of the past breeding season.

Full report: https://ndownloader.figshare.com/files/22394358

10. 21 July – 1 September 2019

DOI: 10.6084/m9.figshare.12179121

Low numbers of penguins in the Catlins breeding areas continued to complicate the tracking work. Of the three birds still presumed to carry data loggers, one could be recaptured at Penguin Bay 5 weeks after device deployment; the device was lost. Due to the unpredictability, methodology was changed form data logging devices to a combination of satellite transmitters and time-depth recorders. Two birds from Penguin Bay – one female and one male – have been fitted with transmitters and are currently being actively tracked. The female performed five multiple-day long foraging trips during which she principally foraged 20-25 km from the shore close to the continental shelf-edge due south of Penguin Bay. The bird was recaptured on 31 August 2019; satellite data suggests that the bird did not leave the colony since 25 August. The male conducts one- to two-day trips and generally stays within 10 km of the coast. The deployment of two GPS dive loggers that transmit data through the cell phone network so far could not be deployed due to a lack of birds.

Full report: https://ndownloader.figshare.com/files/22394361

11. 2 – 24 September 2019

DOI: 10.6084/m9.figshare.12179130

Several fruitless attempts to recover a satellite tag from a male hoiho fitted with the device in Penguin Bay in late July have been made. The satellite tags stopped transmitting on 18 September which may be indicative of the bird being stationary in a location where transmission is blocked (i.e. nest site under dense vegetation). The last known fix is from Jacks Bay which probably explains why searches for the bird at Penguin Bay were without result. Otherwise field work has been suspended due to the penguins now intensive preparations for the upcoming breeding season. Pairs have been found to spend the days together at potential nest sites. Unfortunately, from the numbers of birds observed at our current study site in Penguin Bay, we may have to expect another drop of nest numbers this year. The field work downtime provided the time to perform the dive analysis of the satellite tagged bird recovered in late August.

Full report: https://ndownloader.figshare.com/files/22394364

12. 25 September – 21 October 2019

DOI: 10.6084/m9.figshare.12179139

Field activities in the past month were limited to two more attempts to recover the last satellite tag as well as assisting with nest searches in Aramoana, Papanui and Mahaka. There have been not further satellite transmissions of the second Penguin Bay penguin since 18 September so that it can now be assumed that the device was lost. This also means that we will not be able to access the dive data allowing us to reconstruct the birds' foraging movement more accurately than what can be gleaned from the satellite data (see September 2019 report). One bird at Aramoana was fitted with a GPS dive logger on 18 October 2019.

Full report: https://ndownloader.figshare.com/files/22394376

13. 21 October – 20 November 2019

DOI: 10.6084/m9.figshare.12179142

Tracking of breeding hoiho has resumed at Aramoana with deployments of GPS dive loggers on incubating birds in late October. Two penguins were fitted with AxyTrek devices on 16 and 24 October with devices recovered 8 and 6 days later, respectively. A third penguin was equipped with a new Ornitela GPRS/GSM dive transmitter which sends its data frequently via the mobile phone network. One AxyTrek and the Ornitela device both recorded GPS data showing that both penguins foraged within 20 km of Aramoana, reaching destinations some 15 km due east of Karitane. The second AxyTrek device failed to record GPS positions beyond the first hour of the first foraging trip undertaken; however, the bird followed a similar trajectory as the other two penguins and a full set of dive data was recorded. Tracking was paused during chick hatching. On 18 November 2019, a male hoiho guarding two healthy chicks was fitted with a camera logger and an AxyTrek. The camera was successfully recovered on 19 November 2019 containing 2.5 hours of footage recorded during the bird's active foraging period (0920 - 11.55 hrs). Preliminary analysis suggest that the penguin caught principally opalfish over sandy bottom; during the 2.5 hours of camera footage the bird caught 20+ fish indicating excellent foraging success which aligns with healthy, well-nourished chicks in the bird's nest. The GPS dive logger remained on the bird and is due for recovery on 22 November 2019.

Full report: https://ndownloader.figshare.com/files/22394382

14. 21 November – 20 December 2019

DOI: 10.6084/m9.figshare.12179145

Hoiho tracking is back in full swing. Deployments occurred over a broad range of site ranging from Bobby's Head and Aramoana in North Otago to Long Point and Mahaka in the Catlins and the Bravo Islands in Paterson Inlet, Rakiura/Stewart Island. Mainland data have yet to be fully consolidated and will be summarized in the January 2020 report. In this report, we will focus primarily on data obtained from GPS and camera logger deployments on hoiho from the Bravo Group islands. Field work on the islands commenced on 30 November 2019. Initial nest searches found only 8 active nests (down from 15 nests in 2018), which were down to only six nests by the time the field team arrived. Of these nests, four were found to contain eggs, freshly hatched or chicks <1-

week old so that device deployments on these nests were put off for another week. During this period a further three of the nests failed, all of which were nests that contained eggs or freshly hatched chicks in late November. Hence, only three nests remained for the tracking work. Between 30 November and 09 December 2019, all six remaining breeding birds were fitted with camera and GPS loggers. Two birds managed to pull off the cameras before the devices could be recovered; the remaining for cameras were recovered within 24 hours of deployment. GPS loggers remained on the birds for 4-7 days. Three of the six tracked birds foraged exclusively in Big Glory Bay. Two birds foraged further westwards into Paterson Inlet; one bird left the inlet and foraged closely along the coast to Wooding Bay (Maori Beach) before returning to the nest after a night at sea. Camera data is yet to be fully analysed but preliminary assessment indicates very diverse feeding strategies with one bird feeding exclusively on krill in Big Glory Bay, another bird going after whitebait, while the remaining two cameras suggest that birds target larger fish species, e.g. mullets. Overall, it appears that the penguins experienced excellent foraging conditions with most bird performing half-day trips. The low number of nests likely do not reflect the feeding situation but may be owing to a loss of breeding birds during last season's mainland-wide starvation event as well as a very late start to the breeding season. High numbers of loafing adult on the island suggest that nest numbers could pick up again in the coming season. The study indicates that Rakiura/Stewart Island may represent a relative safe haven for the hoiho mainland population and should receive increased monitoring attention in the future.

Full report: https://ndownloader.figshare.com/files/22394391

15. 21 December 2019 – 20 January 2020

DOI: 10.6084/m9.figshare.12179154

In late December 2019, the chick-guard phase of the current hoiho breeding season has come to an end. Throughout chick-guard, penguins from Bobby Head's/Tavora and Aramoana in North Otago, Mahaka and Long Point in the Catlins, and the Bravo Group, Rakiura/Stewart Island have been successfully tracked with GPS dive loggers. A detailed account of the Rakiura data has been given in last month's report. This report focuses on device deployments that occurred during the chick-guard stage along the various mainland sites. At Bobby's Head/Tavora, three GPS dive loggers were deployed on birds from the only two active nests. One bird was re-deployed after a device it had been carrying proved to be malfunctioning. A total of 12 foraging trips were recorded during which both birds foraged towards the east and south east within a 10 km radius of the colony. Predominantly benthic dives were recorded. At Aramoana, one male and two females from active nests were fitted with devices and performed 17 foraging trips. One female exhibited varying foraging ranges and stayed within 10 km of the colony on some trips while foraging up to 30 km away on others. The longer trips brought the birds into the same region that was utilized during the non-breeding and incubation periods underlining the importance of the continental shelf region between Karitane and Shag Point for North Otago hoiho. The second female's unit failed to record any GPS data; it was subsequently removed from our diminishing pool of reliably working devices. Only one nest is active at Mahaka. We managed to deploy a GPS dive logger on the female penguin and obtain tracking and dive data for one foraging trip during which the penguin foraged southeast to deeper waters some 16 km from the colony during which it mainly foraged pelagically at depths around 60m. At Long Point, penguins from the two nests in Seal Bay were fitted with GPS dive loggers and cameras in late November 2019. One bird preened off the camera while at sea, the other camera only recorded footage during the night. On the eight foraging trips recorded by the GPS dive loggers during chick-guard, the penguins tended to forage mainly to the South in an area also visited by the Mahaka bird. Benthic foraging at depths exceeding 100 m dominated their behaviour.

Full report: https://ndownloader.figshare.com/files/22394400

16. 21 January – 20 March 2020

DOI: 10.6084/m9.figshare.12179169

We report on tracking data recorded during the pre-moult period of hoiho from North Otago and the Catlins. At Bushy Beach, we used novel GSM loggers that submit data frequently via the mobile phone network. As these units are equipped with solar panels, long term deployments are possible. Two non-breeding male penguins from Bushy Beach were fitted with these devices. At Bobby's Head/Tavora and Haywards Point in the Catlins, the standard AxyTrek GPS dive loggers were used on four additional birds. At all sites, penguins showed foraging ranges the are comparable to those recorded during breeding. Foraging ranges seldom exceeded 20 km. Interestingly, all birds showed primarily benthic foraging behaviour. This stands in contrast to the data that was recorded between November 2019 and January 2020 when several birds were found to also forage pelagically. This could be an indication that the sea conditions which facilitated pelagic foraging have subsided so that the penguins have now reverted to a benthic foraging strategy that is common in hoiho from the mainland. Judging from the weights of the birds at the end of the device deployments (6+ kg) foraging success remains high despite this change in strategy.

Full report: https://ndownloader.figshare.com/files/22394418

17. 21 March – 20 April 2020

DOI: 10.6084/m9.figshare.12203168

The final three pre-moult deployments at Papanui Beach were successfully concluded with all devices recovered the weekend prior to the Covid-19 lockdown. The three birds (all males) showed marked individual variation in their foraging distribution with little overlap between the birds. One hoiho foraged mainly south of Papanui and the second bird utilized the region to the east and northeast. The third penguin performed a single overnight trip to the North reaching the foraging zones of penguins from Bobby's Head; the bird entered the moult after this trip and did not perform any further foraging trips. Field work was suspended for the following four weeks, primarily because hoiho along the mainland coast were undergoing the annual moult. Instead, we focused on the analysis of the substantial dive data that was recorded in the previous months, starting with the most recently collected data sets. In this report we provide the results of the dive analysis of the Papanui data set. The analysis process is explained, and individual trip statistics are provided in an extensive supplementary section.

Full report: https://ndownloader.figshare.com/files/22442831

18. 21 April – 20 May 2020

DOI: 10.6084/m9.figshare.12355451

After the COVID-19 alert has been dropped to level 2 in the second week of May, tracking work has resumed at Papanui Beach to obtain movement data representing winter behaviour. On 16 May 2020, a total of five adult hoiho, three males and two females were fitted with GPS dive loggers. Recovery of the devices is planned for the last week of May. Outside of device deployments, processing of the accumulated dive data has continued.

To date, data sets from 25 different deployments have been analysed, representing 153 foraging trips during which the penguins performed a combined total of 47,541 dives across seven different location. Overall, approximately 40% of all dive data have been processed in the past six weeks. In this report we present summaries of deployments that took place during the pre-moult phase at Haywards Point/Catlins, Papanui Beach/Otago Peninsula, Bobby's Head/North Otago and Bushy Beach/North Otago (February-March 2020).

Full report: https://ndownloader.figshare.com/files/22768817

19. **21 May – 19 June 2020** *DOI: 10.6084/m9.figshare.12510743*

Tracking work resumed at Papanui Beach in the second week of May to obtain movement data representing winter behaviour. On 16 May 2020, a total of six adult hoiho, four males and two females were fitted with GPS dive loggers. All birds were recovered on 29 May 2020. Unfortunately, one device malfunctioned and failed to record any viable data. The remaining five deployments all yielded full sets of GPS, dive and accelerometer data. Full analysis of recorded GPS and dive data revealed that it encompassed a total of 51 foraging trips comprising of 10,458 dive events. At-sea movements of the tracked birds were consistent within individuals but varied between birds. Overall, a broad region was utilized ranging from the Northeast to the South of Papanui Beach. Two birds had been tracked during the post-guard period in January 2020 and tracks from that period turned out to be remarkably similar to what was recorded during the deployments reported on here.

Full report: https://ndownloader.figshare.com/files/23214608

20. **20 June – 22 July 2020** *DOI: 10.6084/m9.figshare.12686147*

Winter tracking of hoiho proves to be challenging once again. At two sites only five birds could be captured to attach tracking devices in the past month. While four of these birds could be recaptured within 1-2 weeks after deployment, the fifth bird still eludes recapture despite daily monitoring of the colony for the past two weeks. This report contains data for four deployments. Birds from Long Point/Catlins showed foraging behaviour not dissimilar to what we observed during the post-guard stage of the last breeding season almost half a year ago (see February 2020 report). Same is true for data obtained from two birds at Bobby's Head/Tavora Reserve both of which foraged in similar regions as birds during the pre-moult as well as the breeding period. Remarkably, these two birds foraged cooperatively for at least the first four trips recorded. No GPS data was recorded for the last three trips in one bird; however, similar dive profiles suggest that the two penguins foraged in tandem for the duration of the device deployments.

Full report: https://ndownloader.figshare.com/files/24022073

21. 23 July – 20 August 2020

DOI: 10.6084/m9.figshare.12831512

Hoiho tracking suffered several setbacks in the past four weeks. Despite substantial effort with daily monitoring of the Bobby's Head colony, we could not recover the device from male hoiho 982000365942039. There are two possible explanations for this, either the bird did not return to the site during the nearly three weeks of constant evening surveillance or the penguin removed the device making it impossible to identify the bird without getting a transponder reading. Automatic surveillance of the site up until mid-August revealed very little penguin traffic at the site; trail cameras were removed from Bobby's Head on 9 August. The device is now considered loss which left our team with a device pool of four units. Further deployments were planned at Haywards Point in the Catlins. These were to be the last deployments before conclusion of the project. Deployments were delayed with the recurrence of Covid-19 in Auckland, and the uncertainty whether the South Island would return to a lockdown level that would prevent recovery of devices. After level-2 was announced for the South Island, the Haywards Point colony was visited on the third weekend of August. Plan was to fit devices to pairs to investigate whether cooperative foraging as observed at Bobby's Head may be a common occurrence. However, once in the field, three of the four units malfunctioned which we are currently investigating with TechnoSmart. As a result, only a single individual could be fitted with GPS dive logger. In the evening of 15 August, male hoiho 982000405532334 was captured and the last reliable device deployed; the bird weighed 5.8 kg. Two other birds were seen that night. However, neither appeared to be the captured penguin's partner, so we decided against fitting devices that were unlikely to record data reliably. Beyond field work, analysis of dive data progressed further with 80% of all dive data now processed.

Full report: https://ndownloader.figshare.com/files/24370175

22. 21 August – 20 September 2020

DOI: 10.6084/m9.figshare.12960050

Starting on 24 August 2020, several attempts were made to recover the last GPS dive logger deployed on a male hoiho from Haywards Point nine days earlier. Until 30 August a total 42 observer hours were invested to recapture the penguin. Numbers of penguins landing during these six days was highly consistent, with four birds landing between 4.30pm and 7pm every day on the rock platform furthest from the beach, while three birds were seen landing on the first platform where the deployment was carried out. None of the observed birds carried a data logger. From 26 August, two motion triggered trail cameras were trained on the two rock platforms capturing penguins mainly between 6 and 9am in the morning and during the observation hours of 4-7pm at night. A bird with a data logger was not apparent on any of the trail camera footage. To ensure that the logger bird was not missed because it was roosting in the breeding areas, the flax fields above both rock platforms were searched upon arrival during the last four visits to Haywards Point. The logger carrying penguin was not found and it seemed increasingly likely that the logger bird had removed the device, preventing its visual identification. Yellow-eyed Penguin Trust ranger Sarah Irvine installed additional cameras in the flax on the last weekend of August. Footage recovered from these cameras in the first week of September 2020 strongly suggest that the bird had indeed removed the device. On three clips, a penguin making its way through the flax appears to have a small strip of Tesa-tape still sticking to its otherwise clean back. This means that the last deployment in the Catlins concluded unsuccessfully with the loss of another device.[1]

Full report: https://ndownloader.figshare.com/files/24686339

[1] In late October 2020, Yellow-eyed penguin trust ranger Sarah Irvine found the GPS dive logger lying on the ground in the flax patch utilized by the penguins for nesting. The device contained 9.3 days' worth of GPS and dive data.