Unravelling the population size and the foraging behaviour of Humboldt penguins in Chile

Project Final report

Alejandro Simeone ©

Alejandro Simeone[1], Guillermo Luna-Jorquera[2], Ursula Ellenberg[3,4] and Thomas Mattern[4,5]

[1]Departamento de Ecología y Biodiversidad, Facultad de Ciencias de la Vida, Universidad Andrés Bello. Santiago, Chile.

[2]Departamento de Biología Marina, Facultad de Ciencias del Mar, Universidad Católica del Norte. Coquimbo, Chile.

[3]Department of Marine Science, University of Otago, Dunedin, New Zealand.

[4]Global Penguin Society, Puerto Madryn, Chubut, Argentina.

[5]Department of Zoology, University of Otago, Dunedin, New Zealand.

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Research institutions

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Summary

We present the results of the research project "Unravelling the population size and the foraging behaviour of Humboldt penguins in Chile". During the 2021-2022 and 2022-2023 reproductive seasons (October through December) we assessed the breeding population of the Humboldt Penguin (*Spheniscus humboldti*) at 10 islands along the coast of north-central Chile. Islands varied greatly in surface area, ranging from 3 ha (Islote Pájaro Niño) to 516 ha (Chañaral) and population size, ranging from 35 breeding pairs (islote Ramadas) up to 729 breeding pairs (Isla Cachagua). The total breeding population was estimated in 2,511 pairs.

During the 2021-2022 season we were able to continuously monitor the breeding season of Humboldt penguins at Chañaral and Choros islands, from November throughout February. For 40 nests monitored at Chañaral Island we determined a hatching success of 0.76 and a breeding success of 1.03 fledglings/nest. For Choros Island, these figures were 0.86 and 1.43, respectively. Due to external administrative issues (strike of CONAF personnel) and the later outbreak of avian influenza in the study area, for the 2022-2023 season, we were able to determine only the hatching success for both colonies: 0.21 for Chañaral and 0.91 for Choros. As monitoring was interrupted during December 2022 and January 2023, it was not possible to determine the breeding success at both colonies.

Between 14 and 21 June 2022, we conducted the first tracking study of Humboldt penguins from Choros Island using GPS dive loggers. A total of 12 birds tending small chicks were fitted with devices for an average 4-7 days, of which 10 deployments yielded data; two devices could not be recovered. During this winter breeding season, birds stayed within an average 20 km from their nest sites, performing around 390 dives per foraging trip that took the birds round 16 hours to complete. An apparent pattern emerged that suggested that penguin breeding on the western side of the island foraged primarily to the Southwest and, therefore, more pelagically, while penguins from the eastern coast tended to forage close inshore of the mainland. This pattern was further investigated during the summer breeding period (25 November-17 December 2022) with a further 13 GPS logger and an additional 6 PenguCam camera logger deployments. The resulting foraging data showed that the area to the southwest remained an important foraging ground for chick rearing penguins, but also highlighted that inshore foraging was equally as important with penguins foraging along the mainland coast towards the southwest, practically reaching the area of the (at the time) proposed coastal developments. PenguCam deployments provided new insights into foraging behaviour including cooperative foraging of large groups (50+) of penguins.

ZUSAMMENFASSUNG

Wir präsentieren die Ergebnisse des Forschungsprojekts "Ermittlung der Population und des Nahrungssuchverhaltens von Humboldt-Pinguinen in Chile". Während der Brutsaisons 2021-2022 und 2022-2023 (Oktober bis Dezember) untersuchten wir die Brutpopulation des Humboldt-Pinguins (*Spheniscus humboldti*) auf 10 Inseln entlang der Küste von Nord-Zentral-Chile. Die Inseln unterscheiden sich stark in ihrer Fläche, von 3 ha (Islote Pájaro Niño) bis zu 516 ha (Chañaral), und in der Population, von 35 Brutpaaren (Islote Ramadas) bis zu 729 Brutpaaren (Isla Cachagua). Die Gesamtpopulation wurde auf 2.511 Brutpaare geschätzt.

Während der Saison 2021-2022 konnten wir die Brutzeit der Humboldt-Pinguine auf den Inseln Chañaral und Choros von November bis Februar kontinuierlich überwachen. Bei 40 überwachten Nestern auf Chañaral Island haben wir eine Schlupferfolgsrate von 0,76 und eine Brut-Erfolgsrate von 1,03 flügge gewordenen Jungtieren pro Nest festgestellt. Auf Choros betrugen diese Werte jeweils 0,86 und 1,43. Aufgrund externer administrativer Probleme (Streik des CONAF-Personals) und des späteren Ausbruchs der Vogelgrippe in der Untersuchungsregion konnten wir für die Saison 2022-2023 nur die Schlupferfolgsrate für beide Kolonien ermitteln: 0,21 für Chañaral und 0,91 für Choros. Da die Überwachung im Dezember 2022 und Januar 2023 unterbrochen wurde, war es nicht möglich, den Brut-Erfolg in beiden Kolonien festzustellen.

Zwischen dem 14. und 21. Juni 2022 führten wir die erste Tracking-Studie an Humboldt-Pinguinen auf Choros mit Hilfe von GPS-Tauchloggern durch. Insgesamt wurden 12 Vögel auf Küken mit Geräten ausgestattet, die im Durchschnitt 4-7 Tage lang auf den Vögeln belassen wurden. Bei insgesamt 10 Einsätzen wurden Daten gewonnen; zwei Geräte konnten nicht geborgen werden. Während dieser Winterbrutsaison verblieben die Vögel durchschnittlich 20 km von ihren Nistplätzen und führten etwa 390 Tauchgänge pro Jagdtrip durch; solche Trips dauerten im Schnitt 16 Stunden. Es zeichnete sich ein Muster ab, das darauf hindeutete, dass Pinguine, die auf der westlichen Seite der Insel brüteten, hauptsächlich nach Südwesten und damit pelagisch auf Nahrungssuche gingen. Pinguine von der östlichen Küste neigten dazu, in Küstennähe des Festlandes nach Nahrung zu suchen. Dieses Muster wurde während der Sommerbrutzeit (25. November bis 17. Dezember 2022) mit weiteren 13 GPS-Loggern und 6 zusätzlichen PenguCam-Kamera-Loggern weiter untersucht. Die daraus resultierenden Daten zur Nahrungssuche zeigten, dass das Gebiet im Südwesten ein wichtiger Nahrungssucheort für brütende Pinguine ist, betonten jedoch auch, dass die Nahrungssuche entlang der Festlandküste in Richtung Südwesten ebenso wichtig ist, wobei die Pinguine nahezu das Gebiet der zu dem Zeitpunkt geplanten Minenhafen gelangten. Die PenguCam-Einsätze lieferten neue Einblicke in das Nahrungssuchverhalten, einschließlich kooperativer Nahrungssuche in großen Gruppen (50+) von Pinguinen.

RESUMEN

Presentamos los resultados del Proyecto de investigación "Dilucidando el tamaño poblacional y conducta de alimentación del pingüino de Humboldt en Chile". Durante las estaciones reproductivas de 2021-2022 y 2022-2023 (octubre a diciembre) determinamos el tamaño de la población reproductiva de pinguinos de Humboldt (*Spheniscus humboldti*) en 10 islas de la costa del centro-norte de Chile. Las islas variaron en tamaño desde las 3 ha (Islote Pájaro Niño) hasta 516 ha (Chañaral) y los tamaños poblacionales variaron entre 35 parejas (islote Ramadas) y 729 parejas (Isla Cachagua). El tamaño total de la población reproductiva en estas islas fue estimado en 2,511 parejas.

Durante 2021-2022, pudimos monitorear de manera continua la reproducción de pinguinos de Humboldt en las islas Chañaral y Choros, desde noviembre a febrero. Para 40 nidos monitoreados en Chañaral determinamos el éxito de eclosión en 0,76 y un éxito reproductivo de 1,03 volantones/nido. Para Choros, estos valores fueron de 0,86 y 1,43, respectivamente. Debido a un paro de actividades de personal de CONAF y al posterior brote de influenza aviar en el área de estudio, para la temporada 2022-2023 sólo pudimos determinar el éxito de eclosión para ambas colonias: 0,21 para Chañaral y 0,91 para Choros. Debido a que el monitoreo se debió interrumpir en diciembre 2022 y enero 2023, no fue posible determinar el éxito reproductivo en ambas colonias.

Entre el 14 y 21 de junio 2022, realizamos el primer seguimiento de pingüinos de Humboldt de isla Choros utilizando dispositivos GPS y buceo. Equipamos con dispositivos 12 adultos que tenían nidos con pollos pequeños (1 semana de edad) por períodos de 4-7 días. De éstos, solo 10 produjeron datos pues dos dispositivos no fueron recuperados. Durante este período de invierno, los pinguinos se alimentaron a una distancia promedio de 20 km de su colonia, realizando un total de 390 buceos por viaje de alimentación con duraciones de hasta 16 horas. Detectamos que, aparentemente, hay un patrón en que los pinguinos que anidan en el lado O de la isla se alimentan principalmente en áreas hacia el SO, por lo tanto, tienden a ser más pelágicos. Los pinguinos que anidan en el lado E, tienden a alimentarse más cerca de la costa. Durante el período reproductivo de primavera (25 noviembre -17 diciembre 2022) equipamos adultos con 13 dispositivos GPS y 6 unidades de cámaras PenguCam. Los resultados indicaron que el área SO sigue siendo un área de alimentación importante, pero también se reafirma la relevancia de las áreas de alimentación cercanas a la costa en el área SO, muy cerca de donde están planificados proyectos de desarrollo industrial. Las cámaras PenguCam proporcionaron nuevas informaciones sobre la conducta de alimentación cooperativista en los pingüinos que se alimentan en grandes grupos de más de 50 individuos.

Presentation

In 2021, we joined forces with Sphenisco e.V. to address priority research and conservation needs for the threatened Humboldt Penguin in Chile. After a careful review, we identified three main topics in which urgent research was needed to provide reliable and updated information for conservation and management purposes. We agreed in that estimating the breeding population size, the breeding success and the foraging behaviour were key subjects to include considering the scenario the Humboldt Penguin was facing at the time. That scenario was not favourable at all for the species and threats included both direct and indirect interactions with fisheries and the potential construction of harbour and mining facilities near key breeding and foraging areas of the penguins. All these threats, coupled with other anthropogenic activities, were (and still are) causing an ongoing, underlying rapid decline in the numbers of Humboldt penguins (Birdlife International 2020).

Addressing a project with such geographic, logistic, and technologic requirements needed a strategic alliance with relevant research partners. It was so that we came to join our expertise with Guillermo Luna-Jorquera from the Universidad Católica del Norte (Coquimbo, Chile) and Ursula Ellenberg and Thomas Mattern, both from the University of Otago (Dunedin, New Zealand). In the following chapters we will present you the main results of the research conducted by our teams and how this new information fills in gaps in our knowledge of the Humboldt Penguins and matches with its conservation needs.

Beyond our initial aims when we planned this project, our data will be useful to address two unexpected environmental situations that started to develop in the South-eastern Pacific during the last months: the rapid spread of avian influenza and a new El Niño event. Our data will serve as a base line to understand of these combined factors affect population size, breeding success and foraging behaviour.

Big enterprises such as this project normally starts with big dreams. And we thank Gabriele Knauf (1954-2023), founder and chair of Sphenisco for several years, for stimulating and supporting this dream. Her enthusiasm, perseverance and personal commitment with the Humboldt Penguin research and conservation was always a decisive factor in the success of this and many other projects both in Chile and Peru. We dedicate the results of this project and their future applications to her memory.

Alejandro Simeone
Universidad Andrés Bello, Santiago, Chile
Project leader

PART 1
Estimate of the Humboldt Penguin breeding population size in Chile

AUTHORS:

ALEJANDRO SIMEONE, PAULINA ARCE, MAXIMILIANO DAIGRE, URSULA ELLENBERG AND THOMAS MATTERN.

MAXIMILIANO DAIGRE ©

METHODS

To estimate the size of the breeding population of Humboldt penguins in Chile, we visited a total of ten islands between October and December 2021 and October and December 2022, coinciding with the spring breeding season of the species (Simeone et al. 2002). The census included the main Humboldt penguin colonies between Pan de Azúcar (26°S) and Cachagua (32°S), encompassing ca. 700 km of coastline (Figure 1).

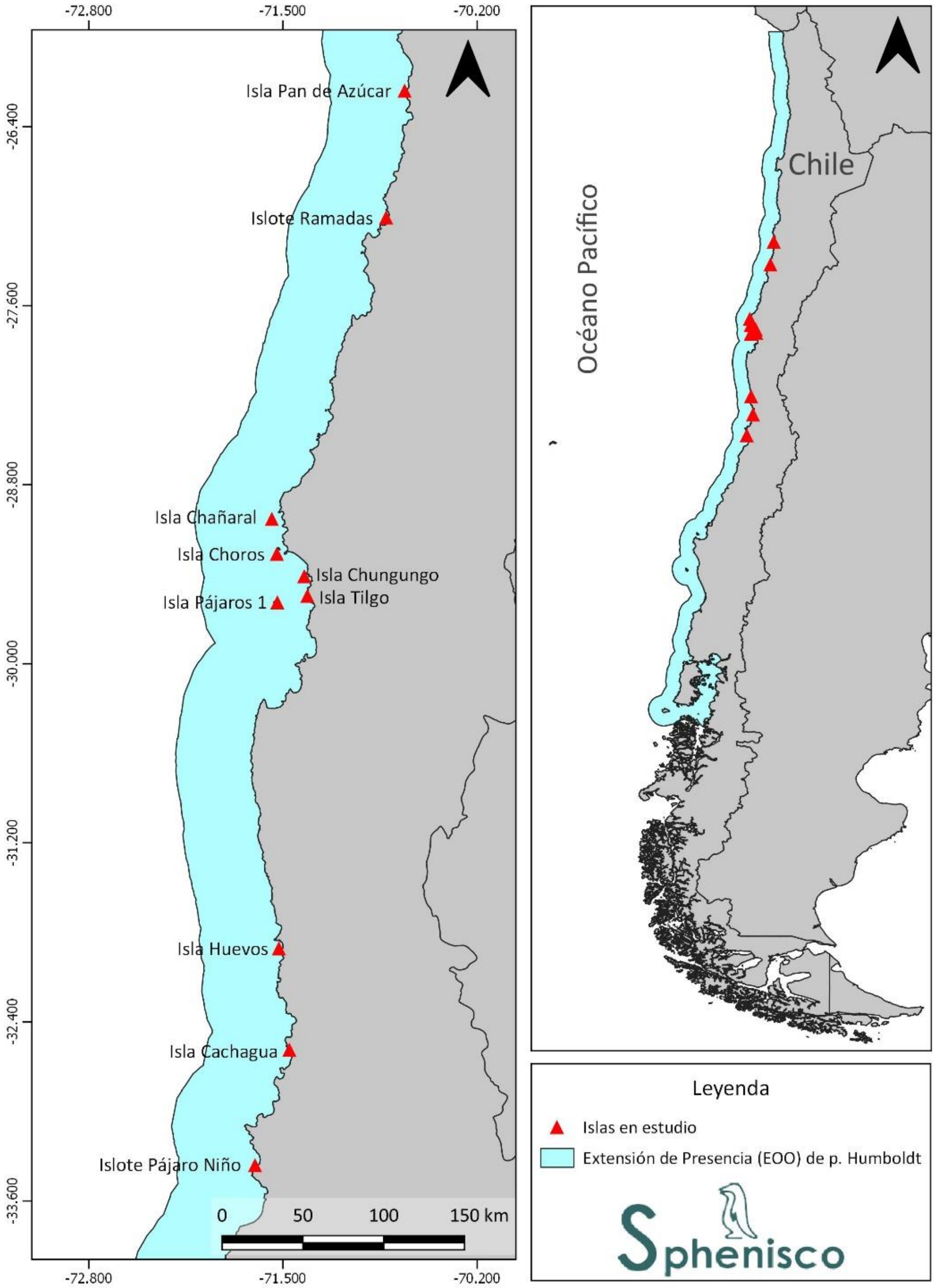

Figure 1
Study area showing the 10 islands (red triangles) where the Humboldt penguin breeding population was assessed. Light-blue area represents the Extent of Occurrence (EOO) of the species in Chile. Figure by M. Daigre.

All the islands were accessed by boat (Figure 2), except for Pájaro Niño, which is joined to the mainland by a breakwater wall and thus can be reached by walking. All boats were hired from local fishermen or local tour operators. As all islands are uninhabited and have no water sources, we established a camp at each site with all the necessary supplies and facilities to develop the study (Figure 3). Depending on the size of the island, working teams stayed from 2 to 4 days at each island to accomplish the census.

Figure 2
Different pictures showing the access by boat to or from the surveyed islands. In D, researchers wearing their masks during the COVID pandemic (November 2021).

Figure 3
Different pictures showing our camp stations and facilities at the surveyed islands, including tents (A, D, G), camp facilities (C, E, F), solar panels (B) for charging electronic devices (H).

At each colony we conducted a census of the breeding population by counting **active nests**. An active nest is defined as a substantial or well-constructed nest capable of holding eggs, chicks and occupied by at least one adult bird (modified from Bibby *et al.* 2000; Figure 4). Active nests allow to estimate the number of mature individuals, which are individuals known, estimated, or inferred to be capable of reproduction (IUCN 2022). Each active nest represents two (a pair) mature individuals. This concept is relevant in conservation biology as

IUCN measures the population size of a taxon as the number of mature individuals only (IUCN 2022).

Additionally, we also counted **inactive nests**, which are nests that were unoccupied when we conducted the survey but showed clear signs of previous occupation. These nests contained nest materials (mostly vegetation, feathers, twigs, bones), dry droppings and/or abandoned eggs (Figure 5).

Figure 4
Examples of active nests, showing adult with chicks (A, C), pair of adults (B), adult with eggs (D).

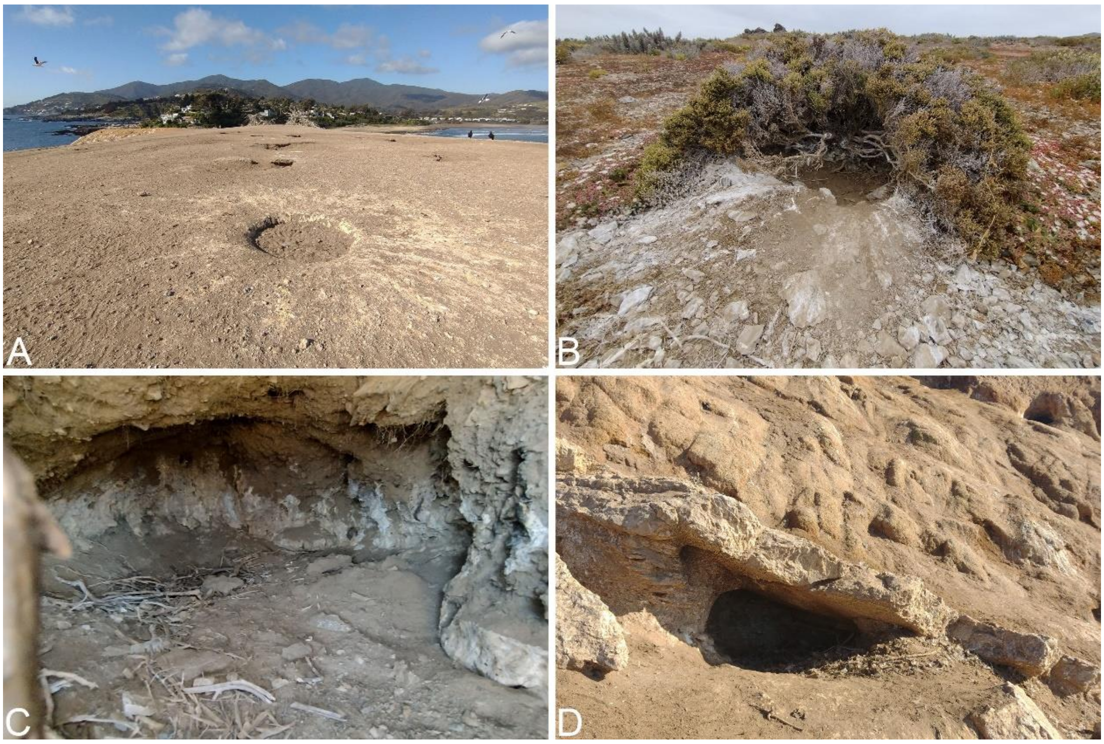

Figure 5
Examples of inactive nests. Only old droppings and nest materials are present, but no adults, eggs or chicks.

We looked for individual nests scattered at the island and checked them visually for their contents (adults, eggs, chicks, and their combinations). Observers walked along a transect, each separated by ca. 50 m, in search of nests, equipped with a GPS device to record the track in one-way travel and minimize double counting on the way back (Figure 6).

Figure 6
Pictures showing research team members looking for penguin nests at the surveyed islands.

Based on satellite images (Google Earth Pro) we estimated the approximate surface covered by our team and linearly extrapolated the count to the 100% of the island´s surface to obtain a total estimate of the breeding population of Humboldt penguins at that specific colony. This methodology is not entirely accurate as it assumes that penguins nest uniformly within the island (while penguins tend to actually nest rather in a clumped way). To reduce this error, we always attempted to cover the largest island´s surface as possible and thus reduce the remaining surface to which the total nest count was extrapolated.

With the counts of both active and inactive nests we calculated for each colony a quotient between both nests. This index provides a valuable information as it allows to obtain a proportion of the nests available at the colony which is being used at the time of the survey.

Depending on the coverage and materials with which nests were constructed, nests were classified into either one of the following eight categories (Figure 7):

a. **Dirt burrow (CT)**: nest excavated by the penguins in the soil in the form of a burrow, usually up to 2 m in depth.
b. **Rock crevice (CU)**: nest inside a natural rock crevice, not excavated by the penguin.
c. **Sea caves (CA)**: normally, multiple open nests located within a big sea cave contiguous to or near the shoreline.
d. **Rock-covered (CR)**: nest in which coverage (from above) is provided by rocks.
e. **Rock-protected (PR)**: nest in which protection (from the sides, not from above) is provided by rocks.
f. **Vegetation-covered (CV)**: nest in which coverage (from above) is provided by vegetation, usually cacti or bushes.
g. **Vegetation-protected (PV)**: nest in which protection (from the sides, not from above) is provided by vegetation, usually cacti and or bushes.
h. **Exposed (EX)**: the nest is just a scrape in the ground with no coverage or protection.

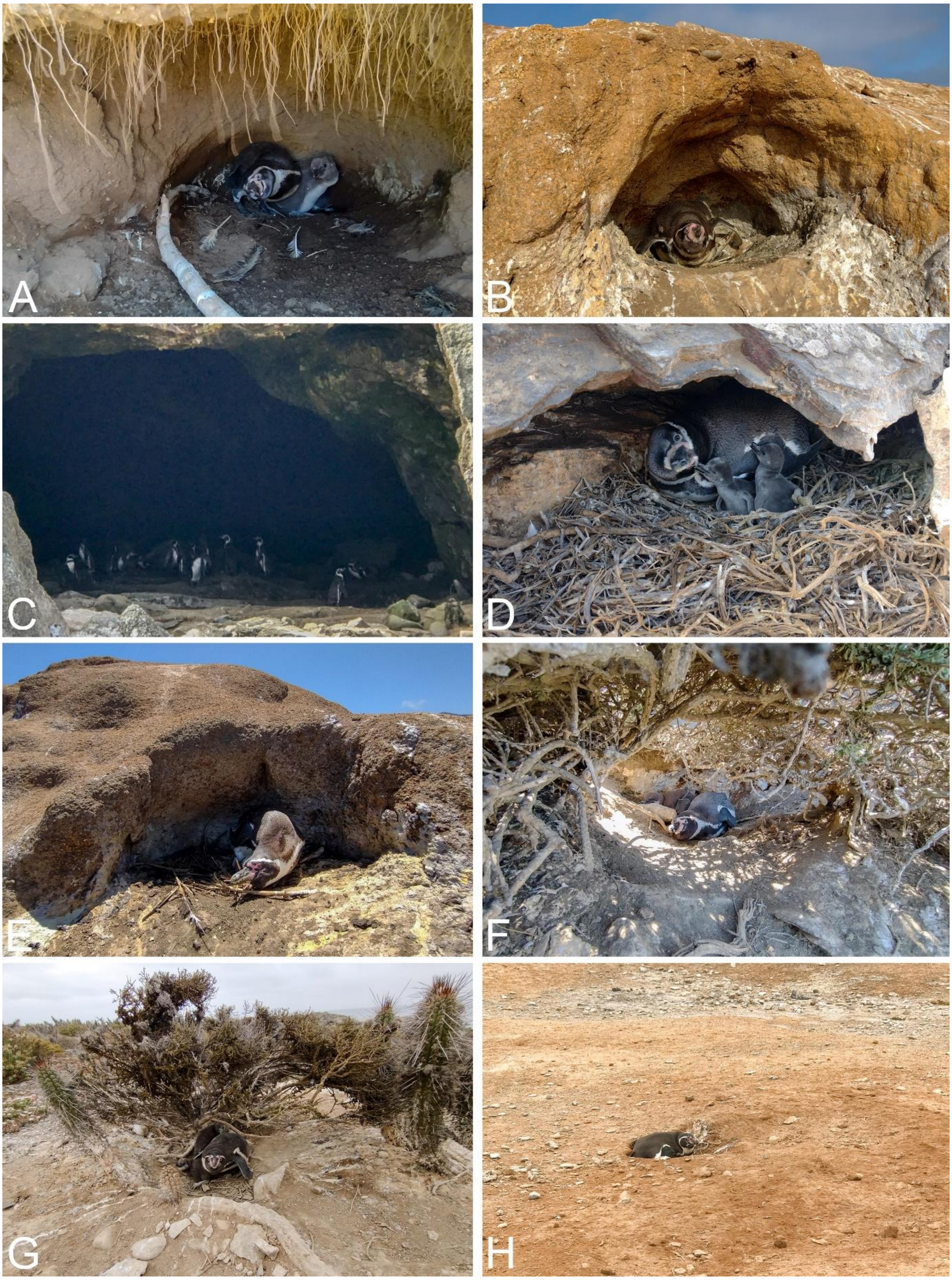

Figure 7
Pictures showing the different nest-types recorded at the surveyed islands: A) dirt burrow, B) rock crevice, C) sea cave, D) rock-covered, E) rock-protected, F) vegetation-covered, G) vegetation-protected, H) exposed.

RESULTS

We surveyed a total of 10 islands where Humboldt penguins breed from isla Pan de Azúcar to islote Pájaro Niño (Table 1). Within this range, the smallest population was at isla Huevos and the largest at isla Cachagua. The total breeding population estimated for the 10 islands was 2,511 pairs (=active nests) which represents slightly over 5,000 mature individuals (Table 1).

At most of the surveyed islands (7 out of 10), the number of inactive nests outnumbered the active nests. This means that there are far more nests available at these islands than are being used by penguins. Two islands (Pájaros and Pájaro Niño) presented as many active nests as inactive nests, and one island (Cachagua) more than doubled the number of active nests compared to inactive nests. Pan de Azúcar and Chañaral presented the lowest rate of active to inactive nests.

Table 1. Humboldt penguin colonies considered in this study and the size of their breeding populations, north-central Chile (26°-33°S).

Colony	Location	Surface area (ha)	Date of census	Number of active nests
Isla Pan de Azúcar	26° 09' S; 70° 41' W	103	29-30/10/2021	162
Islote Ramadas	27° 00' S; 70° 48' W	14	27/10/2021	35
Isla Chañaral	29° 02' S; 71° 34' W	516	30/11-02/12/2021	161
Isla Choros	29° 16' S; 71° 32' W	301	04-06/12/2021	381
Isla Chungungo	29° 24' S; 71° 21' W	15	18/12/2022	65
Isla Tilgo	29° 32' S; 71° 20' W	45	03-04/11/2021	571
Isla Pájaros 1	29° 35' S; 71° 32' W	124	14-15/12/2022	335
Isla Huevos	31° 54' S; 71° 31' W	9	20/12/2022	10
Isla Cachagua	32° 35' S; 71° 27' W	5	24/10/2022	729
Islote Pájaro Niño	33° 21' S; 71° 41' W	3	07/10/2022	62
Total				**2,511**

Table 2. Census of Humboldt penguin nests, including both active and inactive nests (and the rate between both), at 10 colonies in north-central Chile (26°-33°S).

Colony		Nest types								
		CT	CU	CA	CR	PR	CV	PV	EX	Total
Pan de Azúcar	*Active nests*	0	0	0	131	31	0	0	0	**162**
	Inactive nests	0	0	0	568	94	0	0	0	662
	Active/inactive									0,24
Ramada	*Active nests*	1	1	0	18	15	0	0	0	**35**
	Inactive nests	2	2	0	47	13	4	1	0	69
	Active/inactive									0,51
Chañaral	*Active nests*	3	3	0	4	1	150	0	0	**161**
	Inactive nests	10	13	0	37	3	1567	3	0	1633
	Active/inactive									0,1
Choros	*Active nests*	1	36	0	172	46	109	11	6	**381**
	Inactive nests	0	108	0	394	265	224	72	44	1107
	Active/inactive									0,34
Chungungo	*Active nests*	0	0	0	17	10	38	0	0	**65**
	Inactive nests	1	2	0	24	24	76	7	0	134
	Active/inactive									0,49
Tilgo	*Active nests*	3	0	0	445	55	68	0	0	**571**
	Inactive nests	8	0	0	718	54	312	0	0	1092
	Active/inactive									0,52
Pájaros 1	*Active nests*	11	1	23	146	119	26	4	5	**335**
	Inactive nests	39	0	23	114	86	50	7	0	319
	Active/inactive									1,05
Huevos	*Active nests*	0	0	0	8	2	0	0	0	**10**
	Inactive nests	0	0	0	14	1	0	0	0	15
	Active/inactive									0,67
Cachagua	*Active nests*	492	56	0	116	51	12	1	1	**729**
	Inactive nests	117	43	0	88	52	8	0	13	321
	Active/inactive									2,3
Pájaro Niño	*Active nests*	1	19	13	27	2	0	0	0	**62**
	Inactive nests	1	16	17	18	2	0	0	0	54
	Active/inactive									1,15

DISCUSSION

When the figures of the breeding population size of Humboldt penguins obtained in the present study are contrasted with the previous comparable data obtained by Simeone et al. (2018) during the spring of 2017, a marked reduction of nearly 50% is observed within a period of 4 years (Table 3). Particularly strong seem to be the reductions observed in the breeding population from Chañaral and Choros islands which average 85%. However, we suggest that these apparent reductions are likely to be due to methodological reasons rather than representing a true decline in the breeding population.

Table 3. Comparison of the breeding population size of Humboldt penguins obtained by the present study (2021-2022) and that reported by Simeone *et al.* (2018) during 2017.

Colony	Location	Surface area (ha)	Present study	Simeone et al. (2018)
Isla Pan de Azúcar	26° 09' S; 70° 41' W	103	162	75
Islote Ramadas	27° 00' S; 70° 48' W	14	35	4
Isla Chañaral	29° 02' S; 71° 34' W	516	161	1,045
Isla Choros	29° 16' S; 71° 32' W	301	381	2,859
Isla Chungungo	29° 24' S; 71° 21' W	15	65	22
Isla Tilgo	29° 32' S; 71° 20' W	45	571	97
Isla Pájaros 1	29° 35' S; 71° 32' W	124	335	33
Isla Huevos	31° 54' S; 71° 31' W	9	10	16
Isla Cachagua	32° 35' S; 71° 27' W	5	729	456
Islote Pájaro Niño	33° 21' S; 71° 41' W	3	62	25
Total			**2,511**	**4,632**

The methodology employed in the present study and that used by Simeone *et al.* (2018) is comparable in that both are based on the count of active nests (as defined in page 11, present study), but differ in that Simeone *et al.* (2018) used the Distance Sampling methodology (Buckland *et al.* 1993, Thomas *et al.* 2010) to estimate the breeding population at Chañaral and Choros. These are the sites which exhibit the largest differences in population size (see Table 3). Although not presented in the results, during the 2021-2022 season, we conducted simultaneous counts of active nests employing both Distance Sampling and the "traditional method" (as described in pages 11-13, present study). The results obtained with both methodologies showed to be dramatically different, with those derived with Distance Sampling being up to 6-8 times higher than those obtained with the "traditional method". While Distance Sampling allows to significantly reduce the time spent at the colony and reduces disturbance to the breeding birds, we consider it likely that the numbers obtained by Simeone *et al.* (2018) overestimated the number of breeding pairs at Chañaral and Choros in 2017. Further calibration of Distance Sampling is needed if it is to be employed for determining the breeding population of Humboldt penguins.

In a recent study, Vargas-Rodríguez *et al.* (2022) estimated that the average number of mature individuals for Choros island between 2015 and 2019 was around 1,110 (555 pairs), a number much consistent with those reported by us than those reported by Simeone *et al.* (2018) (see Table 3 for comparison). Vargas-Rodríguez *et al.* (2022) also state that differences in the population sizes determined in their study and those reported by Simeone *et al.* (2018) are due to the use of Distance Sampling which overestimated the results. Simeone *et al.* (2003) reported 360 pairs breeding at Choros island during the 2001-2002 season, also a number much consistent with those reported in our study (see Table 3).

As for the rate between active and inactive nests, this is a useful index which provides information on the proportion of nests that are available to penguins at the islands and the nests that are being used. At two islands we found particularly low rates of active to inactive nests (Table 2): at Pan de Azúcar, for each active nest there were 4 inactive, while at Chañaral, for each active nest there were 10 inactive. This suggest that at both islands, particularly Chañaral, only a small fraction of its breeding population is using this colony.

PART 2

Nest monitoring and breeding success of Humboldt penguins at Chañaral and Choros islands

AUTHORS:

GUILLERMO LUNA-JORQUERA, NICOLÁS LUNA AND MYLENE SEGUEL

NICOLÁS LUNA ©

METHODS

To estimate the breeding success of Humboldt penguins we monitored nests containing adult birds with eggs or small chicks (Figure 8). We placed a wooden marker (30 cm long and 1,3 cm width) near the entrance of each nest Figure 8C and D); each marker was assigned with a number to facilitate nest identification. Additionally, for each monitored nest we obtained a GPS waypoint. At the end of the season, all markers were removed.

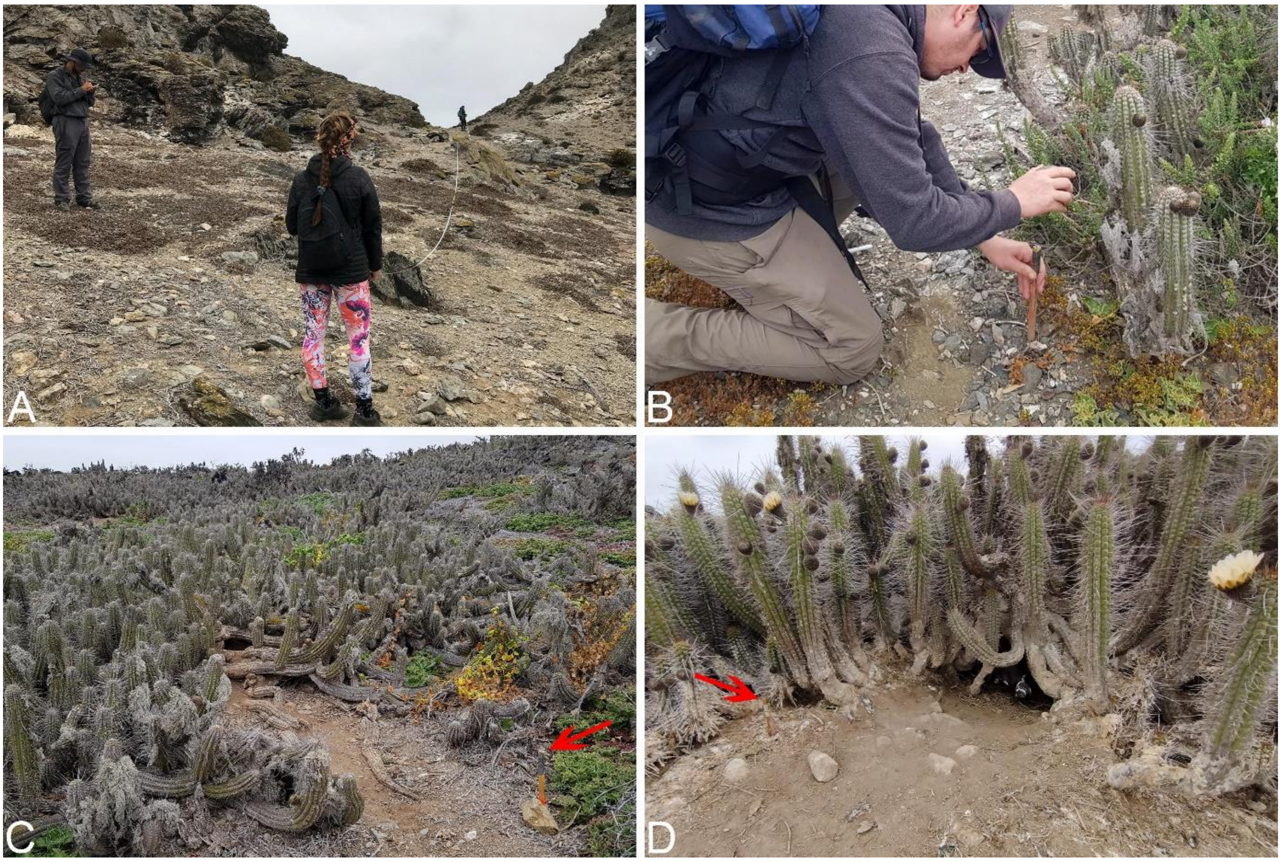

Figure 8
Pictures showing field work of the monitoring team (A), wooden marker installation (B), and nests identified with wooden markers near the nest entrance (C, D). Red arrows in C and D indicate the position of the markers.

Nests were monitored for estimating breeding success during the season 2021-2022 and 2022-2023 at Chañaral and Choros islands. Nests were visited periodically, depending on the sea and wind conditions. During each visit, we recorded the nest contents (adults, eggs, chicks, and their combinations). The frequency of visits to the monitored nests for both islands is shown in Table 4.

Table 4. Frequency of visits to the monitored nests at Chañaral and Choros islands during the 2021-2022 and 2022-2023 breeding seasons.

	Oct		Nov		Dec		Jan		Feb
2021-2022 season	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-31	1-15
Chañaral			✓	✓		✓	✓	✓	✓
Choros			✓		✓	✓	✓	✓	✓
2022-2023 season									
Chañaral	✓	✓					✓		
Choros	✓	✓			✓				

RESULTS

Chañaral Island

2021-2022 breeding season. We monitored a total of 40 nests. The progression of the number of eggs and chicks during the season in the monitored nests is shown in Figure 9A and the fate of the nests in Figure 9B. From all 40 active nests, 5 (12.5%) were deserted during the incubation. Average hatching success was estimated in 0.76 (SD= 0.44; 95% CI= 0.15, upper limit= 0,91, lower limit= 0.61). Average chick mortality was 0.15 (SD = 0.33; 95% CI = 0.13, upper limit = 0.27, lower limit= 0.02). At the end of the season, a total of 41 fledglings were produced in the 40 nests, rendering a breeding success of 1.03 fledglings per nest.

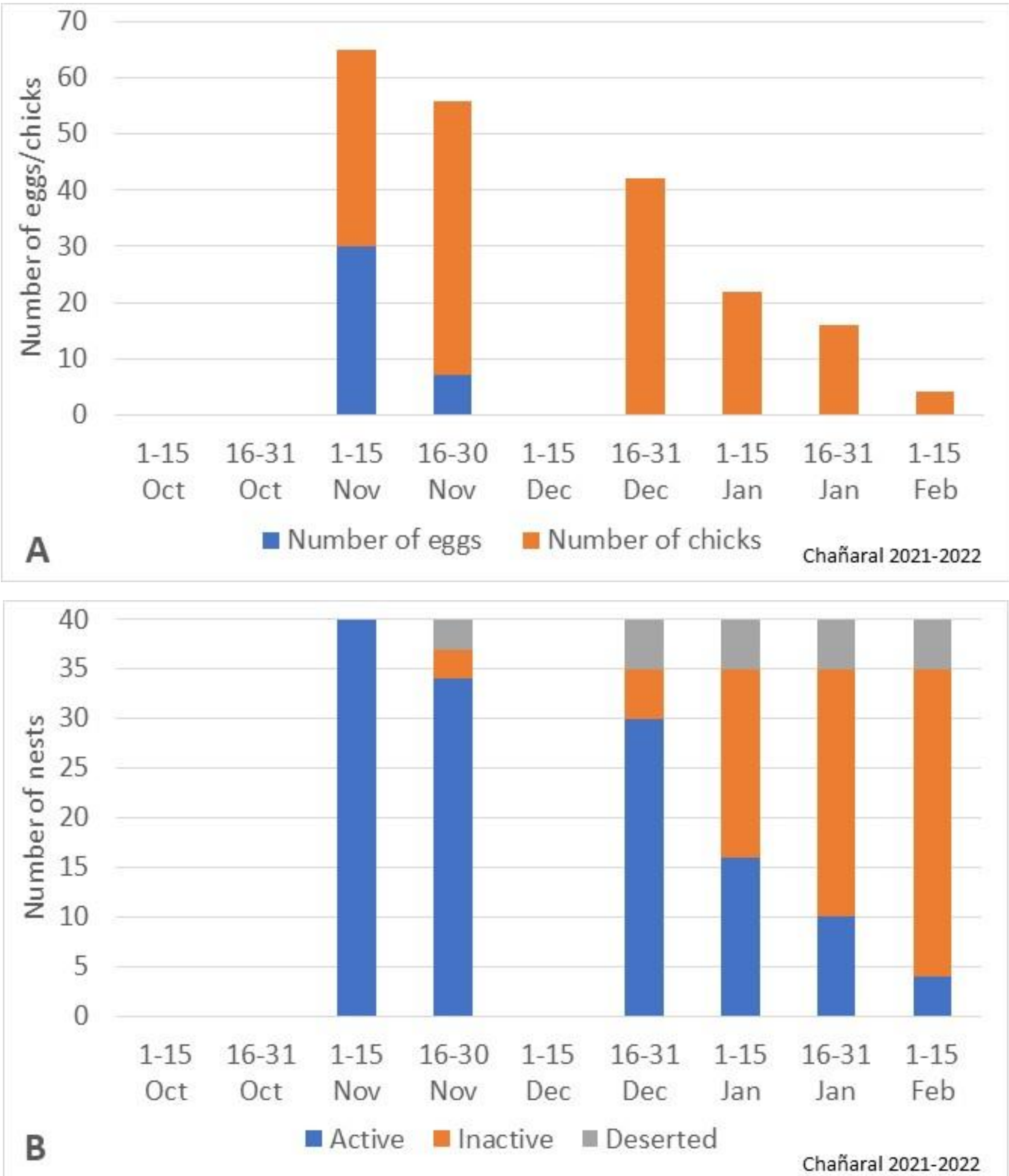

Figure 9
A) Progression of the number of eggs and chicks and B) fate of the monitored nests (n= 40). Chañaral island, 2021-2022 breeding season.

2022-2023 breeding season. We monitored a total of 37 nests. The progression of the number of eggs and chicks during the season in the monitored nests is shown in Figure 10A and the fate of the nests in Figure 10B. From all 37 active nests, 2 (5.4%) were deserted during the incubation. Average hatching success was estimated in 0.21 (SD = 0.41, 95% CI= 0.13, upper limit= 0.35, lower limit= 0.08).

The low number of visits during this season is explained by three main factors. During November 2022, a general strike of CONAF personnel (who manages Chile´s terrestrial protected areas) hindered access to isla Choros and Chañaral. Access to the islands was resumed in late November. During December, strong winds made difficult the access to the islands and starting in late December, access to the islands was totally restricted due to sanitary reasons related to avian influenza.

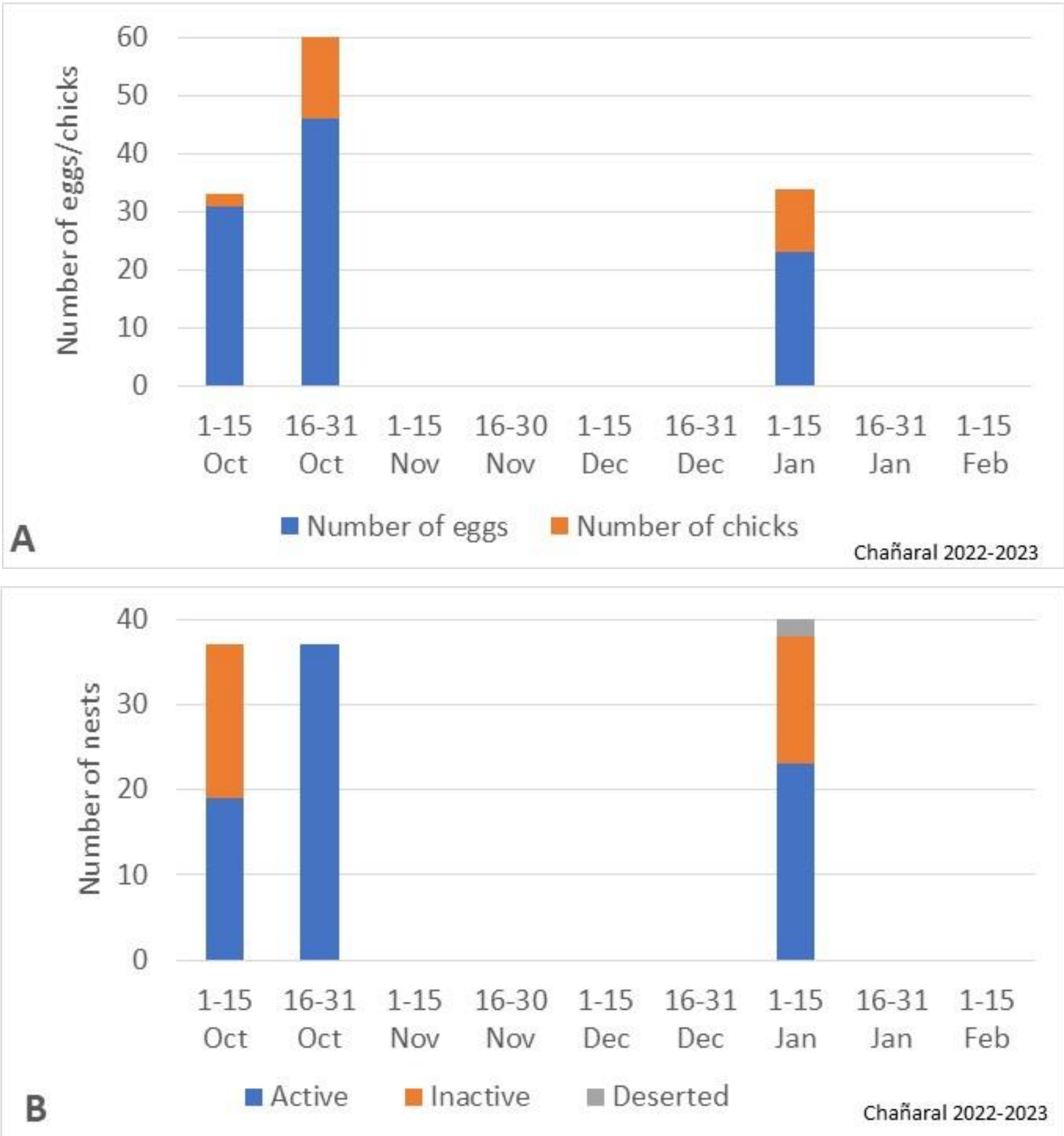

Figure 10
A) Progression of the number of eggs and chicks and B) fate of the monitored nests (n= 37). Chañaral island, 2022-2023 breeding season.

Choros Island

2021-2022 breeding season. We monitored a total of 77 nests. The progression of the number of eggs and chicks during the season in the monitored nests is shown in Figure 11A and the fate of the nests in Figure 11B. We detected no nests with abandoned eggs during the season. Average hatching success was estimated in 0.86 (SD= 0.28; 95% CI= 0.06; upper limit= 0,93, lower limit= 0.8). Average chick mortality was 0.11 (SD= 0.27; CI= 0.06; upper limit= 0.17, lower limit= 0.05). At the end of the season, a total of 110 fledglings were produced in the 77 nests, rendering a breeding success of 1.43 fledglings per nest.

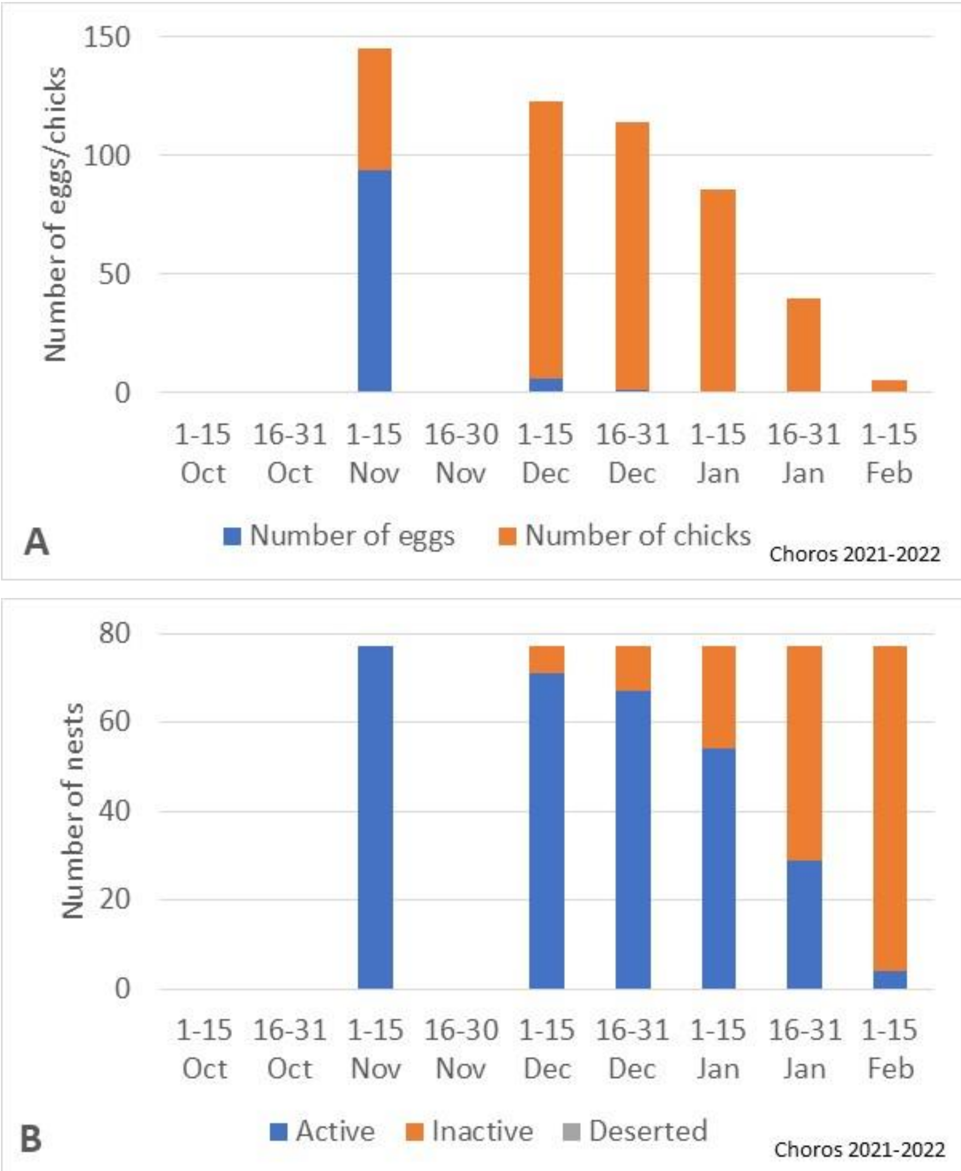

Figure 11
A) Progression of the number of eggs and chicks and B) fate of the monitored nests (n= 77). Choros island, 2021-2022 breeding season.

2022-2023 breeding season. We monitored a total of 51 nests. The progression of the number of eggs and chicks during the season in the monitored nests is shown in Figure 12A and the fate of the nests in Figure 12B. We detected no nests with abandoned eggs during the season. Average hatching success was estimated in 0.91 (SD = 0.24, 95% CI = 0.06, upper limit= 0.97, lower limit= 0.84).

The same reason mentioned for Chañaral apply to Choros foe explaining the low number of samplings performed during this season.

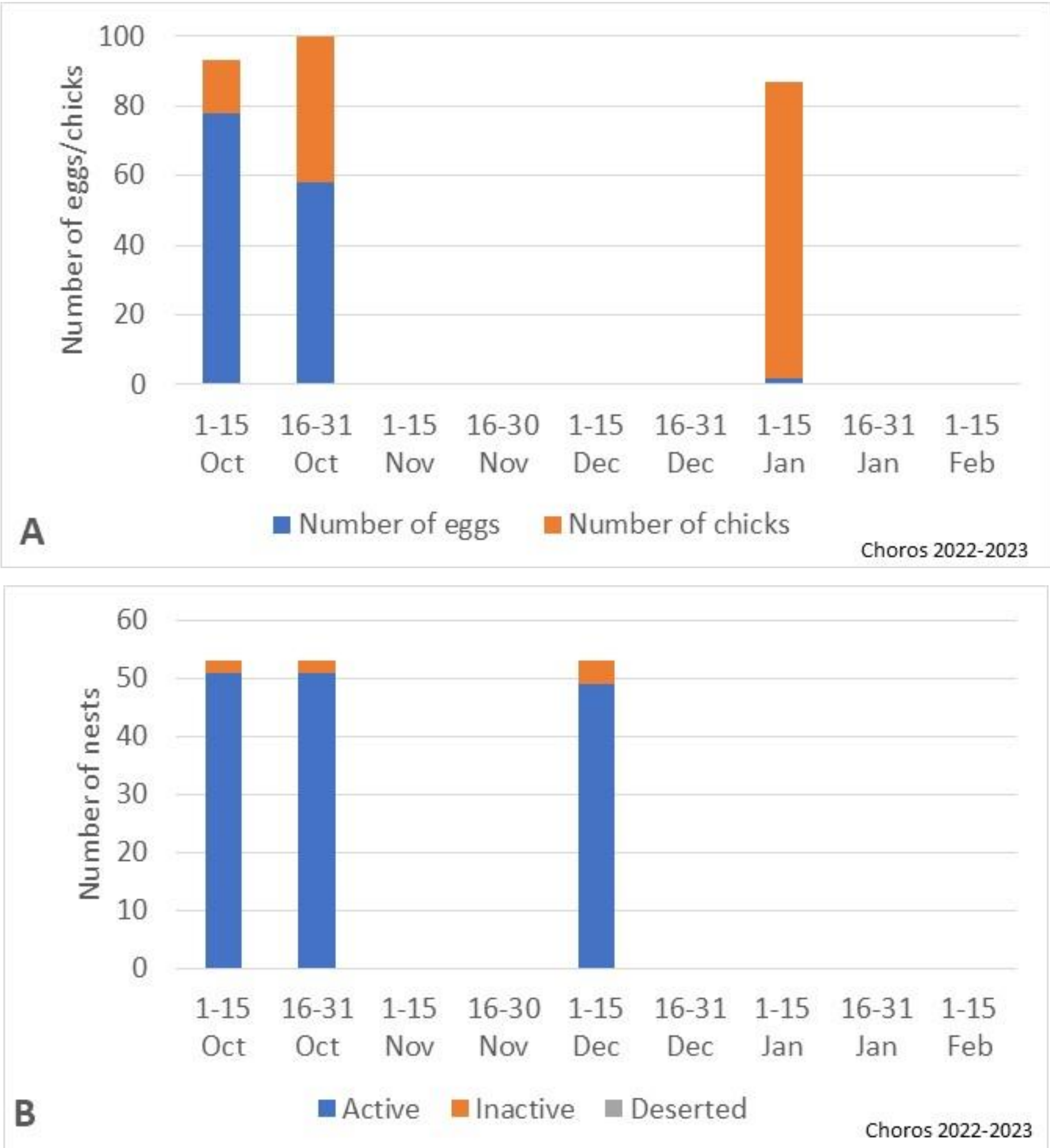

Figure 12
A) Progression of the number of eggs and chicks and B) fate of the monitored nests (n= 51). Choros island, 2022-2023 breeding season.

PART 3:

Foraging behaviour of Humboldt penguins from Choros Island

AUTHORS:

THOMAS MATTERN, URSULA ELLENBERG, MAXIMILIANO DAIGRE AND ALEJANDRO SIMEONE

PHOTO BY PENGUCAM

Winter 2022 fieldwork

Methods

Between 13 and 24 June 2022 (austral winter), nest searches were conducted across all parts of Choros island, although most of the search effort was focussed on the island´s northern region. A total of 134 nests were mapped during these 11 days; not all active nests found were recorded because nests were deemed unsuitable for our work or disturbance of penguins was considered too excessive. While many of the nests were still on eggs in the first week, most eggs had hatched by the end of our stay. Nest densities were highest in the north and the eastern regions of the island when compared to the ocean facing western side, with some nests established in the upper ranges or on top of the island’s high plateaus (Figure 13).

Figure 13
Location of mapped Humboldt penguin nests (yellow triangles), June 2022. Not all active nests were mapped.

GPS logger deployments

Of all mapped nests, only a fraction was deemed suitable for deployments of GPS dive loggers on attending adult Humboldt penguins. Suitable nests on one hand had to contain chicks of at least weeks of age and, on the other hand, had to be enclosed with only a single entrance to avoid nest abandonments resulting from the interaction with attending birds.

GPS loggers were deployed between 14-19 June 2022 on a total of 12 adult Humboldt penguins from different nests. Morphometric measurements revealed that these were eight females and four male penguins. The logger deployment procedure was as follows.

Penguins were removed from the nest using a leg crook made from rigid wiring, by hooking one of the bird's feet or flippers and gently pulling it out of the nest cavity. Once removed from the nest, the bird was then placed in a cloth bag and then weighed with a handheld spring balance. After this tracking devices were deployed on the bird.

We used AxyTrek Marine GPS dive loggers that monitor foraging movements and driving behaviour. The devices are streamline shaped and have the following dimensions: 70 mm X 40 mm X 15 mm (length X width X height). The units are fitted with a 1600 mAh battery which allows an operation time of 7-10 days. Each unit weighs 60 grams (Figure 14).

Figure 14
AxyTrek Marine GPS dive logger. 100- and 10-Peso coins for scale.

Devices were attached to a penguin's back using waterproof adhesive tape. Using a cut-out template, the proposed position of the device on the bird was marked. Then a series of tape striped were threaded under lines of feathers before placing the device on the prepared spot and wrapping the loose ends of the tape around the device. The whole procedure of device attachment is shown in Figure 15.

Figure 15
Procedure of GPS logger attachment to a Humboldt penguin.

A cable tie was also threaded around feather and device to ensure penguins could not preen off tape and device. Finally, the top of the device was coated with a thin layer of rubber-based glue to prevent end of tapes loosing while at sea (Figure 16A). Devices removal was simply a reverse of the process; tape stripes could easily be peeled off the feathers so that no permanent damage was caused to the penguin's plumage (Figure 16B-C).

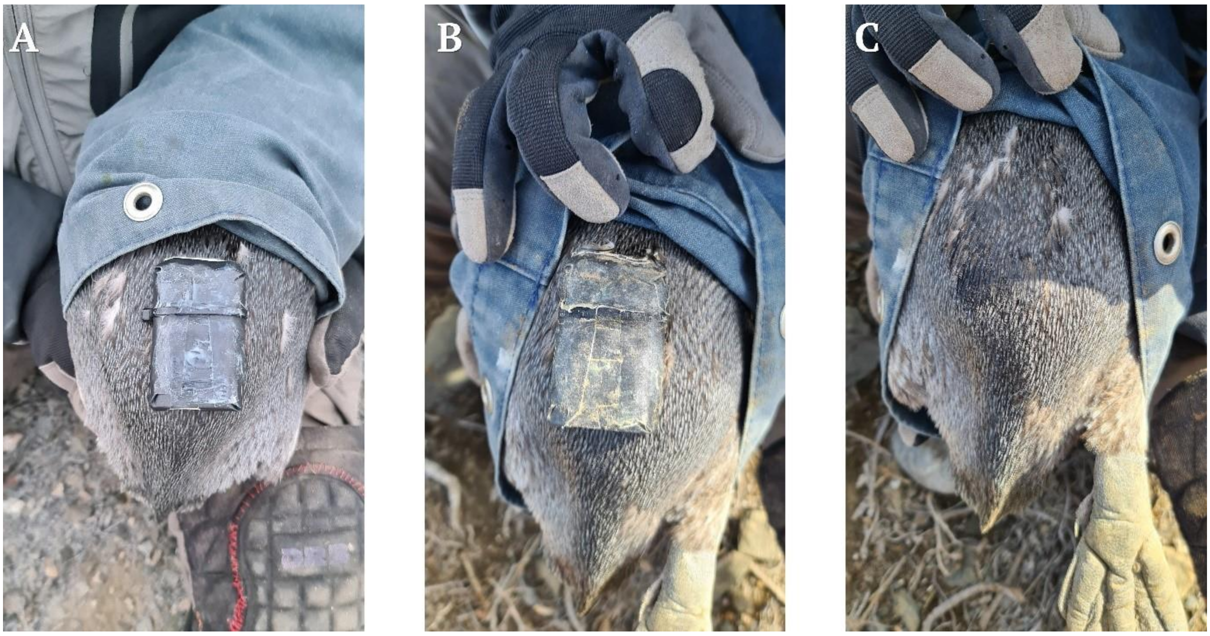

Figure 16
GPS dive logger during deployment (A), after recapture of the penguin five days later (B, cable tie already removed when photo was taken), and state of plumage after removal of device and tape (C).

Device deployments took between ca. 10 minutes from capture to release of the bird. Device recovery which included capture and weighing of bird on the nest as described above, device removal and release into nest, took < 5 minutes.

GPS dive loggers were recovered after 4-7 days (mean: 4.5±1.2 days). Two of the 12 birds fitted with devices could not be recovered and loggers were subsequently lost:

1. One female penguin appears to have abandoned its nest after the chicks disappeared the day after the deployment; its partner attended the nest for three days after the device deployment before also abandoning its nest.
2. A male penguin did not return to its nest for four days and could not be recaptured before our team had to leave the island. The most likely explanation is that the bird performed a longer foraging trip as both its chicks were still alive and well with the attending female when we left the island. However, neither abandonment nor the possibility that the penguin died at sea can be ruled out as alternative explanation.

Of the remaining 10 devices that were recovered from penguins (Figure 17), one deployment did not yield any foraging data. In this case, the male penguin that was fitted with GPS dive logger did not leave its nest over the course of the four days of deployment. During this time, the bird lost nearly 1 kg of body mass. It remained on the nest for another five days and only abandoned the nest after the chick had died, presumably of starvation.

Figure 17
Adult Humboldt penguin guarding two chicks on the day of device recovery.

RESULTS

The nine successful device deployments on adult Humboldt penguins resulted in a total 8,356 GPS positions recorded while the penguins were at sea. These data allowed the reconstruction of 17 complete foraging trips (Figure 18).

These trips generally lasted between 10 and 24 hours (mean: 16.7±4.5 hours) the exception being one foraging trip that lasted 87.3 hours. Distances covered during these trips averaged 41.0±18.6 km. The bird performing the single long foraging trip covered at least 284 km.

Interestingly, six of the nine tracked birds left their nests shortly after they were relieved by their partners. The birds then entered the water that same evening and spent the night drifting inactive at the surface. Diving behaviour would only commence at first light the next morning.

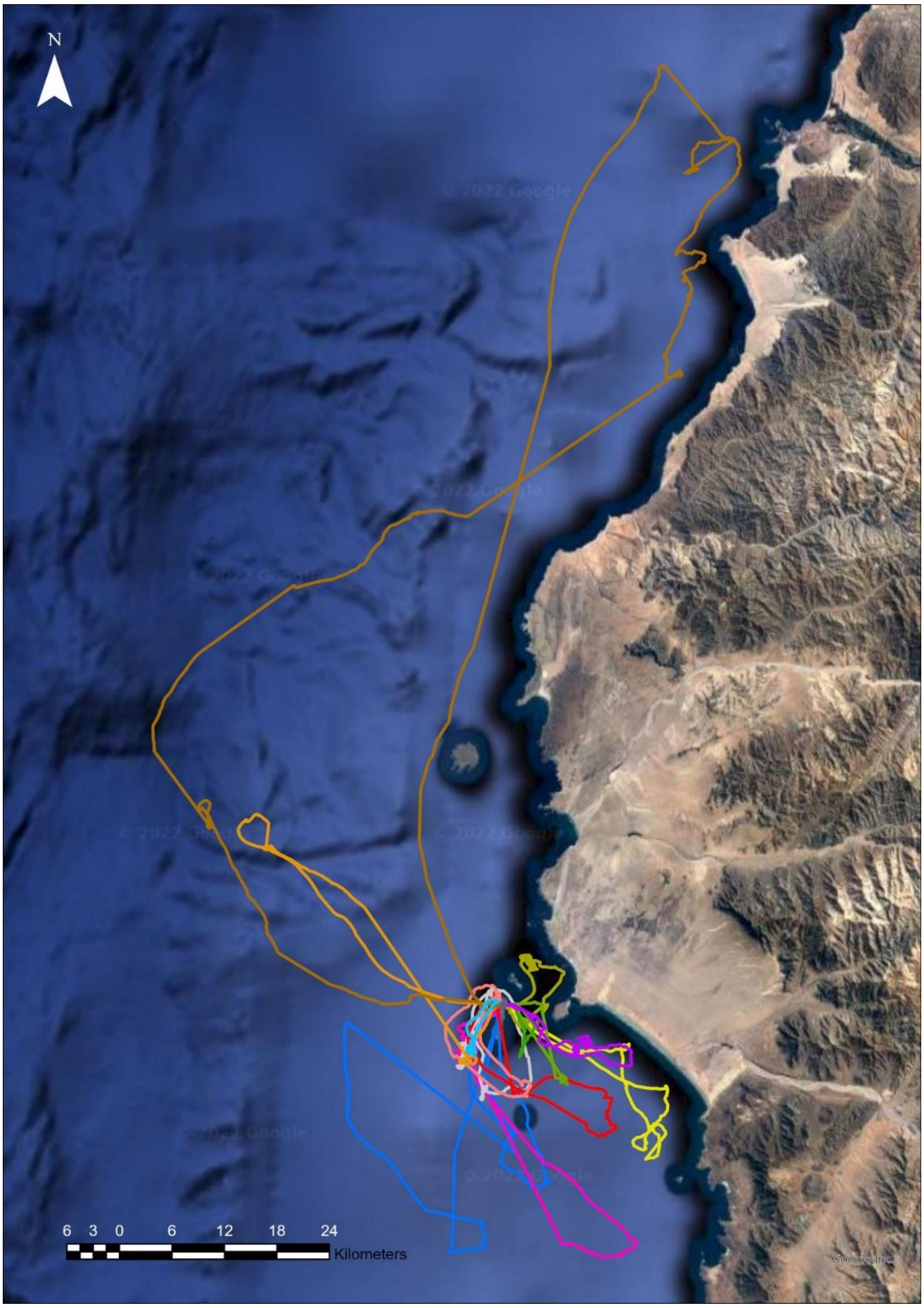

Figure 18
Foraging trips recorded with GPS dive loggers on nine different Humboldt penguins breeding on Isla Choros in June 2022. Lines with similar hue represent different trips performed by the same bird.

At-sea distribution of the penguins appeared to be governed on which side of the island the birds would enter the water. Penguins breeding on the eastern, landward side of the island (n=3) all foraged within 1-5 km from the mainland shore (Figure 19A), whereas penguins breeding in the northwest and west that used landing sides on the seaward side of the island foraged principally to the south and southwest of Isla Choros some 15-40 km from the coast (Figure 19B).

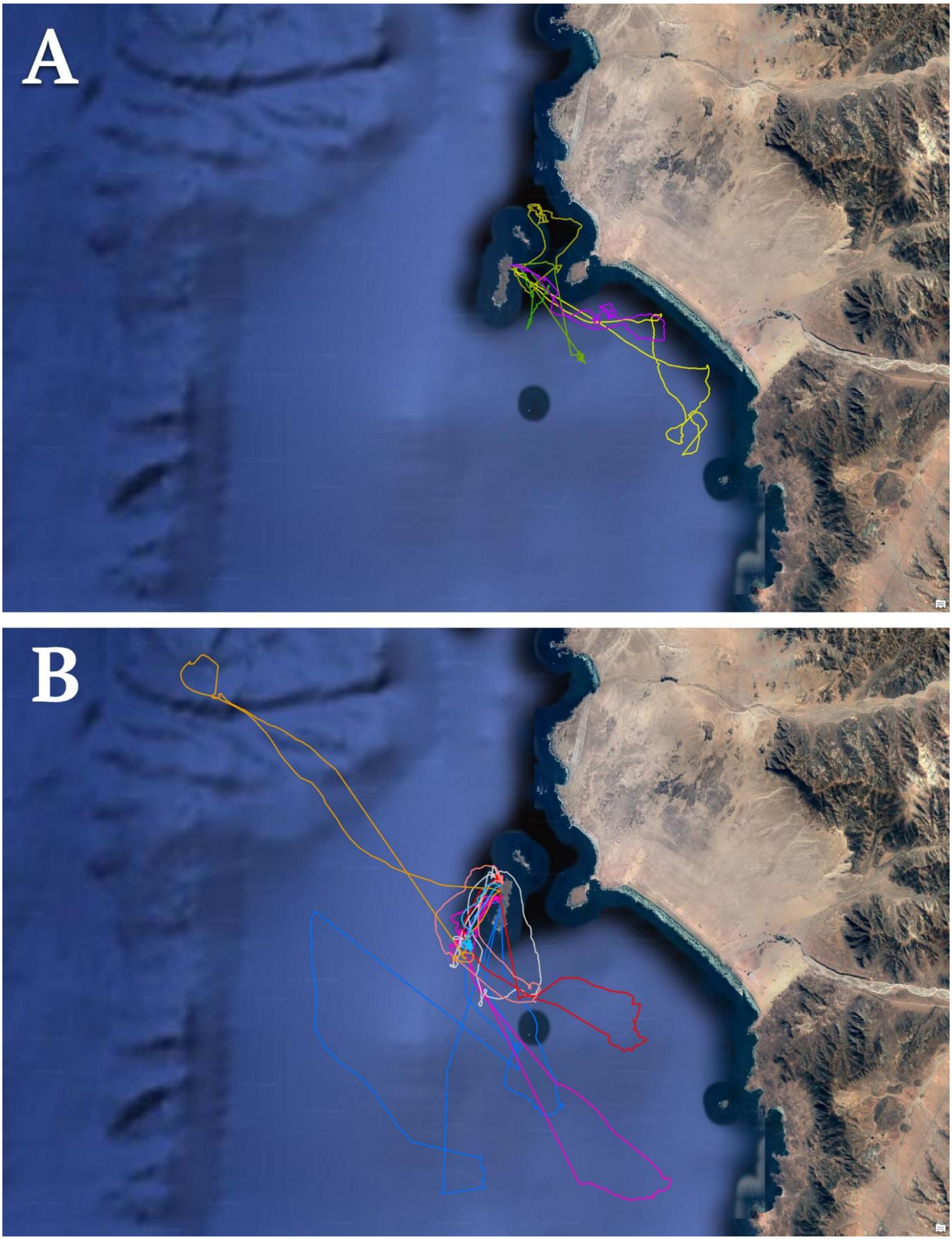

Figure 19

Single-day foraging trips (n=16) recorded in breeding Humboldt penguins from Isla Choros in June 2022. (A) shows trips performed by three birds that breed on the eastern, landward side of the island whereas (B) highlights trips from birds breeding on the western, seaward side of the island. This highlights the apparent different utilization of the surrounding marine habitat by penguins depending on the location of their nests.

One female undertook a long foraging trip during which the bird travelled almost 100 km north along the coastline, reaching the latitude of Huasco before returning to Isla Choros (Figure 20). This long foraging trip occurred after the female had performed a single day foraging trip (duration: 21.7 hours) on 16 June and had spent the following days guarding the chicks on the nest. Therefore, it can be ruled out that the deployment process had anything to do with the birds' decision to stay at sea for that long. Instead, we assume that the bird failed to locate suitable prey patches to forage and, therefore, continued to swim northwards until it encountered better foraging conditions off Huasco. Considering that this was also the only penguin that foraged north of the island may indicate that prey availability is better in the south of Isla Choros.

During their foraging trips, the penguins performed and average 388±186 dives per day (range: 146-878 dives) during which they reached maximum depths of 31.5-110.6 metres. When diving, they stayed under water for an average 53±14 seconds and covered mean diving distances of 111.7±23.2 metres.

Figure 20
Overview of a three-day trip performed by a female Humboldt penguin from Isla Choros, June 2022. Note that the same bird had performed a one-day trip two days prior to this extended journey (see track of same colour in Figure 7B).

SPRING 2022 FIELDWORK

METHODS

Between 25 November and 15 December 2022, comprehensive nest searches were conducted across all parts of the island with exclusion of penguin landing beaches and the small (~150 nests) Neotropic cormorant (*Phalacrocorax brasilianus*) colony in the Northeast of the island to reduce human disturbance impact (Figure 21). We mapped 381 active Humboldt penguin nests and 1,586 empty nests during 82 hours of designated search effort.

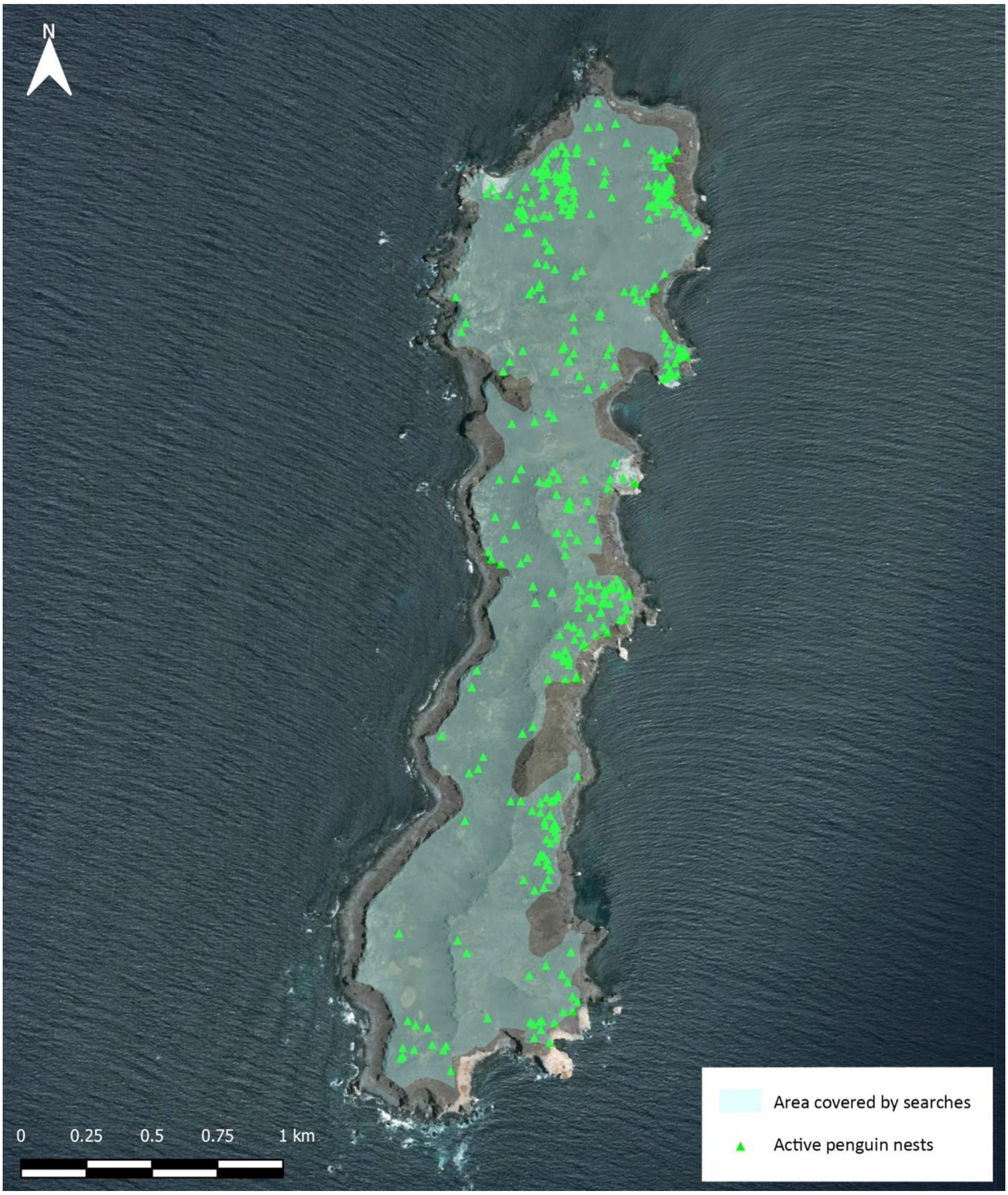

Figure 21
Location of all mapped Humboldt penguin nests (green triangles) on Isla Choros, Humboldt Penguin National Reserve, 25 Nov – 14 Dec 2022. The area covered by nest searches derives from GPS track logs is marked in color.

Nest densities were highest in the northern and the eastern regions of the island when compared to the ocean facing western side, with a small number of nests established in the upper ranges or on top of the island's high plateaus (Figure 21). Observations using binoculars (Leica, 10X42) from the first plateau (while well concealed from resting penguins below) suggest that we may have missed up to 10 nests per bay on the busy Eastern landing beaches and a few additional nests in the West. Some of the steep eastern slopes were not included in ground searches due to health and safety concerns. However, scans with binoculars revealed little sign of penguin presence.

Neotropic cormorants are extremely timid and human approach may cause abandonment of an entire colony resulting in egg or chick loss to the ever-vigilant gulls. Hence, we carefully searched only the cacti along the fringes around the colony. We are glad to report that by keeping a close eye on cormorant behaviour and dropping back when the first birds showed signs of vigilance, we did not cause any nest abandonment. As a result, we may have missed a few nests of penguins breeding within the cactus field occupied by the Neotropic cormorant colony. However, penguin nest numbers in the Northeast were comparable to counts completed during June 2022, when the cormorants were not present, and the entire colony area could be searched.

Most (274) of the active nests had one adult present guarding chicks (72%), in two cases both adults were present with the chicks, 45 birds were still on eggs (12%), and 29 (8%) of the nests contained post-guard chicks, in another 29 cases prone sitting adults were encountered deep within nest caves and contents (likely eggs or small chicks) could not be established without causing unnecessary disturbance; in two cases only eggs were found with no adult present. To our knowledge, through our careful approach, we did not cause any of the penguin nests to fail.

Most of the nests were below rocks (46%), protected by rocks (9%), or in rock caves (6%), with the remaining covered by vegetation (shrub and/or cactus, 34%) or protected by vegetation (5%). Only one nest was found in the open with little protection.

Nests of the 12 individuals marked during the winter tracking period (see preceding section from June 2022) were revisited. We found seven of the nests active and, in five cases, could confirm an individual marked on the same nest in June as one of the pair encountered in November (Figure 22). Despite repeated nest checks we only ever encountered unmarked birds on the remaining two nests.

Figure 22
Maximilliano getting a read of a marked female breeding successfully in June and attending two eggs in the same nest (CH-W-04) on 29 November 2022. Both eggs hatched with two chicks present when we last checked the nest on 15 December 2022.

GPS logger and PenguCam deployments

Of all mapped nests, only a fraction was deemed suitable for logger deployments. Suitable nests had a single attending adult penguin, contained chicks of at least one week of age, and were fully enclosed with only a single entrance to reduce the chance of nest abandonment potentially resulting from the interaction with the attending bird.

Loggers were deployed between 25 November and 17 December 2022 on 16 adult Humboldt penguins from different nests. Morphometric measurements revealed that these were eleven females and five male penguins. Penguins were carefully removed from the nest either by hand or by using a leg crook made from rigid wiring, by hooking one of the bird's feet or flippers and gently walking it out of the nest cavity. Once in hand, the bird was placed headfirst into a cloth bag and weighed with a handheld spring balance (5kg Pesola). Subsequently, tracking devices were deployed. During deployment, the head of the bird was kept within the cloth bag to reduce stress exposing the beak to facilitate breathing while allowing the bird to rest prone in a natural position. The device was placed on the lower back to reduce drag once at sea. Following device deployment, morphometric measurements were taken, and the bird marked with a transponder (11mm TROVAN) before releasing it back into the nest. All 16 birds immediately returned and stayed with their chicks following release.

To record three-dimensional foraging trips, we used AxyTrek Marine GPS dive loggers (AxyTrek, TechnoSmart, Italy, https://www.technosmart.eu/) that monitor at-sea movements and diving behaviour (Figure 14). The devices are streamline shaped (dimensions: 70mm x 40mm x 15mm; Figure 14). The units are powered by a 1600 mAh battery which allowed an operation time of 7-10 days. Each unit weighed 50 grams.

Following monitoring of ideal logger nests with surveillance cameras (Bushnell Trophy Cam – low glow) to establish nest attendance patterns, we chose six nests for the deployment high-definition video loggers (PenguCam, New Zealand, https://pengu.cam/) which were deployed in conjunction with AxyDepths (TechnoSmart, Italy, https://www.technosmart.eu/) to provide depth and accelerometer data in conjunction with the videos. Using our PenguCam footage, accelerometer data will be evaluated using corresponding penguin foraging behaviour. The six birds attending at the time of deployment were by chance all females. Devices were attached to a penguin's back with waterproof adhesive tape. Using a cut-out template, the proposed position of the device on the bird was marked. Then a series of tape stripes were threaded under the feathers (Figure 23A, B) before placing the device on the spot and wrapping the loose ends of the tape around the device (Figure 23C).

One small cable tie was threaded around feathers and unit to ensure the logger stayed in place and penguins could not preen off tape and device (Figure 16A). Device removal was simply a reverse of the process; tape stripes were twisted and could easily be peeled off the feathers so that no permanent damage was caused to the penguin's plumage (Figure 16B, C).

Figure 23
Ursula & Maximiliano attaching a PenguCam logger to a Humboldt penguin (Photo by Karen Lau).

Device deployments took ca. 15 minutes from capture to release of the bird, including capture and weighing of the attending bird as described above, taking morphometric measurements required for sexing the bird, as well as individually marking the bird with a transponder. Device removal and release back into the nest, took less than five minutes.

GPS dive loggers were recovered after 4-7 days. PenguCam loggers were recovered following one single foraging trip. One of the 16 birds fitted with devices disappeared and could not be recovered. The GPS logger was subsequently lost (see page 46).

RESULTS

Logger deployments yielded GPS and dive data for 12 birds (7 females, 5 males), and dive data for the 6 birds deployed with PenguCams representing 736 hours of at-sea spread over 41 different single-day, 2 two-day foraging trips, and one brief evening trip (median 15.6h, range 1.4h-47.8h). A total of 16,562 GPS positions as well as 24,320 dives events were recorded. Some birds achieved maximum dive depths of up to 100m, however, most birds focused their efforts shallower with average dive depths of only 17.5m and a median maximum dive depth of 65m. Birds achieved median horizontal travel speeds of 1m/s and travelled on average 43.9km during their foraging trip (range 3.7km-77.2km; compare overview table in Appendix). These data allowed the reconstruction of 38 complete foraging trips (Figure 24). Most foraging activity took place within 10km of Isla Choros with some birds ranging up to 30km away. The comparably short foraging ranges are likely a result of the productive marine environment around the Humboldt Penguin National Reserve during La Niña with good food availability close to the island.

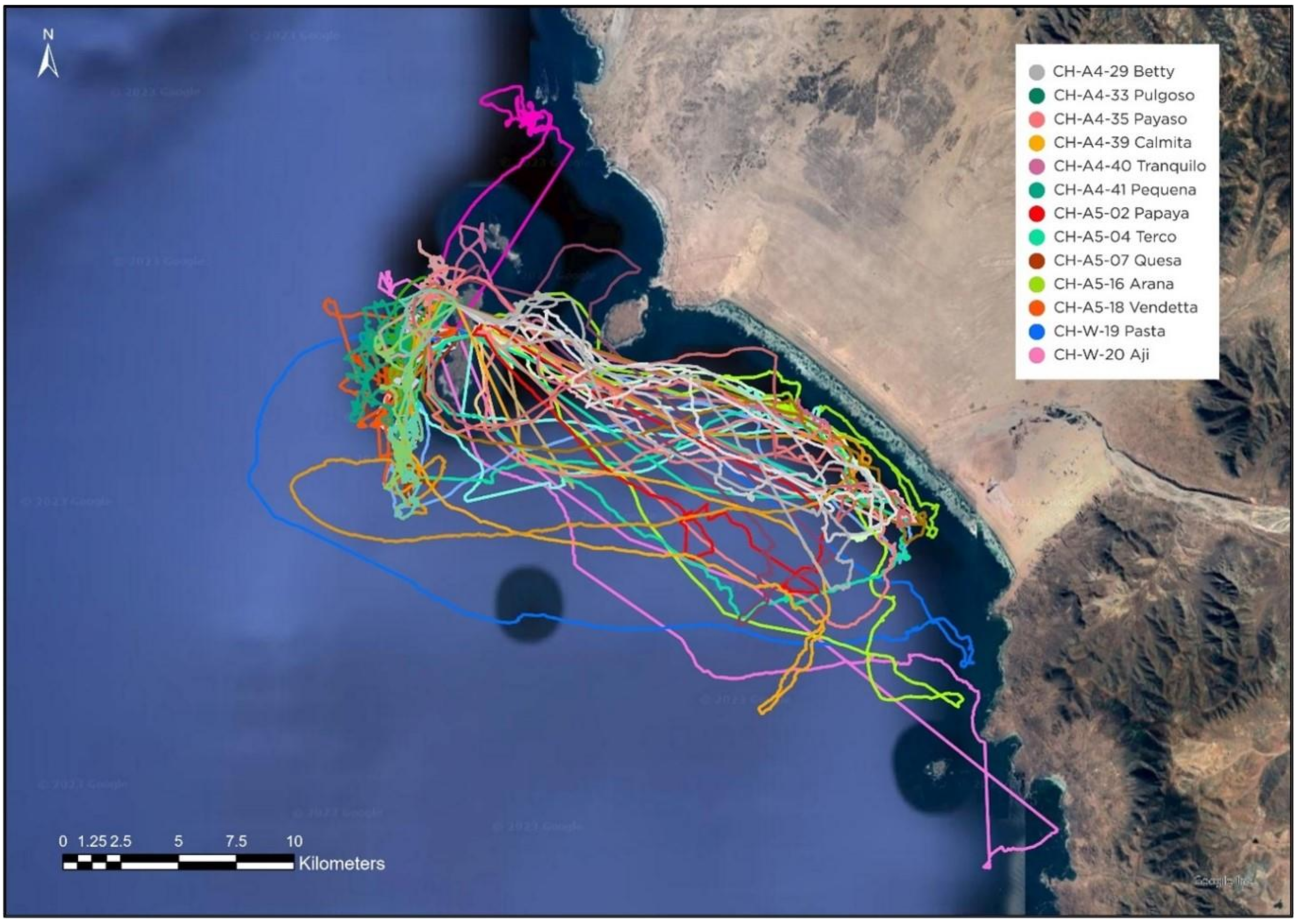

Figure 24

Twelve penguins tracked with GPS devices from Isla Choros, returned at total of 38 complete foraging trips (2-4 trips per bird, lines with similar hue represent different trips performed by the same bird). These tracks can be explored in greater detail using following link: https://penguintracking.org/humboldt/)

The six video loggers deployed were all successfully retrieved and provided 23.5 hours of high-definition video footage. These include 20 hours of continuous video footage and a further 3.5 hours of shorter video clips at the end of the video logger's battery capacity. Some videos were taken at low light conditions including at night. Preliminary evidence suggests that some birds successfully foraged solitary near the surface for small fish including anchoveta and sardines (Fig 25, a-i), fish larvae (Fig 25, j-l) and squid (Fig 25, m-o).

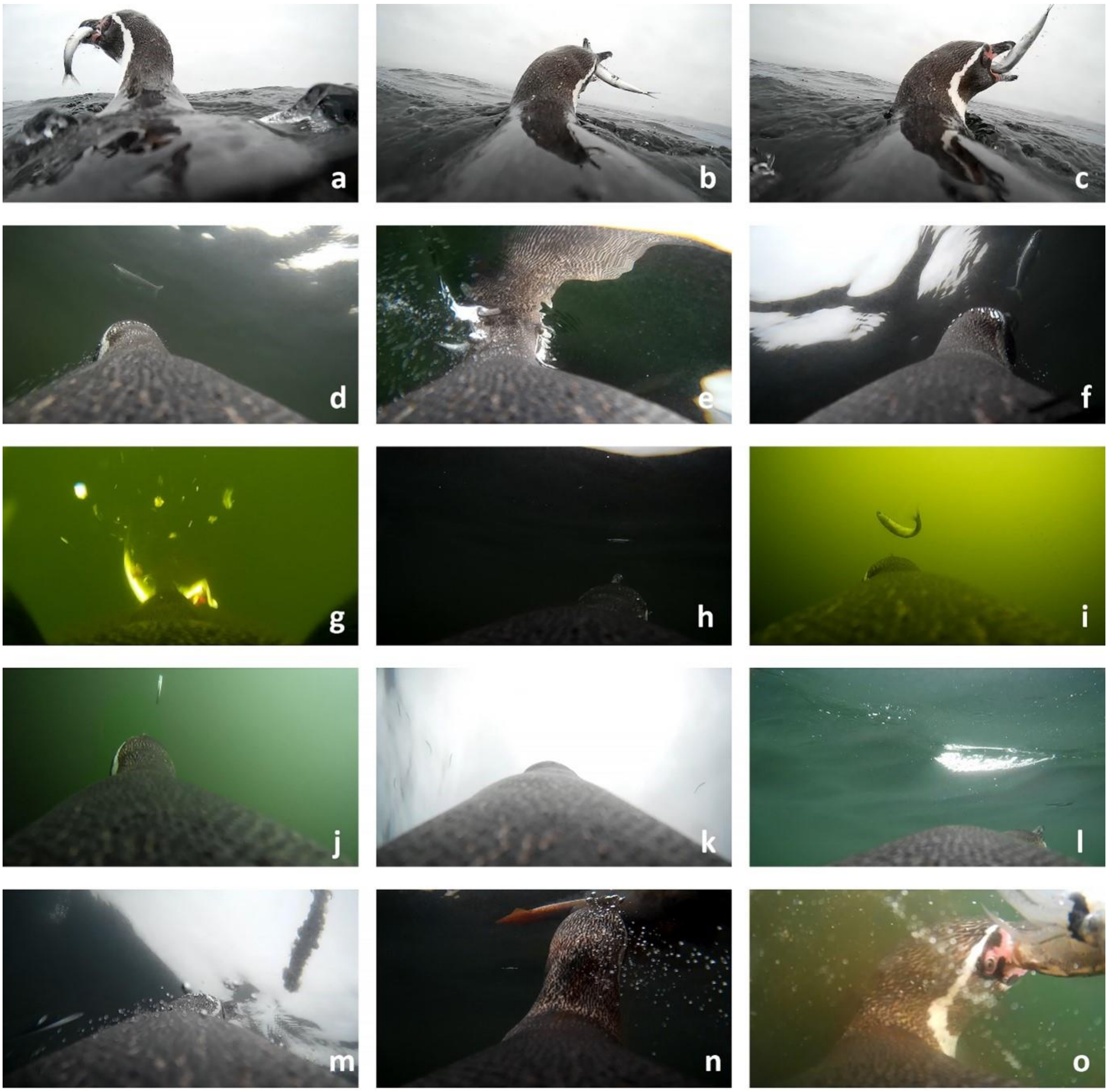

Figure 25
Screen captures of PenguCam carried by Humboldt penguin female "Calmita" on her single day foraging trip on 2 Dec 2022. The bird caught most prey near the surface by ambushing prey from below. Prey included small forage fish (a-i), fish larvae (j-l), and squid (m-o).

The productive waters near the coast/East of the islands often had a green tinge with comparably poor visibility at depth. Some of these areas contained high quantities of jellyfish. Penguins routinely checked the huge and poorly known South American Sea Nettle *Crysaora plocamia* for small commensal fish hiding within the tentacles (Fig 26) while ignoring smaller species of jellyfish. About every third Sea Nettle yielded success (Fig 26 e-f)

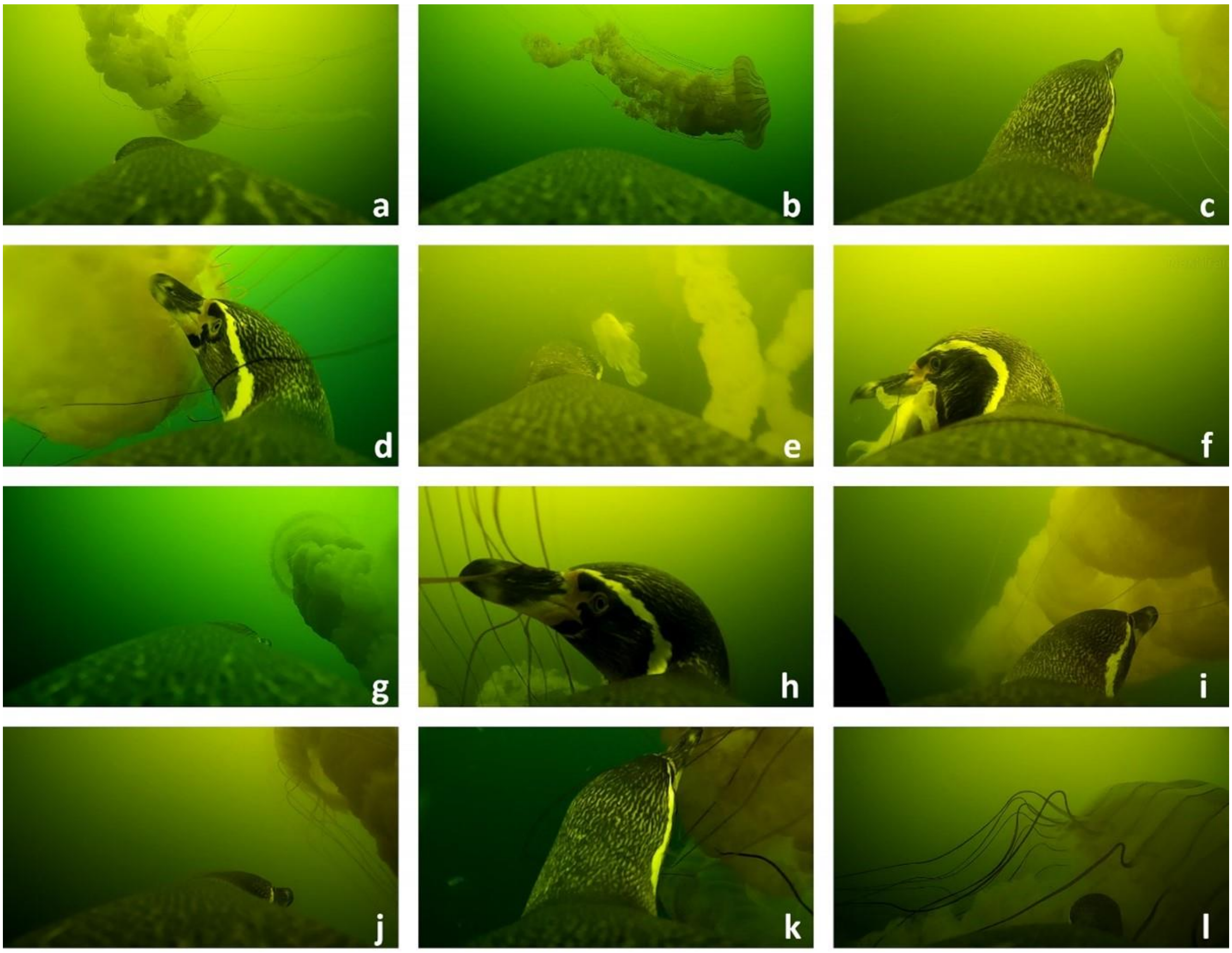

Figure 26

Screen captures of PenguCam carried by Humboldt penguin female "Calmita" on her single day foraging trip on 2 Dec 2022. Large Sea Nettle Cr*ysaora plocamia* opportunistically encountered were routinely checked for small commensal fish (seen in e & f) hiding among the tentacles.

Three penguins foraged solitary and exclusively pelagically often near the surface for individual fish or small/juvenile swarm fish and squid (Figure 25 and 26), the other three penguins were observed foraging occasionally in groups of more than 50 individuals while herding demersal fish at depths of between 65-95m in the clearer waters to the west of the island (see video). This latter behaviour has so far not been observed in Humboldt penguins and leads to much higher risk of bycatch mortality, since a single net could catch an entire group of birds hunting together.

Loss of bird carrying GPS device

Nest CH-W-30 was monitored with a surveillance camera from 4 December to establish nest attendance patterns. The pair worked well together and did alternating one-day trips to feed their chicks; hence, the pair was deemed reliable for video logger deployment. On 8 December we deployed a PenguCam on the attending female ("Flecha", ID 956 0000128 37001). She brought back fantastic and unexpected footage of cooperative foraging on benthic fish. The PenguCam logger was recovered following a single foraging trip 10 December and, as in other birds, she was deployed with a GPS logger at the same time. The female was last seen via surveillance camera leaving her nest on 12 December (Figure 27). Subsequent nest checks only encountered her partner attending two chicks that were still alive during our last check on 17 December, however, had obviously not been fed recently.

Figure 27
Final observation of Humboldt penguin female "Flecha" on 12 December 2022 leaving her nest CH-W-30 situated up the access track to the left under rock overhang behind bush. Insert on left is the same bird on the nest guarding her two chicks on 5 December 2022. Insert on right is a close-up pointing out the small, streamlined GPS logger on her lower back.

It is unlikely that a bird previously doing predictable one-day foraging trips (observed via surveillance camera since 4 December) would suddenly embark on a trip of more than 5 days, especially given the excellent foraging conditions close to the island. Thus, unfortunately we must assume this bird has perished taking the logger with her. Kelpers and fishers operating from Punta Choros as well as CONAF (Chilean Forest Service) staff have been informed in case the bird has been retrieved from a net or gets washed ashore somewhere.

FUTURE RESEARCH AND CHALLENGES

Animal populations tend to vary in size following the natural fluctuations in their resources, mainly habitat and food. This is particularly the case in highly variable environments such as the Humboldt Current which alternate periods of high food availability during La Niña years and low food availability during El Niño events. Additionally, human-induced threats such as overfishing, pollution, by-catch and coastal development may further impact on population numbers and persistence. Thus, monitoring of relevant population parameters (including population size and breeding success) of Humboldt penguins is an important management tool that needs to be sustained for the next years to detect changes, search for likely causes and be able to provide timely and adequate responses. Future planning should consider revisiting the colonies we already assessed in 2021 and 2022, but also add new islands where Humboldt penguins breed, but to which we were unable to access. Continuing the population monitoring in the following seasons will also allow us to determine the effects of the ongoing El Niño event on the current population size and how breeding success if affected.

The at-sea behaviour of Humboldt penguins has been studied in only few occasions in Chile and most research has been conducted at specific colonies, for reduced periods (1-2 seasons the most) and only during the spring breeding season. In this study, and for the first time, we equipped chick-rearing penguins during the winter breeding season, obtaining very interesting information that suggests that Humboldt penguins may accordingly adjust their foraging strategies to the prevailing oceanographic seasonal conditions. Also, our results suggest penguins may have preferred foraging areas depending on the island´s area on which they nest. These new insights and apparent behavioural patterns may change our current understanding of the at-sea behaviour of Humboldt penguins. However, further research is needed to confirm whether these data represent defined and persistent behavioural patterns or are just anecdotic observations. Next steps should include studying the foraging behaviour of Humboldt penguins at other relevant colonies (*e. g.* Tilgo, Cachagua) and see whether local strategies arise. If we can study the at-sea behaviour of penguins under the current El Niño conditions, we will be able to learn how penguins cope with this strong oceanographic disruption.

Other achievements of the project

Presentations at scientific meetings

XIII Chilean Ornithological Congress, Valdivia (Chile), December 2022.

Simeone, A., Mattern, T., Daigre, M., Lau, K. 2022. Conducta de alimentación en pingüinos de Humboldt (*Spheniscus humboldti*) de Isla Choros durante la época reproductiva de otoño. XIII Congreso Chileno de Ornitología. Valdivia (Chile), 7-9 diciembre 2022: 94.

Arce, P., Simeone, A., Daigre, M., Vial, F. 2022. Importancia de la metodología para la estimación de tamaños poblacionales: el caso del pingüino de Humboldt (*Spheniscus humboldti*). XIII Congreso Chileno de Ornitología. Valdivia (Chile), 7-9 diciembre 2022: 115.

11th International Penguin Congress, Viña del Mar (Chile), September 2023.

Arce, P., M. Daigre, F. Vial, A. Simeone. 2023. Methodological constraints for estimating the Humboldt Penguin population in Chile. To be presented at the forthcoming 11th International Penguin Congress. Viña del Mar, Chile.

Ellenberg, U., M. Daigre, T. Mattern, A. Simeone. 2023. Seeing the sea through the eyes of Humboldt penguins - how do things look in the face of growing anthropogenic threats? To be presented at the forthcoming 11th International Penguin Congress. Viña del Mar, Chile.

Vial, F., A. Simeone, G. Luna. 2023. Oceanographic and habitat traits affecting colony size in Humboldt penguins (Spheniscus humboldti) in Chile. To be presented at the forthcoming 11th International Penguin Congress. Viña del Mar, Chile.

Research thesis

Undergraduate

- Marambio, Sofía (Chile). Effect of nest-type on fledgling success in Humboldt penguins on Choros and Chañaral islands, Chile. Marine Biology. Universidad Católica del Norte, Coquimbo, Chile.

Master´s degree

- Bastías, Isabel (Chile). Spatial and temporal overlap between the sardine-anchovy fisheries and the foraging areas of Humboldt penguins during the breeding season in the adjacent waters to Choros Island, Chile. Master in Natural Resources Program. Universidad Andrés Bello, Santiago, Chile.

- Lau, Karen (Perú). Construction of energy landscape to clarify movement and distribution of foraging Humboldt penguin. Master in Marine Sciences Program. Universidad Católica del Norte, Coquimbo, Chile.

- Florencia Vial (Chile). Influence of food availability and habitat characteristics on the population size of Humboldt penguins (*Spheniscus humboldti*) in Chile. Master in Natural Resources Program. Universidad Andrés Bello, Santiago, Chile.

RESEARCH PERMITS

All our research activities within the frame of this project comply with the Chilean legislation and were done with the adequate permits:

Permits for working on protected areas, issued by the Chilean Forest Service (CONAF):

- Autorización para realizar actividades de investigación en el Sistema Nacional de Areas Silvestres Protegidas del Estado N° 014/2021.
- Extensión Autorización para realizar actividades de investigación en el Sistema Nacional de Áreas Silvestres Protegidas del Estado N° 019/2022.

Permits for deploying GPS devices on Humboldt penguins at isla Choros, issued by the Undersecretariat for Fisheries and Aquaculture (Subpesca):

- Permiso de Pesca de Investigación Resolución Exenta N° E-2021-652, 22/11/2021. Publicación de extracto en Diario Oficial Núm. 43.136, 24 de Diciembre de 2021.

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LITERATURE CITED

Bibby, C. J., N. D. Burgess, D. A. Hill, and S. H. Mustoe. 2000. Bird census techniques. Second edition. Academic Press, London.

BirdLife International. 2020. *Spheniscus humboldti*. The IUCN Red List of Threatened Species 2020: e.T22697817A182714418. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T22697817A182714418.en

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling: Estimating Abundance of Biological Populations. Chapman and Hall.

Simeone, A., B. Araya, M. Bernal, E. N. Diebold, K. Grzybowski, M. Michaels, J. A. Tare, R. C. Wallace, and M. J. Willis. 2002. Oceanographic and climatic factors influencing breeding and colony attendance patterns of Humboldt penguins *Spheniscus humboldti*. Marine Ecology Progress Series 227: 43–50.

Simeone, A., G. Luna-Jorquera and R. Aguilar. 2018. Proyecto FIPA N°2016-33: "Censo de Pingüinos de Humboldt". Final Report. 62 pp.

IUCN Standards and Petitions Committee. 2022. Guidelines for Using the IUCN Red List Categories and Criteria. Version 15.1. Prepared by the Standards and Petitions Committee. Downloadable from https://www.iucnredlist.org/documents/RedListGuidelines.pdf.

Thomas, L., S. T. Buckland, E. A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47: 5–14.

Vargas-Rodríguez, R., C. Louit-Lobos, C. Chávez-Villavicencio, P. Arróspide-Alonso, P. Correa-Álvarez & P. Martínez-Palma. 2022. Monitoreo institucional de largo plazo de la colonia reproductiva del pingüino de Humboldt (*Spheniscus humboldti*) en la isla Choros de la Reserva Nacional Pingüino de Humboldt. Biodiversidata 10: 29-43.