SEGUIMIENTO DE LAS COLONIAS REPRODUCTORAS DE PAÍÑO EUROPEO (*Hydrobates pelagicus melitensis*) EN LA ISLA DE BENIDORM (ZEPA E-121) P.N. SERRA GELADA

INFORME DE ACTIVIDADES Y RESULTADOS OBTENIDOS EN 2023.

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1. El paíño europeo (*Hydrobates pelagicus*)

Identificación

Es la más pequeña de las aves marinas europeas. Tiene un tamaño medio de 14-18 cm y un peso medio de 28 gramos. Su plumaje es negro con una mancha blanca en el obispillo y franjas blancas en la cara inferior de las alas. Sus ojos, pico y patas son oscuros. Destacan sus grandes narinas. Ambos sexos son muy poco dimórficos aunque las hembras presentan un tamaño ligeramente superior. La subespecie atlántica es de menor tamaño que la mediterránea. Vuelan muy próximos a la superficie del mar con planeos y rápidos aleteos. La especie presenta un fuerte olor.

En el período reproductivo ambos sexos emiten múltiples y constantes sonidos. Existen diferencias en las vocalizaciones de la subespecie atlántica y mediterránea.

Foto 1. Paíño europeo, *Hydrobates pelagicus melitensis*

Estatus de conservación y amenazas

Categoría global IUCN (2012): Preocupación Menor LC.

Categoría IUCN para España (2004): Vulnerable VU.

Catálogo Nacional de Especies Amenazadas: "De interés especial".

Libro Rojo España: “En Peligro”

Comunidad Valenciana: Vulnerable (Decreto 32/2004, 27 de febrero de 2004)

Las principales amenazas de la especie engloban la modificación/destrucción de sus hábitats, la introducción de especies exóticas, los depredadores, la contaminación y el cambio climático. Las molestias y parásitos pueden afectar negativamente a algunas de sus poblaciones.

Distribución

La subespecie *pelagicus* cría principalmente en islotes del cantábrico y Canarias. En invierno la subespecie atlántica se desplaza a la zona sur del continente africano. La subespecie *melitensis* con colonias de cría en islotes del levante peninsular y las islas Baleares podría ser residente en el mar mediterráneo.

Hábitat

Es una especie pelágica que sólo visita tierra durante la época reproductora. La mayoría de las colonias de cría se localizan en islas e islotes libres de ratas. Sus nidos se encuentran en zonas oscuras y generalmente poco accesibles: grietas, fisuras y cavidades. Durante la época reproductora las principales agregaciones en el mar se localizan en zonas de borde de la plataforma continental.

Movimientos

Los individuos jóvenes prospectan diferentes colonias de cría antes de comenzar a reproducirse. Son capaces de alimentarse a más de 300 km de la colonia. En el caso de paíños reproductores en Benidorm, pasan el invierno en el océano atlántico.

Ecología trófica

Su dieta es variada e incluye fundamentalmente zooplancton y pequeños peces o cefalópodos, que son capturados picoteando la superficie del mar.

Biología de la reproducción

En febrero-marzo comienzan a visitar las colonias. Desde finales de abril hasta el mes de agosto se producen las puestas, concentrándose la mayoría de las puestas en mayo y junio. Ponen un único huevo de grandes dimensiones en relación con su tamaño corporal que será incubado por ambos sexos durante 40 días. El pollo es cebado por las noches por ambos progenitores y abandonará la colonia a los 60-70 días de edad. En general comienzan a reproducirse a partir de su tercer año de vida. Presenta una alta supervivencia adulta con valores que normalmente oscilan entre el 80-90% anual, pero pueden verse afectados por depredadores y/o situaciones ambientales adversas. A nivel individual, factores como la edad, experiencia reproductora y calidad del individuo influyen en su éxito reproductor y supervivencia.

Interacciones con otras especies

Como depredadores del paíño destacan los mamíferos introducidos en islas, la gaviota patiamarilla (Foto 2) y algunas especies de rapaces. Presenta diferentes tipos de parásitos: ácaros, piojos, pulgas y garrapatas blandas. En ocasiones, otras especies de aves marinas pueden desplazarlos de sus lugares de nidificación.

Foto 2. Egagrópila de gaviota patiamarilla con restos de un paíño europeo depredado.

Patrón social y comportamiento

Generalmente se reproduce en colonias y en tierra presenta una actividad estrictamente nocturna. Es una especie monógama con gran fidelidad a su pareja y lugar de nidificación. Presenta un gran olfato que le permite el reconocimiento de otros individuos.

Para una información detallada sobre la especie consultar:
http://www.vertebradosibericos.org/aves/hydpel.html

2. Marco de estudio

Las Islotes de Benidorm (Alicante), situados en la costa oeste del mar Mediterráneo (38º 30'N, 0º 08'E), son una zona de especial protección para las aves (ZEPA) y de conservación para el paíño europeo. La isla de Benidorm tiene una superficie de 6 hectáreas y se sitúa a 3,6 kilómetros de Benidorm, uno de los principales destinos turísticos europeos. El paíño europeo se distribuye por toda la isla, pero se concentra especialmente en 2 cuevas dónde anida en grietas, bajo derrubios de rocas y en cajas-nido artificiales. La población reproductora de paíño europeo presente en la isla se ha estimado tradicionalmente entorno a las 400 parejas (Mínguez 1994), por lo que representa una de sus mayores poblaciones mediterráneas. Además, la isla de Benidorm tiene la particularidad de que las 2 colonias de paíño ubicadas en 2 cuevas pueden ser monitorizadas de forma relativamente sencilla, puesto que en una gran cantidad de nidos las aves presentes pueden ser capturadas a mano. Este es un hecho poco corriente en gran parte de las colonias de esta especie ya que en su gran mayoría anidan en lugares de muy difícil acceso y el único método de captura viable es el uso de redes. Las colonias de cría de la isla de Benidorm representan una oportunidad única para el seguimiento de la especie a largo plazo. La captura-recaptura de individuos reproductores y pollos posibilita la estimación de parámetros demográficos clave como la supervivencia, el reclutamiento o el éxito reproductor (Lebreton *et al.* 1992). Además, el seguimiento de nidos posibilita la obtención de estimas anuales de densidad relativa y productividad de las colonias. En las 2 colonias de paíño europeo se realiza un monitoreo a largo plazo desde 1993. El seguimiento a largo plazo de las colonias ha permitido avanzar en el conocimiento de los rasgos de vida de la especie, la dinámica local de sus poblaciones y detectar problemas de conservación (Oro *et al.* 2005). Uno de los principales problemas para la especie en Benidorm es la depredación que las gaviotas patiamarillas (*Larus michahellis*) ejercen sobre el paíño (Oro *et al.* 2005). Para solventar el problema, el año 2004 se comenzó con un programa de descaste selectivo de parejas de gaviota patiamarilla predadoras de paíño, cuya eficacia ha podido ser evaluada posteriormente (ver sección "depredación por las gaviotas patiamarillas").

3. Metodología aplicada

El seguimiento demográfico del paíño en la isla de Benidorm comenzó el año 1993.

El año 2008 el protocolo de campo de seguimiento de las colonias reproductoras se modificó ligeramente con el fin de mantener una muestra representativa de nidos prospectados, reduciendo la carga de trabajo y eliminando del seguimiento aquellos nidos considerados confusos. Con respecto al protocolo seguido hasta la 2008, se eliminaron del seguimiento aquellos nidos en los que sus ocupantes no pueden ser capturados.

Las actividades realizadas para el seguimiento de las colonias fueron (Tabla 1):

- Recolección de datos de nidificación, éxito de eclosión, emplumamiento y reproductor. (1).
- Toma de datos individuales: anillamiento y recaptura de adultos reproductores (2).
- Toma de datos individuales: anillamiento de pollos (3).
- Seguimiento de las tasas de depredación de la gaviota patiamarilla sobre el paíño (4).

Recolección de datos de nidificación, éxito de eclosión, emplumamiento y reproductor.

Durante el presente año se revisaron los nidos de paíño que constan en el cuaderno de campo para su seguimiento permanente en la cueva grande o cueva de la "*Fenolla*" y la cueva pequeña o de "*Bombo*", se revisaron cada 7 días y se anotó su contenido en el cuaderno de campo de la siguiente forma:

- Vacío (x)
- Pareja sin incubar (2A)
- Adulto sin incubar (A)
- Huevo sólo (H, además se indicó si se encontraba abandonado o parecía de la temporada anterior)

- Adulto incubando (□)
- Adulto marcado con typex incubando (Δ)
- Adulto empollando (se añadirá un punto en el interior del cuadrado)
- Adulto marcado con typex empollando (se añadirá un punto en el interior del triángulo)
- Pollo (■)
- Muerto (se añadirá el sufijo RIP al símbolo correspondiente)

Se marcaron los nuevos nidos en los que existió puesta y al menos uno de los adultos reproductores que lo ocupaban fue capturado (se trata de nidos que se llegaba a ellos con la mano).

La productividad de las colonias se estimó al final de la campaña. Para estimar el éxito de eclosión, emplumamiento y reproductor se utilizó el método Mayfield 40% (Mayfield 1961, Mayfield 1975, Johnson 1979, Hensler & Nichols 1981). El periodo medio de incubación se consideró 40 días (Davis 1957, Mínguez 1998) y el periodo medio de empollamiento, tiempo que permanece uno de los progenitores sobre el pollo tras la eclosión del huevo, 7 días (Mínguez & Oro 2003). Las estimas relativas de éxito reproductor utilizadas fueron:

- El ***éxito de eclosión*** (hatching success) representa el número de pollos que nacen frente al número de puestas realizadas expresado en tanto por uno.

- El ***éxito de emplumamiento*** (fledgling success) representa el número de pollos que completan su emplumamiento frente al número de pollos que nacen expresado en tanto por uno. Se consideró que un pollo había completado su emplumamiento si sobrevivió, al menos, 40 días (Davis 1957, Mínguez 1998). A esta edad los pollos se desplazan del nido habitualmente y es más difícil su localización, además de presentar mayor supervivencia que durante sus primeros días de vida (Mínguez & Oro 2003).

- El ***éxito reproductor*** (breeding success) representa el número de pollos que completan su emplumamiento frente al número de puestas realizadas expresado en tanto por uno.

Para poder determinar las fechas de puesta con precisión es necesario un seguimiento bastante continuo durante todo el periodo de puesta, por lo que la base datos en este sentido aparece incompleta.

Toma de datos individuales: anillamiento y recaptura de adultos reproductores y pollos.

Las aves adultas se capturaron una sola vez durante la temporada de cría, al final del periodo de incubación o durante el periodo de empollamiento, para evitar molestias y deserciones (Blackmer *et al.* 2004). La captura se realizó durante el día, a mano, sobre los individuos que se encontraban en el nido. El primer miembro de cada pareja capturado en cada nido se marcó con pintura blanca (typex) en cabeza y cola para evitar volver a ser capturado en posteriores visitas. Las aves que abandonaron la incubación del huevo durante las primeras semanas de incubación no pudieron ser capturadas. En algunos casos, únicamente se pudo capturar uno de los miembros de la pareja, puesto que las visitas a la colonia coincidieron con sus turnos de incubación. Los pollos se capturaron a partir de los 30 días de edad.

En base a estudios previos que indicaron la escasa utilidad de la toma de medidas biométricas para determinar el sexo en esta especie, se decidió no tomar medidas a los ejemplares capturados. De esta forma se minimizó el tiempo de manipulación de las aves.

Seguimiento de las tasas de depredación de la gaviota patiamarilla sobre el paíño europeo.

La gaviota patiamarilla cría en toda la isla, los nidos se concentran principalmente en las laderas con menor pendiente pero unas cuantas parejas nidifican en los acantilados próximos a las colonias de paíño e incluso en el interior de las cuevas. Su población reproductora mientras se realizaba seguimiento variaba entre las 350 y las 750 parejas, actualmente se desconoce su número. Las gaviotas suelen mostrar una alta fidelidad sus los lugares de nidificación (Burger & Lesser 1980). Este hecho permitió que, mediante la búsqueda de egagrópilas en el entorno de sus nidos, se pudiera identificar las parejas especializadas en la depredación de paíños (Oro *et al.* 2005). Desde el año 2002 hasta la actualidad se ha realizado un protocolo de muestreo específico en el entorno de las dos cuevas y un transecto entre ambas destinado a recolectar las egagrópilas de gaviotas con restos de paíños y detectar a las parejas especialistas (ver detalles en Oro *et al.* 2005 y Sanz-Aguilar *et al.* 2009). Los primeros resultados obtenidos indicaron que una pequeña fracción de la población reproductora de gaviotas era responsable de la mayor parte de la depredación y siguiendo las recomendaciones de Oro y colaboradores se procedió a eliminar aquellas parejas consideradas especialistas (Sanz-Aguilar *et al.* 2009). Se trampearon y eliminaron, mediante inyección con un exceso de sedantes en la yugular, 11, 18 y 13 gaviotas, en 2004, 2005 y 2006, respectivamente. Durante las temporadas 2007-2009 no se eliminaron gaviotas en el entorno de las colonias de cría de paíño europeo. En 2010 se retomó el control anual de gaviotas patiamarillas.

Con una frecuencia semanal o máxima de 15 días se inspeccionó el interior de las colonias de cría de paíño europeo, las plataformas de entrada a las cuevas y el transecto o camino existente entre ambas. Se recogieron todas las egagrópilas encontradas en bolsas de plástico y se revisó su contenido en busca de posibles anillas. Además, se indicó en las fichas de campo el número de egagrópilas encontradas que pertenecían a pollos "si aparecían restos de plumón o toda la pluma era nueva, normalmente a partir de julio", y adultos depredados "si no se sabe la edad se asignaron a adulto"; así como el lugar de recolección (Cueva 1 "grande", Cueva 2 "pequeña", Transecto).

Se tomó nota del número de las anillas encontradas en egagrópilas.

Material necesario para el seguimiento de las colonias de paíño.

- Frontales +Pilas
- Rodilleras
- Lápiz, bolígrafos y rotuladores permanentes
- Cuadernos y fichas de campo
- Anillas metálicas
- Alicates
- Abre-anillas
- Typex
- Bolsas de plástico con cierre hermético

Durante la temporada (2019) se configuraron nuevos croquis para detallar la localización de los nidos en el interior de las colonias (Apéndice 1). Estos croquis se actualizarán con los nuevos nidos encontrados cada temporada.

Personal encargado del trabajo de campo.

El personal encargado del seguimiento de las colonias reproductoras de la isla de Benidorm durante la temporada 2023 ha sido:

- Ana Sanz Aguilar (IMEDEA, CSIC-UIB). Coordinación y Seguimiento.
- Enrique Marco Jover. (Centro de Recuperación de Fauna de Santa Faz). Coordinación. Seguimiento. Captura-Marcaje-Recaptura de pollos y adultos reproductores.
- Andreu Rotger Vallespir (IMEDEA-UIB). Seguimiento
- José Santamaría, Román Aldeguer y Carles Grau (P.N. Serra Gelada-Ifac-Puig Campana i Ponotx-Bernia i Ferrer). Seguimiento Mitjana. Divulgación y Educación Ambiental.

- Daniel Gilabert (P.N. Serra Gelada-Ifac-Puig Campana i Ponotx-Bernia i Ferrer). Patrón.
- Joan Segovia (P.N. Serra Gelada-Ifac-Puig Campana i Ponotx-Bernia i Ferrer). Patrón.
- Juanjo Mascarell García (Guarda Rural-Guardapescas Marítimo del Ayto. de Benidorm). Recuperación y liberación de paíños juveniles. Divulgación y Educación Ambiental.
- Han colaborado en el seguimiento Eduardo Mínguez Díaz y Roberto Rodríguez Caro.

4. Anillamientos y recapturas en 2023

Durante la temporada de anillamiento 2023 se capturaron en sus nidos **407 aves adultas: 243 en la cueva grande y 164 en la cueva pequeña** (Tabla 1,2).

Se anillaron **131 pollos** (Tabla 1,2).

Tabla 1. Número de anillamientos, recapturas y recuperaciones de paíño en 2023.

Nº Recapturas adultos	Nº nuevos adultos anillados	Nº pollos anillados	Nº indv anillados encontrados muertos	Nº total de indv capturados
309	98	131	0	538

Tabla 2. Códigos de anillas utilizadas para marcaje de paíño en 2023

Serie
T093301-T093421 (Perdidas T093324, T093341, T093359)
T093088-T093200 (Perdida T093172, T093182)

Durante la presente temporada el **remanente de anillas** es: **T093422 – T093500**.

Para la próxima campaña serían necesarias unas 250-300 anillas más.

Como curiosidad, hay que indicar que unos pescadores recuperaron el 20/11/2023 a varias millas de la Marina un paíño anillado como pollo en la cueva pequeña en 2016 (T055665).

5. Reclutas

Se recapturaron como adultos reproductores 27 nuevos reclutas (individuos nacidos en las colonias que criaron por primera vez durante la temporada 2023). Del total de adultos reproductores capturados en nido (n=407) un 31% son individuos controlados como reproductores por primera vez este año (24% de nuevos anillamientos + 7% reclutas, Figura 3). En la colonia 1 hubo 15 reclutas y en la colonia 2, 12 reclutas.

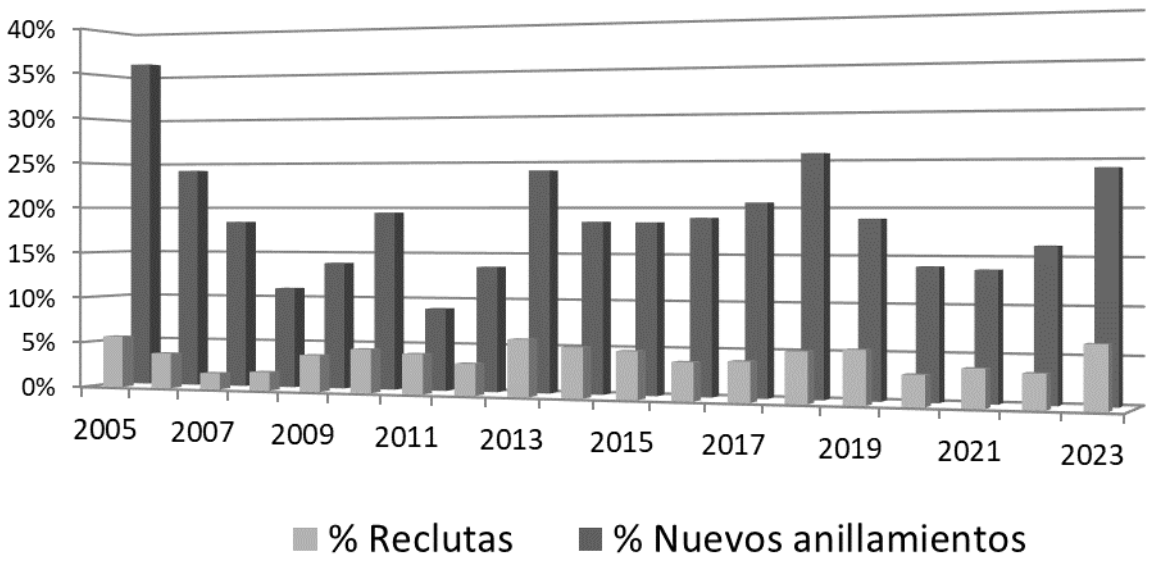
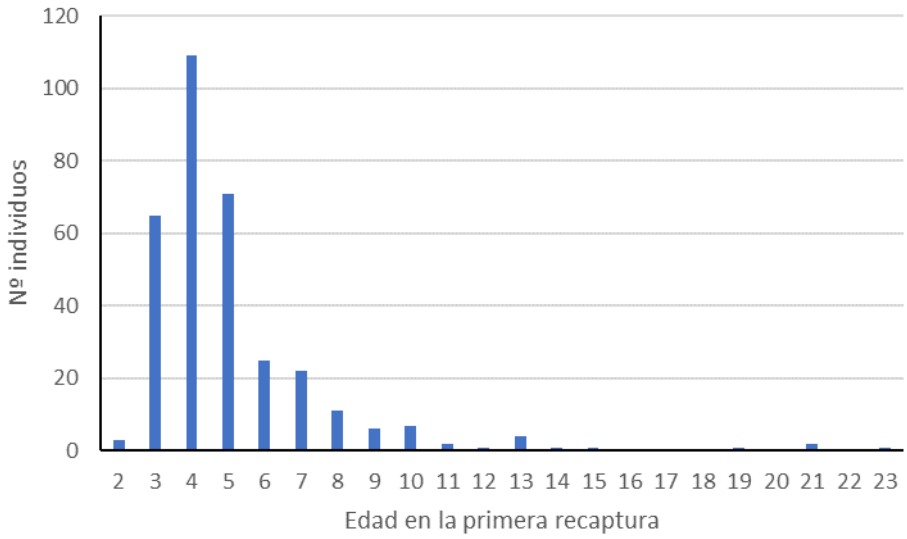


Figura 3. Relación (%) entre el número de nuevos reproductores anillados y el número de nuevos reclutas locales con el número total de reproductores capturados.

*** En 2005-2006 se produce un crecimiento importante de las colonias de reproducción tras la eliminación de gaviotas depredadoras durante la temporada de cría 2004.

Hasta la fecha, la mayor parte de los individuos marcados como pollos que han sido recapturados en la isla de Benidorm (n=332) fueron recapturados por primera vez con edades entre los 3-5 años. Tan sólo 3 individuos fueron recapturados con 2 años y en los 3 casos no se reprodujeron. La edad máxima detectada hasta la fecha es de 23 años. Sin embargo, 7 individuos se han observado reproduciéndose durante 21-24 años, lo que indica que su edad mínima en la última reproducción estaría entre los 24-27 años.



6. Depredación por gaviotas patiamarillas

Durante la presente temporada la depredación de paíños por gaviotas en la isla de Benidorm ha sido baja, afectando únicamente a la colonia de la cueva grande (Tablas 3-5, Figuras 4). El personal del centro de recuperación de Santa Faz llevó a cabo medidas de control de gaviota patiamarilla en la cueva grande mediante colocación de 4 cebos en 2 ocasiones: el 25 de abril y el 6 de julio 3. Con posterioridad a la primera actuación se detectaron 1 adulto y 2 pollos muertos, y tras la segunda actuación 2-3 pollos muertos.

Tabla 3. Número anual de parejas reproductoras de gaviota patiamarilla e individuos eliminados en la isla de Benidorm. *En 2020 se prospectaron las zonas 1,2 y 8 que se asume representaban 18% del total de gaviotas en la isla. *** En 2023 se prospectaron las zonas 1,2 y 3 que se asume representaban 48% del total de gaviotas en la isla.

Año	Zonas 1+2	Zona 8 (Faro)	Parejas estimadas	Eliminadas
1999	24	15		
2000	29	44		
2001	30	54		
2002	26	-	460	0
2003	62	44	560	0
2004	62	16	550	11
2005	43	56	650	14
2006	79	-	670	13
2007	56	-	600	0
2008	76	47	750	0
2009	21	51	700	0
2010	72	72	755	3
2011	51	53	727	1
2012	68	44	611	0
2013	28	28	347	~2-3
2014			?	2
2015			?	7
2016			?	4
2017			?	0
2018			?	~2-3
2019			?	~8-10
2020*	66	38	578	Mínimo 1
2021			¿?	Mínimo 1
2022			¿?	Mínimo 1
2023**	63 (+107 Zona 3)		354	5-6

Tabla 4. Número de egagrópilas con restos de paíño recolectadas en las diferentes áreas de estudio de la isla de Benidorm. Notación: T= transecto.

Año	Grande	Pequeña	T2	T 1	Total	Nº anillas reprod.
2000	-	-	-	-	230	8
2002	167 (70%)	36 (15%)	33 (13%)	4 (2%)	244	16
2003	151 (60.4%)	37 (14.8%)	62 (24.8%)	-	248	7
2004	84 (69.42%)	5 (4.13%)	32 (26.45%)	-	121	1
2005	29 (46,77%)	10 (16,13%)	23 (37,10%)	-	62	1
2006	71 (45,5%)	70 (44,9%)	15 (9,6%)	-	156	10
2007	43 (59.72%)	6 (8.33%)	23 (31.94%)	-	72	1
2008	66 (78.6%)	3 (3.6%)	15 (17,9%)	-	84	0
2009	100 (68%)	32 (22%)	15 (10%)	-	147	13
2010	25 (71%)	4 (11%)	6 (17%)	-	36	2
2011	35 (74%)	0	12 (26%)	-	47	1
2012	61 (91%)	3 (4.5%)	3 (4.5%)	-	67	0
2013	57 (90.5%)	0	6 (9.5%)	-	63	8
2014	104 (96.3%)	1 (0.9%)	3 (2.9%)	-	108	12
2015	64 (88%)	5 (7%)	4 (5%)	-	73	10
2016	62 (95%)	1 (2%)	2 (2%)	-	65	4
2017	1 (17%)	4 (67%)	1 (17%)	-	6	0
2018	35 (66%)	13 (25%)	5 (9%)	-	53	4
2019	9 (43%)	12 (57%)	0	-	21	8
2020	46 (85%)	3 (6%)	5 (9%)	-	54	2
2021	18 (80%)	2 (10%)	2 (10%)	-	22	0
2022	27 (69%)	10 (26%)	2 (5%)		39	6
2023	14 (100%)	0	0		14	0

Tabla 5. Número de egagrópilas con restos de paíño recolectadas en los diferentes meses y años de estudio de la isla de Benidorm.

año	Abril	Mayo	Junio	Julio	Agosto	Septiembre	Total anual
2002	21	59	78	43	13	29	243
2003	24	74	61	46	25	18	248
2004	13	43	35	13	9	8	121
2005	5	13	22	17	5	0	62
2006	6	10	54	39	42	5	156
2007	3	5	37	13	7	-	65
2008	1	11	27	27	18	-	84
2009	11	51	61	13	11	-	147
2010	4	11	10	8	3	-	36
2011	2	8	33	2	2	-	47
2012	-	10	33	17	7	-	67
2013	0	23	37	3	0	0	63
2014	-	27	56	25	0*	-	108
2015	2	18	45	3	5	-	73
2016	1	13	22	15	14	0	65
2017	0	1	1	0	4	0	6
2018	0	10	30	10	1	2	53
2019	0	8	11	0	2	0	21
2020		21	15	14	0	4	54
2021	0	5	11	3	0	3	22
2022		15	16	6	0	2	39
2023	4	1	8	1			14
Total mensual	97	437	703	318	168	71	1794

*No revisado la segunda quincena

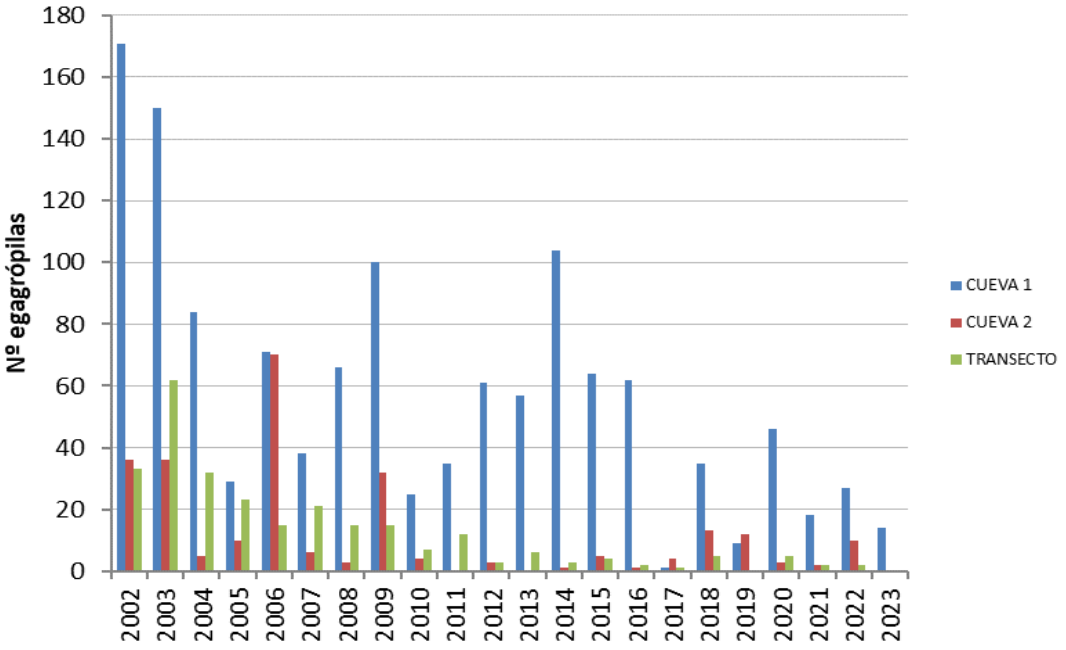


Figura 4. Número de egagrópilas recolectadas en la isla de Benidorm en las 3 zonas prospectadas (Cueva 1=grande, Cueva 2= pequeña y Transecto 2) desde el año 2002. La eliminación de gaviotas depredadoras de paíños se realizó de 2004 a 2006, 2010-11 y 2013-2016 y 2018-2023.

7. Fechas de puesta.

Durante 2023 la primera puesta estimada corresponde al día 28/04/2023 y la última al 7/07/2023 (Figura 5). La fecha de puesta media fue el 22/5/23 y la mediana el 23/5/23.

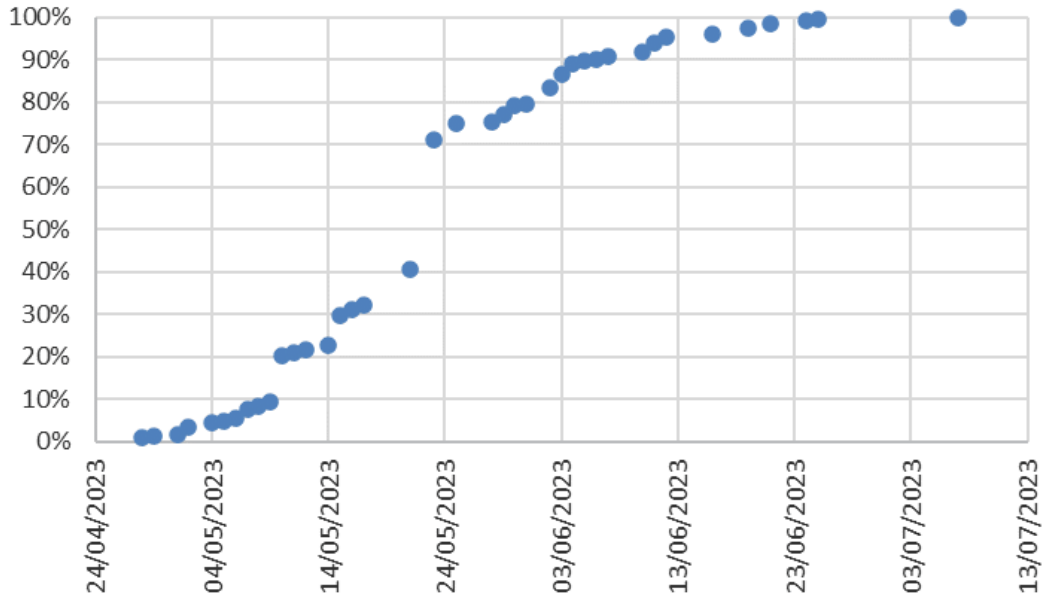


Figura 5. Distribución acumulada de las fechas de puesta de paíño en 2023.

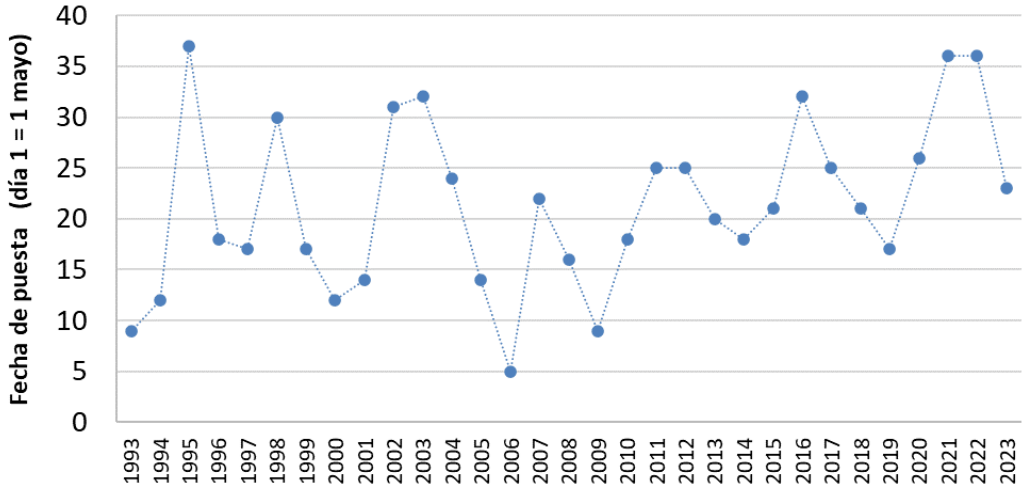


Figura 6. Evolución temporal de las fechas medianas de puesta. Se considera día 1 al 1 de mayo.

Tabla 6. Fechas medianas de puesta del paíño en la isla de Benidorm.

Año	Tamaño de muestra	Fecha (DD-MM-AA)	Precisión
1993	217	09-05-93	+/- 3 días
1994	241	12-05-94	+/- 3 días
1995	161	06-06-95	+/- 3 días
1996	175	18-05-96	+/- 7 días
1997	163	17-05-97	+/- 7 días
1998	133	30-05-98	+/- 7 días
1999	163	17-05-99	+/- 7 días
2000	140	12-05-00	+/- 7 días
2001	174	14-05-01	+/- 7 días
2002	136	31-05-02	+/- 7 días
2003	161	01-06-03	+/- 7 días
2004	188	24-05-04	+/- 7 días
2005	230	14-05-05	+/- 3 días
2006	267	05-05-06	+/- 3 días
2007	260	22-05-07	+/- 7 días
2008	157	16-05-08	+/- 7 días
2009	174	09-05-09	+/- 7 días
2010	188	18-05-10	+/- 7 días
2011	148	25-05-11	+/- 7 días
2012	158	25-05-12	+/- 7 días
2013	183	20-05-13	+/- 7 días
2014	203	18-05-14	+/- 3 días
2015	188	21-05-15	+/- 7 días
2016	182	01-06-16	+/- 3 días
2017	205	25-05-17	+/- 3 días
2018	234	21-05-18	+/- 3 días
2019	239	17-05-18	+/- 3 días
2020	221	26-05-20	+/- 7 días
2021	200	06-06-21	+/- 7 días
2022	209	05-06-22	+/- 7 días
2023	232	23-05-23	+/- 7 días

8. Ocupación de cajas nido.

En la cueva pequeña se ocuparon 36 cajas sobre un total de 41 disponibles (86%) y en la cueva grande 10 sobre 21 (48%) (Figura 7).

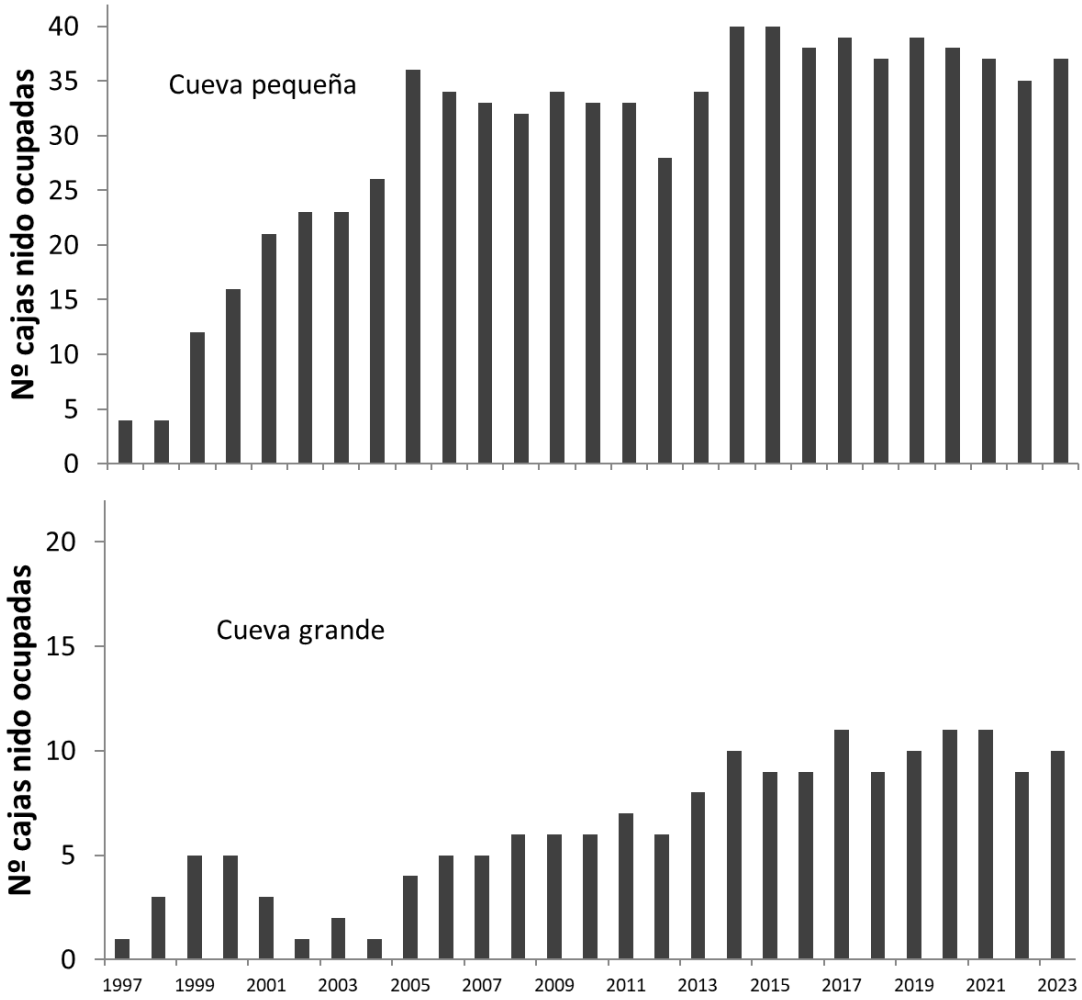


Figura 7. Número de cajas nido ocupadas.

9. Parámetros reproductores

El número de puestas detectadas el presente año 2023 en la isla de Benidorm ha aumentado con respecto a 2022, en un 13%. El aumento de parejas ha sido similar en ambas cuevas, un 13.6% en la cueva grande y un 12.1% en la cueva pequeña (Figura 8). Se han detectado 244 puestas en los nidos en seguimiento (142 en la cueva grande y 102 en la cueva pequeña).

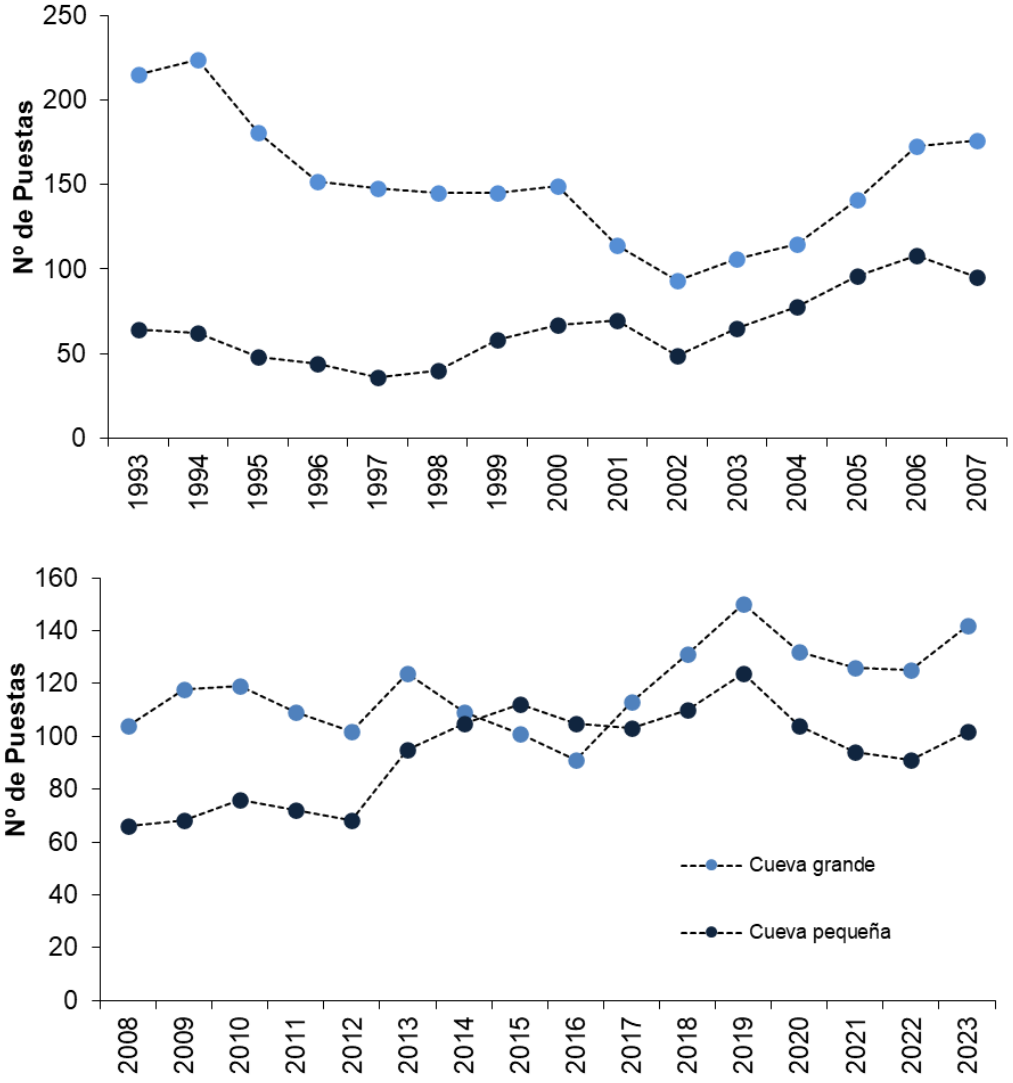
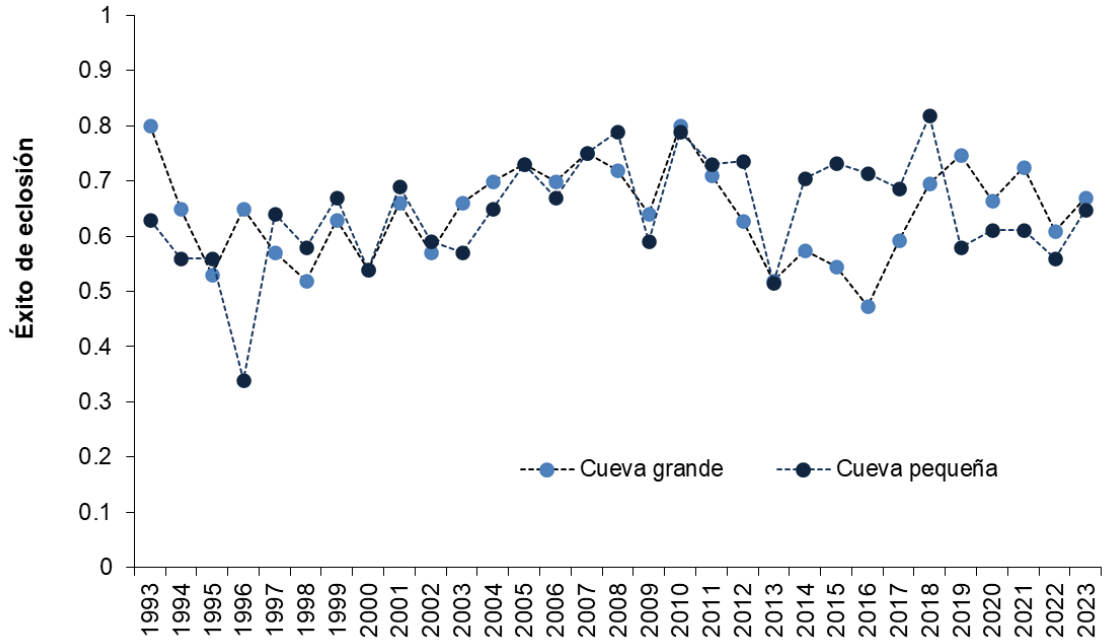


Figura 8. Evolución anual del número de puestas monitorizadas en cada una de las colonias de la isla de Benidorm (Los datos a partir de 2008 reflejan un protocolo mínimo).

El éxito de eclosión ha sido similar en ambas colonias, pero el éxito de emplumamiento y, por lo tanto, también el éxito reproductor, han sido inferiores en la cueva grande (Tabla 7-8, Figuras 9-10). Durante la presente temporada el éxito de eclosión (0.66), de emplumamiento (0.89) y reproductor (0.59) han sido ligeramente superiores al promedio del periodo de estudio 1993-2023 (Promedios: Éxito de eclosión= 0.65; Éxito de emplumamiento=0.86; Éxito reproductor=0.56; Tabla 7-8).



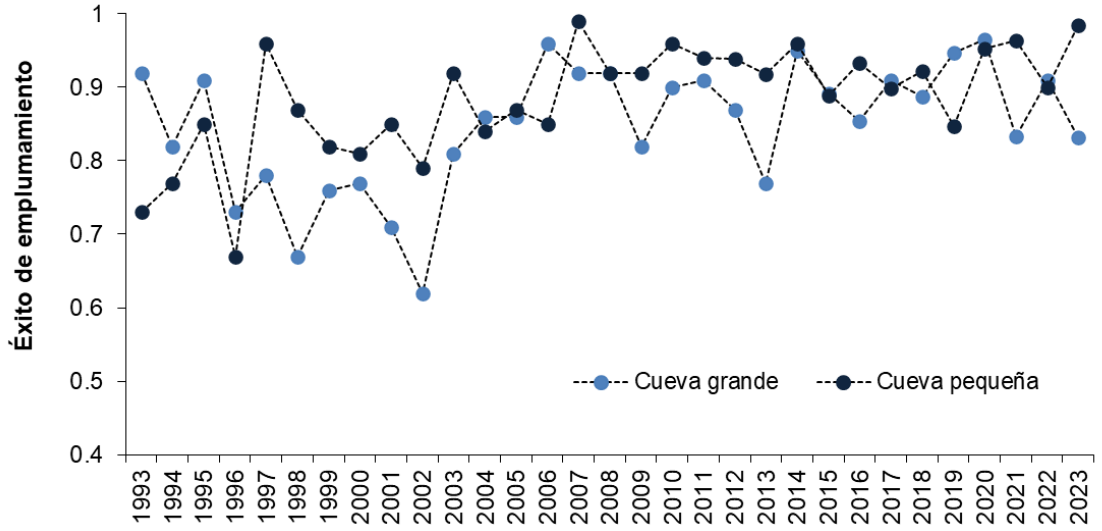


Figura 9. Estimas del éxito de eclosión y emplumamiento del paíño en la isla de Benidorm.

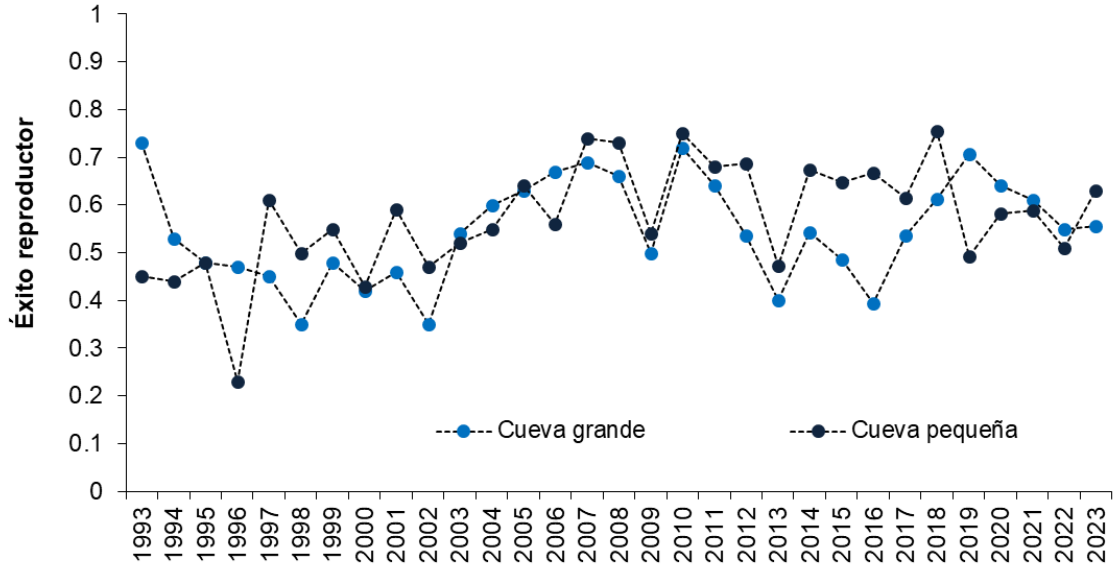


Figura 10. Estimas del éxito reproductor del paíño en la isla de Benidorm.

Tabla 7: Parámetros reproductores básicos del paíño en la Isla de Benidorm.

año	Nº puestas	éxito eclosión	éxito emplumamiento	éxito reproductor
1993	279	0.76	0.89	0.67
1994	286	0.63	0.81	0.51
1995	229	0.54	0.89	0.48
1996	196	0.58	0.72	0.42
1997	184	0.59	0.81	0.48
1998	185	0.54	0.72	0.38
1999	203	0.65	0.78	0.50
2000	216	0.54	0.78	0.42
2001	184	0.67	0.76	0.51
2002	142	0.58	0.68	0.39
2003	171	0.63	0.85	0.53
2004	193	0.68	0.85	0.58
2005	237	0.73	0.87	0.63
2006	281	0.69	0.92	0.63
2007	271	0.75	0.95	0.71
2008	170	0.75	0.92	0.68
2009	186	0.62	0.86	0.54
2010	194	0.79	0.93	0.73
2011	181	0.72	0.92	0.66
2012	170	0.67	0.90	0.59
2013	219	0.53	0.81	0.43
2014	214	0.64	0.95	0.61
2015	213	0.64	0.89	0.57
2016	196	0.60	0.91	0.54
2017	216	0.64	0.90	0.57
2018	241	0.75	0.91	0.68
2019	274	0.67	0.91	0.61
2020	236	0.64	0.96	0.62
2021	220	0.68	0.88	0.60
2022	216	0.59	0.91	0.53
2022	244	0.66	0.89	0.59
Promedio (93-23)		0.65	0.86	0.56

Tabla 8a: Parámetros reproductores básicos de la cueva grande

año	Nº puestas	éxito eclosión	éxito emplumamiento	éxito reproductor
1993	215	0.8	0.92	0.73
1994	224	0.65	0.82	0.53
1995	181	0.53	0.91	0.48
1996	152	0.65	0.73	0.47
1997	148	0.57	0.78	0.45
1998	145	0.52	0.67	0.35
1999	145	0.63	0.76	0.48
2000	149	0.54	0.77	0.42
2001	114	0.66	0.71	0.46
2002	93	0.57	0.62	0.35
2003	106	0.66	0.81	0.54
2004	115	0.7	0.86	0.6
2005	141	0.73	0.86	0.63
2006	173	0.7	0.96	0.67
2007	176	0.75	0.92	0.69
2008	104	0.72	0.92	0.66
2009	118	0.64	0.82	0.5
2010	119	0.8	0.9	0.72
2011	109	0.71	0.91	0.64
2012	102	0.63	0.87	0.54
2013	124	0.52	0.77	0.40
2014	109	0.57	0.95	0.54
2015	101	0.54	0.89	0.49
2016	91	0.47	0.85	0.39
2017	113	0.59	0.91	0.54
2018	131	0.69	0.89	0.61
2019	150	0.75	0.95	0.71
2020	134	0.66	0.97	0.64
2021	126	0.73	0.83	0.61
2022	125	0.61	0.91	0.55
2023	142	0.67	0.83	0.56

Tabla 8b: Parámetros reproductores básicos de la cueva pequeña.

año	Nº puestas	éxito eclosión	éxito emplumamiento	éxito reproductor
1993	64	0.63	0.73	0.45
1994	62	0.56	0.77	0.44
1995	48	0.56	0.85	0.48
1996	44	0.34	0.67	0.23
1997	36	0.64	0.96	0.61
1998	40	0.58	0.87	0.5
1999	58	0.67	0.82	0.55
2000	67	0.54	0.81	0.43
2001	70	0.69	0.85	0.59
2002	49	0.59	0.79	0.47
2003	65	0.57	0.92	0.52
2004	78	0.65	0.84	0.55
2005	96	0.73	0.87	0.64
2006	108	0.67	0.85	0.56
2007	95	0.75	0.99	0.74
2008	66	0.79	0.92	0.73
2009	68	0.59	0.92	0.54
2010	76	0.79	0.96	0.75
2011	72	0.73	0.94	0.68
2012	68	0.74	0.94	0.69
2013	95	0.52	0.92	0.47
2014	105	0.70	0.96	0.67
2015	112	0.73	0.89	0.65
2016	105	0.71	0.93	0.67
2017	103	0.69	0.90	0.61
2018	110	0.82	0.92	0.75
2019	124	0.58	0.85	0.49
2020	104	0.61	0.95	0.58
2021	94	0.61	0.96	0.59
2022	91	0.56	0.90	0.51
2023	102	0.65	0.98	0.63

10. Supervivencia

Se ha analizado la supervivencia de aves adultas reproductoras mediante modelos de captura recaptura en el programa E-Surge. Cabe destacar que existe una gran heterogeneidad en los datos, debida principalmente a individuos que se recapturan tras numerosos años de no haber sido controlados. Este hecho hace que todos los tests de los GOF sean significativos y además de tener en cuenta una supervivencia diferencial para individuos recién marcados y experimentados, y una probabilidad de recaptura diferencial para individuos capturados y no capturados en la ocasión anterior (efecto de trap-dependence) se deban aplicar factores de corrección (c-hat) elevados: de 2.35 para la cueva grande y 2.39 para la cueva pequeña (en este caso se han eliminado 6 historias de captura que aumentaban de forma muy acusada la heterogeneidad). La selección de modelos (Tabla 9a) indica que tanto supervivencia como recaptura variaron con los años en la cueva grande, mientras que en la pequeña la supervivencia se ha mantenido relativamente constante. En promedio la supervivencia ha sido más elevada para los reproductores de la cueva pequeña.

Tabla 9a. Selección de modelos

Cueva grande c1					
Modelo	Supervivencia	Recaptura	np	Dev	QAICc
1c1	**experiencia+t**	**trap+t**	**62**	**9683.139**	**4246.0527**
2c1	experiencia+t	trap	33	9864.0467	4263.9145
3c1	Experiencia*t	trap+t	89	9651.9004	4288.4248
4c1	Experiencia	trap	33	9838.46	4253.0266
Cueva pequeña c2					
Modelo	Supervivencia	Recaptura	np	Dev	QAICc
1c2	experiencia+t	trap+t	60	5411.5851	2386.5159
2c2	experiencia+t	trap	32	5555.767	2389.2336
3c2	Experiencia*t	trap+t	86	5381.7125	2428.4083
4c2	**Experiencia**	**trap+t**	**32**	**5484.0711**	**2359.2353**
5c2	Experiencia	trap	4	5651.7849	2372.7757

Tabla 9b. Estimas de supervivencia promedio

Colonia	Nuevo reproductor/anillado	Experimentado
1	0.72 (0.68-0.76)	0.83 (0.81-0.85)
2	0.75 (0.69-0.80)	0.88 (0.86-0.90)

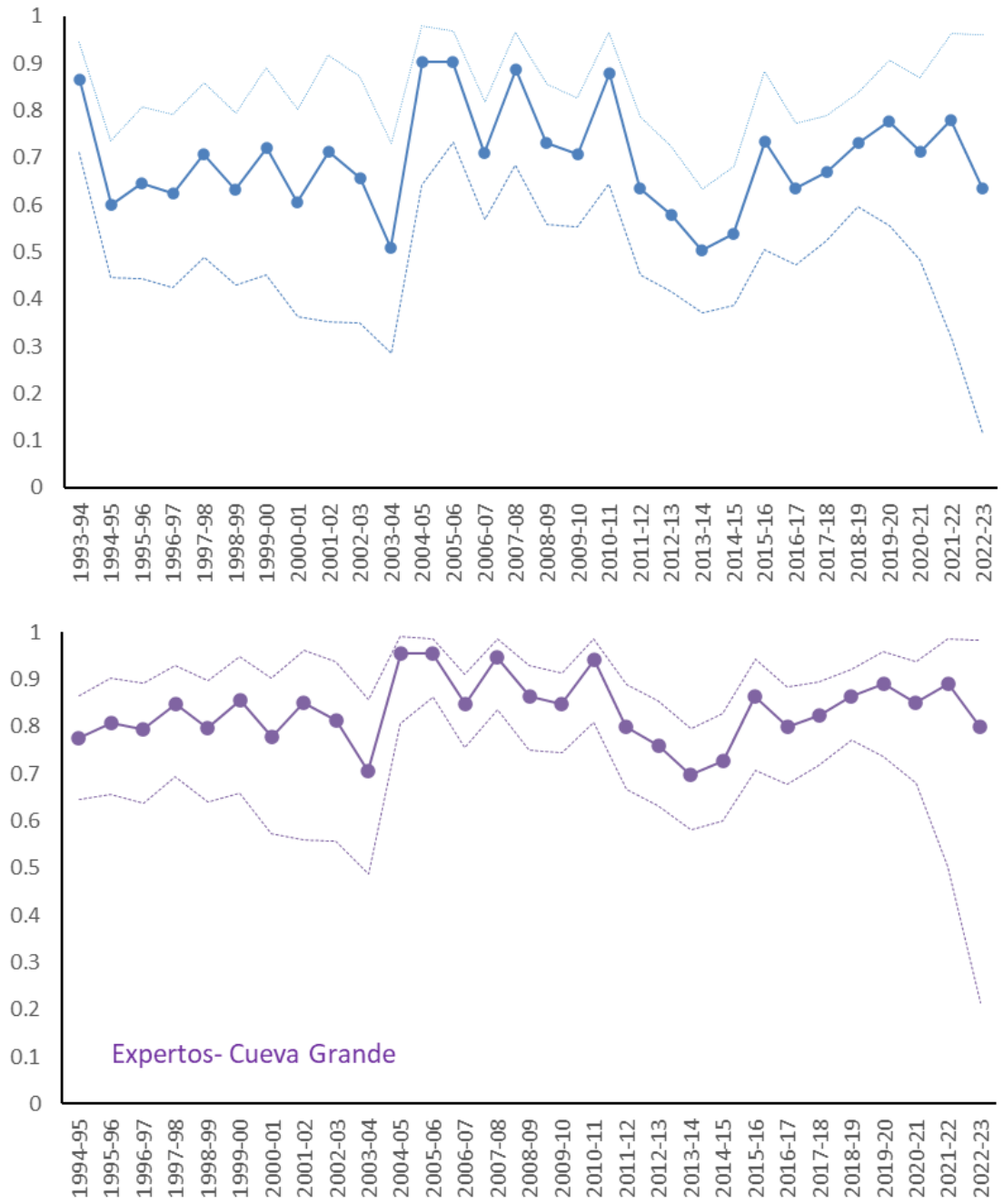


Figura 10a. Estimas de supervivencia (e intervalos de confianza 95%) del paíño en la isla de Benidorm- Cueva grande. Tras la primera reproducción observada en azul y reproductores experimentados en lila.

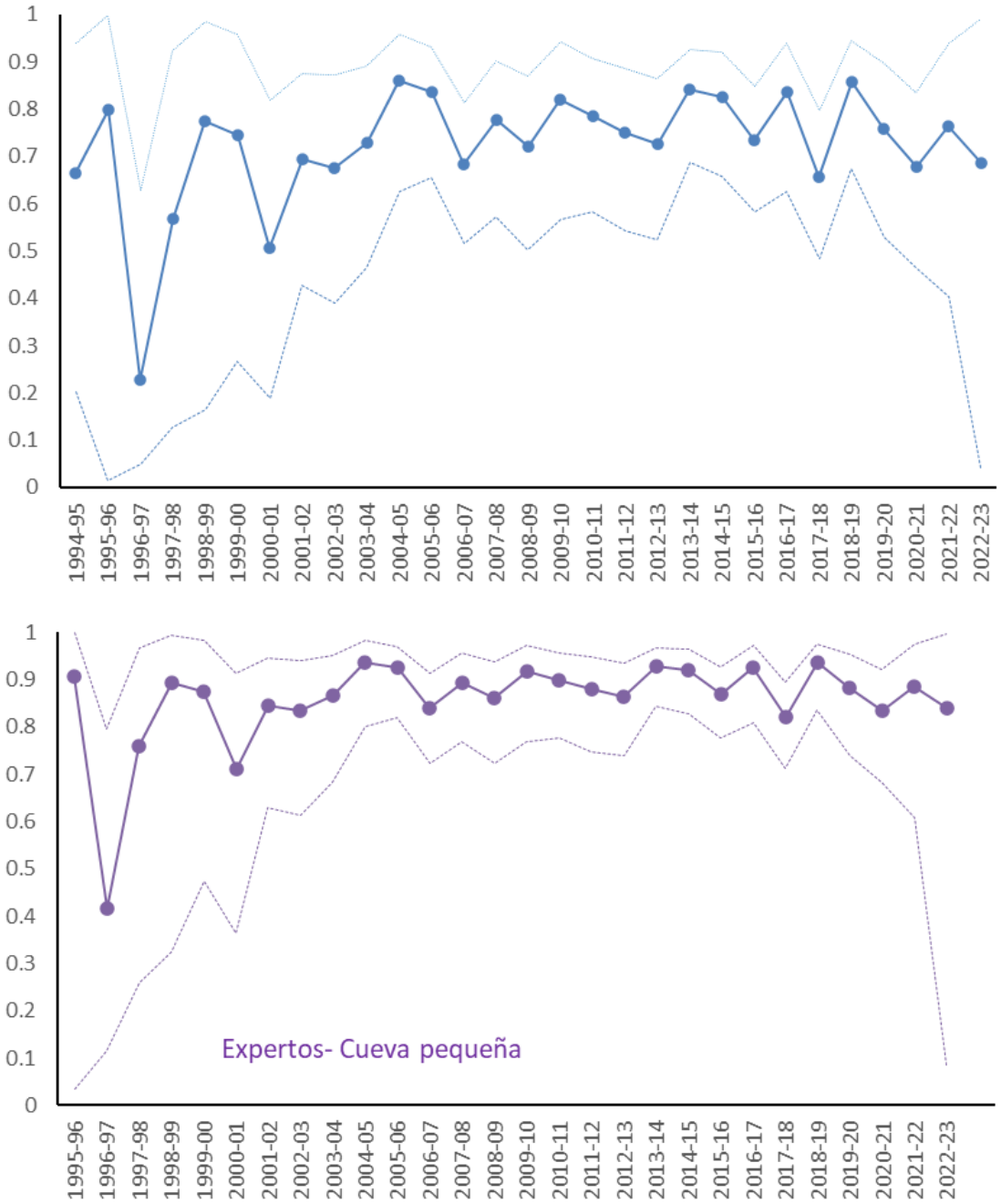


Figura 10b. Estimas de supervivencia (e intervalos de confianza 95%) del paíño en la isla de Benidorm- Cueva pequeña. Tras la primera reproducción observada en azul y reproductores experimentados en lila.

11. Seguimiento en Mitjana

Isla Mitjana (Serra Gelada)

En 2023 sólo se visitó la colonia en una única ocasión, el 20 de julio. El seguimiento fue realizado por José Santamaría y Román Aldeguer. Al tratarse de una revisión muy tardía, el número de nidos ocupados detectados estará subestimado. No se detectó ningún nido activo en la zona norte, aunque el esfuerzo fue inferior al de otros años de seguimiento. Se destaca la ocupación de 5 cajas nido de cemento y además se detectó una importante depredación de paíños por parte de gaviotas patiamarillas (con 14 egagrópilas encontradas bajo la grieta roja)

2023									
DIA	ORIENTACIÓ	ZONA	NIU	ADULTS	OUS	POLLS	NIUS SEGURS	TOTAL NIUS	OBSERV
20-07-2023	NORD	RAMPA CARTELL	NOR1						NO ES LOCALITZA NINGUN NINU ACTIU EN AQUESTA ZONA (revisió ràpid de la zona…)
		BAIX SILENE 38-20	NOR2						
			NOR3						
		DALT GRIETA ROJA	AGR1			1	1	1	
			AGR2						
			AGR3						
		RAMPA BAJADA PASO AGUJERO (dcha cartel)	DC1						
			DC2						
	SUR	ADOSADOS	5						
			Iz 5						
			6	1			1	1	
			7			1	1	1	
			BLOQUES/ NIDALS	1 COV	1	3	5	5	¡¡ prou blocs ocupats!!!
			en la zona			1	1	1	Bajo 6-7
		SALIENDO ADOSADOS	-						
		ZONA PARED	2						
			3						
			BLOQUES/ NIDALS			1	1	1	
			en la zona						
		1ER BLOQUE GRANDE	en la zona						
		BLOQUES DCHA.	-						
		CUEVA-GRIETA	-						
		BADALL	9	1 RIP			1	1	ad. mort
			12			1 RIP	1	1	poll mort
			11						
			13						moltes plomes (¿?)
		ZONA TOLL	-						
		CUEVA	-	4		11	15	15	3 ad. covant - 1 ad. Empollant - 2 polls RIP
		BLOQUE GRANDE	-						
		ZONA N19	19						
			en la zona						
		ZONA BADALL 2	20						
			en la zona						
		CUEVA ANTES PARED ROJA	-			2	2	2	no està en el mapa (¿?)
		CUEVA 2	-			1	1	1	
		GRIETA ROJA		1		1	2	2	
	!! NIU GAVINA BAIX GRIETA ROJA!! =	14 egas	: fer una vista en abril-maig				32	32	NOVA SER UNA BÚSQUEDA TAN INTENSA COM EN 2021

Tabla 11b. Datos históricos de ocupación de nidos y éxito reproductor del paíño en Mitjana (extraídos de las memorias del Plan de Acción de Aves marinas de la Comunidad Valenciana).

Colonia Isla Mitjana	1988	1999	2002	2003	2004	2005	2006	2007	2008	2009
Puestas Controladas			53	49	47	55	61		40	41
TOTAL ESTIMADO	20	25	60	50	50	60	65	81*	45	46
Éxito Reproductor										0.6
N										20

Colonia Isla Mitjana	2010	2011	2012	2013	2016	2018	2019	2020	2021	2022	2023
Puestas Controladas		49	34	54	58	68	45**	26	50+8 ***	29	32 ***
TOTAL ESTIMADO	46	55	50	80					60	43	
ER		0.73									
N		49									

*Seguimiento en toda la isla mediante uso de reclamos
**Esfuerzo de seguimiento inferior al de otros años
*** Se prospecta también la zona norte, no mirada en otros años
En 2020 y 2022-23 el seguimiento es tardío (número de parejas infraestimado)

12. Recuperación de jóvenes desorientados

En 2023 se recuperó un único joven extraviado, el 25 de agosto en Campello. Se liberó en Campello por el personal de Santa Faz, al comprobar que se encontraba en buen estado.

Tabla 13. Registro histórico de entradas de paíño en el centro de recuperación de Santa Faz.

FECHA ENT	MUNICIPIO	FASE VITAL	CAUSAS DE ENTRADA
20-ago-98	Benidorm	Inmaduro	Traumatismo indeterminado
23-sep-98	Benidorm	Indeterminada	Hallazgo accidental
10-sep-99	Denia	Indeterminada	Hallazgo accidental
04-ene-01	Calpe/calp	Indeterminada	Indeterminada
26-ago-01	Benidorm	Indeterminada	Hallazgo accidental
08-oct-02	Benidorm	Indeterminada	Indeterminada
11-oct-02	Altea	Indeterminada	Indeterminada
02-sep-03	Benidorm	Cría	Indeterminada
08-dic-03	Javea/xabia	Indeterminada	Indeterminada
04-jul-04	Benidorm	Adulto	Indeterminada
19-ago-04	Guardamar del segura	Juvenil	Indeterminada
22-ago-04	Benidorm	Adulto	Hallazgo accidental
10-ago-05	Benidorm	Adulto	Hallazgo accidental
29-ago-05	Denia	Adulto	Hallazgo accidental
31-ago-06	Calpe	Inmaturo	Hallazgo accidental
09-nov-06	Benidorm	Juvenil	Hallazgo accidental
28-ago-07	Benidorm	Adulto	Trampeo anzuelo
08-sep-07	Benidorm	Juvenil	Hallazgo accidental
23-ago-08	Benidorm	Adulto	Hallazgo accidental
07-sep-08	Calpe	Adulto	Intoxicación petróleo
18-mar-09	Javea	Adulto	Hallazgo accidental
29-sep-09	Torrevieja	Adulto	Hallazgo accidental
01-may-11	Calpe	Adulto	Hallazgo accidental
23-sep-11	Torrevieja	Adulto	Atrapada en estructura
05-oct-11	Benidorm	Adulto	Hallazgo accidental
21-may-12	Campello	Adulto	Atrapada en piscifactoría
08-sep-13	Benidorm		Indeterminada
08-nov-13	Alacant		Traumatismo indeterminado
08-nov-13	Alacant		Hallazgo accidental
23-ago-14	Benidorm	Adulto	Hallazgo accidental
26-ago-14	Benissa	Subadulto	Indeterminada
26-ago-14	Benidorm	Cría	Indeterminada
29-ago-14	Benidorm	Adulto	Traumatismo indeterminado

FECHA ENT	MUNICIPIO	FASE VITAL	CAUSAS DE ENTRADA
13-ago-15	Benidorm		Hallazgo accidental
13-ago-15	Benidorm		Hallazgo accidental
22-ago-15	Villajoyosa		Desnutrición
24-ago-16	Benidorm	Adulto	Hallazgo accidental
28-ago-16	Benidorm	Cría	Hallazgo accidental
22-sep-16	Benidorm	Juvenil	Hallazgo accidental
22-ago-17	Altea	Cría	Crías
17-sep-17	San Vicente del Raspeig	Juvenil	Hallazgo accidental
14-sep-18	Torrevieja		Hallazgo accidental
19-ago-19	Benidorm	Juvenil	Hallazgo accidental
24-ago-19	Benidorm	Juvenil	Hallazgo accidental
27-ago-19	Benidorm	Juvenil	Hallazgo accidental
4-sep-19	Benidorm	Juvenil	Hallazgo accidental
7-sept-20	Benidorm	Juvenil	Hallazgo accidental
17-sept-20	Benidorm	Juvenil	Hallazgo accidental
1-sept-21	Benidorm	Juvenil	Hallazgo accidental
13-sept-21	Benidorm	Juvenil	Hallazgo accidental
7-sept-22	Benidorm	Juvenil	Hallazgo accidental
23-sept-22	Elche (Aeropuerto)	Juvenil	Hallazgo accidental
25-ago-23	Campello	Juvenil	Hallazgo accidental

Los datos históricos de entradas en Santa Faz (Tabla 13) destacan la presencia de paíños durante el invierno (diciembre, enero y marzo) en aguas alicantinas.

Tabla 14. Registro histórico de paíños desorientados recuperados y liberados en Benidorm por personal de Serra Gelada y/o Guarda Rural.

Año	Número	Observaciones
2016	6	Uno de ellos anillado en cueva grande
2017	1	
2018	1	
2019	4	
2020	2	
2021	2	
2022	1	
2023	0	

13. Publicaciones científicas (1989-2023)

1. Martínez Abraín, A. and Dolz, R. 1989. Avance del primer censo exhaustivo de aves marinas nidificantes en la Comunidad Valenciana (primavera 1988). Libro Actas de la primera reunión del GIAM (Formentera). GOB: Volumen: Especial Páginas: 119-126.
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3. Mínguez, E. 1994. Censo, cronología de puesta y éxito reproductor del paiño común (*Hydrobates pelagicus*) en la Isla de Benidorm (Alicante E de España). Ardeola 41:3-11.
4. Mínguez, E. 1996. Nestling feeding strategy of the British storm-petrel *Hydrobates pelagicus* in a Mediterranean colony. Journal of Zoology 239:633-643.
5. Mínguez, E. 1997. Evidence of occasional re-laying in the British Storm-petrel (*Hydrobates pelagicus*). Colonial Waterbirds 20:102-104.
6. Minguez E. 1997. Olfactory nest recognition by British storm-petrel chicks. Animal Behaviour, 53:701-707.
7. Minguez E. 1997. Estimation of metabolic costs and food conversion efficiency in British storm-petrel, *Hydrobates pelagicus* chicks. Folia Zoologica, 46:94-96.
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14. Contribuciones a Congresos

1. **7th World Seabird Twitter Conference.**

   2021.

   Militao T, Sanz-Aguilar A, Rotger A, Ramos R. Non-breeding distribution and at-sea activity patterns of the smallest European seabird, the European storm petrel (Hydrobates pelagicus). 4-6 May 2021.

2. **6th World Seabird Twitter Conference.**

   2020.

   Rotger, A. GPS tracking of breeding Mediterranean Storm Petrels (Hydrobates pelagicus melitensis) reveals long-distance foraging movements. 4-6th May 2020.

3. **XXIV Congreso Español y VII Ibérico de Ornitología.**

   Cádiz, 2020.

   Poster: Sola Galindo, A.; Rotger, A.; Tavecchia, G.; Sanz-Aguilar, A. 2019. Descubriendo las áreas de alimentación del paíño mediterráneo.

4. **Universidad de Valencia**.

   Valencia, 2019.

   Comunicación invitada: Sanz-Aguilar A. Seabird survival

5. **II Joint Congress on Evolutionary Biology**.

   Montpellier, Francia. 2018.

   Comunicación: Boulinier T; Ramos R; Garnier R; Sanz-Aguilar A; Burthe S; Poisibleau M; Weimerskirch H; Gamble A; Quillfeldt P; González-Solís J; Staszewski V; Granroth-Wilding H; Jaeger A; Delord K; Barbraud C; Cunningham E; McCoy KD; Daunt F; Tveraa T; Tornos J. Evolution of a neglected trait between life history and immunology: maternal antibody persistence.

6. **14th International Seabird Group Conference**.

   Liverpool, UK. 2018.

   Comunicación invitada: Sanz-Aguilar A. Seabird survival

7. **XX Congreso de Anillamiento Científico de Aves.**

   Murcia, 2017.

Comunicación invitada: Sanz-Aguilar A. Estudios de captura-recaptura aplicados al anillamiento.

8. Jornada de seguimiento del paíño en el Mediterráneo.

   Benidorm, España. 2017.

   Comunicaciones de Eduardo Mínguez, Ana Sanz Aguilar y Alejandro Izquierdo.

9. 2nd World Seabird Conference.

   Cape Town, South Africa. 2015.

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10. 2nd World Seabird Conference.

    Cape Town, South Africa. 2015

    Comunicación: Dell'Ariccia G, Blanc L, Bonadonna F, Sanz-Aguilar A. "Mediterranean storm petrels rely on nest position for homing after migration: a test with artificial nest boxes".

11. Long-term studies as a tool for wildlife conservation.

    Benidorm, Spain. 25-06- 2012 al 2-06- 2012. Ciudadanos por la Ciencia & CEFE-CNRS .

    Comunicación: Sanz-Aguilar A, "20 years guarding storm petrels in Benidorm Island".

12. 13th MEDMARAVIS Pan-Mediterranean Symposium.

    Alghero, Italy. 14-10-2011 al 17-10-2011. MEDMARAVIS and Porto Conte Regional Park. In association with PIM Mediterranean Small Islands Initiative

    Comunicación: Sanz-Aguilar Ana, Libois Emmy, Minguez Eduardo, Oro Daniel, Pradel Roger, Olivier Gimenez. Nest boxes: a successful management tool for the conservation of the Mediterranean storm petrel at Benidorm Island (Spain).

13. ICCB 2011.

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14. **IV Congrés d'Ornitologia de les Balears.**

    Menorca, 18-01-2008 al 20-01-2008.Societat Ornitològica de Menoría (SOM).

    Comunicación: Sanz-Aguilar A. "Pequeños y nocturnos: métodos de Estudio del Marineret, *Hydrobates pelagicus*".

15. **Jornadas Técnicas: Aves Marinas, Islas y Cambio Global en el Mediterráneo. Una Estrategia para la Conservación.**

    Murcia, 29-11-2007 al 30-11-2007. Región de Murcia, ANSE, Naturama, CEMACAM.

    Comunicación: Sanz-Aguilar A. "Cambios poblacionales en aves marinas por el cambio global".

16. **Taller Internacional sobre Ecología de paiños y pardelas en el sur de Europa**

    Cariño (A Coruña), 16-11-2007 al 18-11-2007. Sociedade Galega de Ornitología (SGO), Sociedade Galega de Historia Natural (SGHN) y Grupo Ibérico de Aves Marinas (GIAM-SEO/Birdlife).

    Comunicación: Sanz-Aguilar A. "El Paíño Europeo, situación general, biología reproductora, tendencias poblacionales, amenazas y medidas de conservación".

17. **31st Wbs. Annual meeting of the Waterbird Society.**

    Barcelona, 30-10-2007 al 3-11-2007. Waterbird Society- Universidad de Barcelona- Seo-BirdLife.

    Comunicación: Sanz-Aguilar A. "Age and experience dependent tradeoff between survival and reproduction in a long lived bird".

18. **El Escateret en el Parque Natural de Serra Gelada. Labores para su conservación**

    Benidorm (Alicante), 16-10-2007. Parque Natural de la Serra Gelada.

    Comunicación: Sanz-Aguilar, A. Resultados del seguimiento a largo plazo de las colonias de la Illa de Benidorm ¿son suficientes 15 años?"

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Comunicación: Santamaría J. "La colaboración con el estudio del paíño".

19. **Talleres de Ecología 2007.**

    Elche (Alicante), 14-09-2007. Área de Ecología, Departamento de Biología Aplicada, UMH.

    Comunicación: Sanz-Aguilar A. "Experience-dependent tradeoff between survival and reproduction in a long lived bird".

20. **XVIII Congreso Español y III Ibérico de Ornitología**

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    Poster: Sanz-Aguilar, A.; Mínguez, E.; Noguera, J.M.; Perez-García, J.M.; Santamaría, J. & Oro, D.-"Patrones de reclutamiento y edad de la primera reproducción del Paíño europeo (Hydrobates pelagicus) en la Isla de Benidorm".

    Poster: Sanz-Aguilar, A.; de León, A; Martínez-Abraín, A.; Mínguez, E.; Noguera, J.M.; Perez-García, J.M.; Santamaría, J.; Sarzo, B. & Oro, D.- "Eliminación selectiva de gaviotas predadoras de Paíño europeo (Hydrobates pelagicus) en la Isla de Benidorm, implicaciones para su conservación"

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    Comunicación y publicación en actas: Martínez Abraín, A. y Dolz, R. "Primer Censo de Aves Marinas nidificantes en el litoral e islas de la Comunidad Valenciana".

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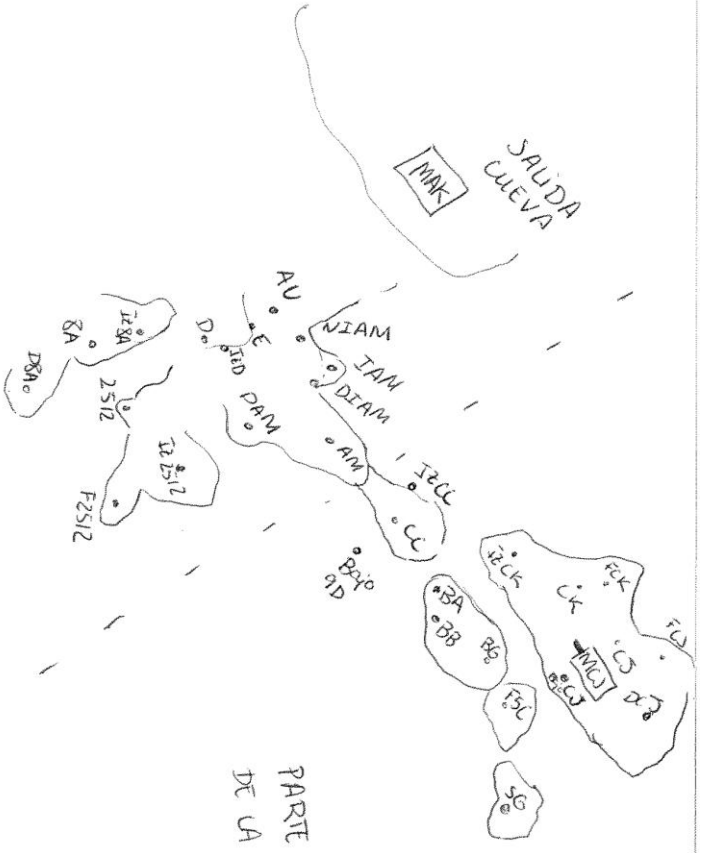
ANEXO 1

Imágenes de la campaña 2023

ANEXO 2

Croquis de las colonias

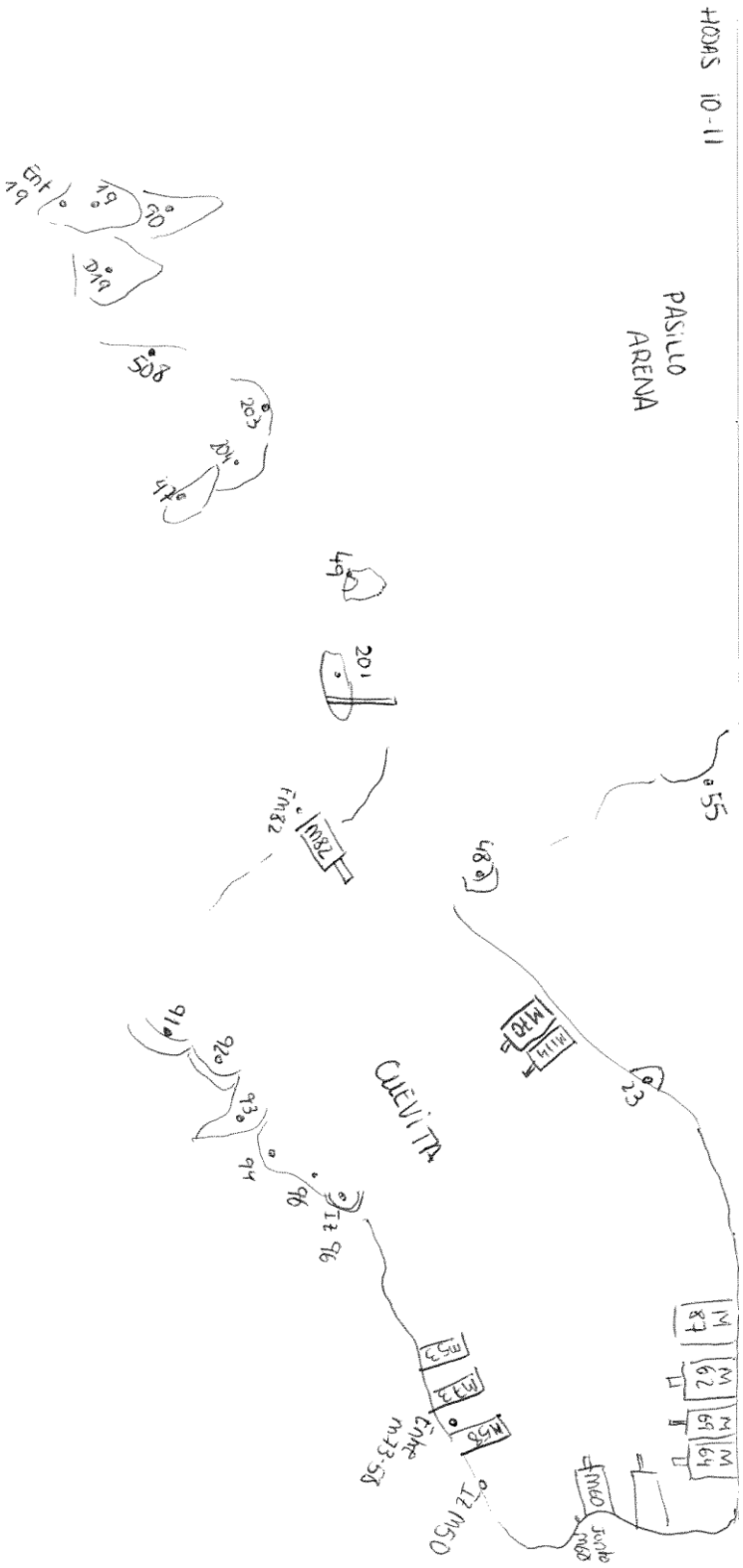

ENTRADA CUEVA
SALIDA
CUEVA PEQUEÑA
HOJAS 1-6



CUEVA PEQUEÑA
HOJAS 6-7


HOJAS - 1 - 4
MAR
ENTRADA CUEVA
Arena
Piedra resbaladiza
Bloque grande
FONDO CUEVA


HOJAS 5-9
"Bajo roca grande"
"Bajo roca pequeña"
Piedra resbaladiza
"METERSE DE LADO"
FONDO CUEVA
Hacia pasillo arena


HOJAS 10-11
PASILLO
ARENA
CUEVITA
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101
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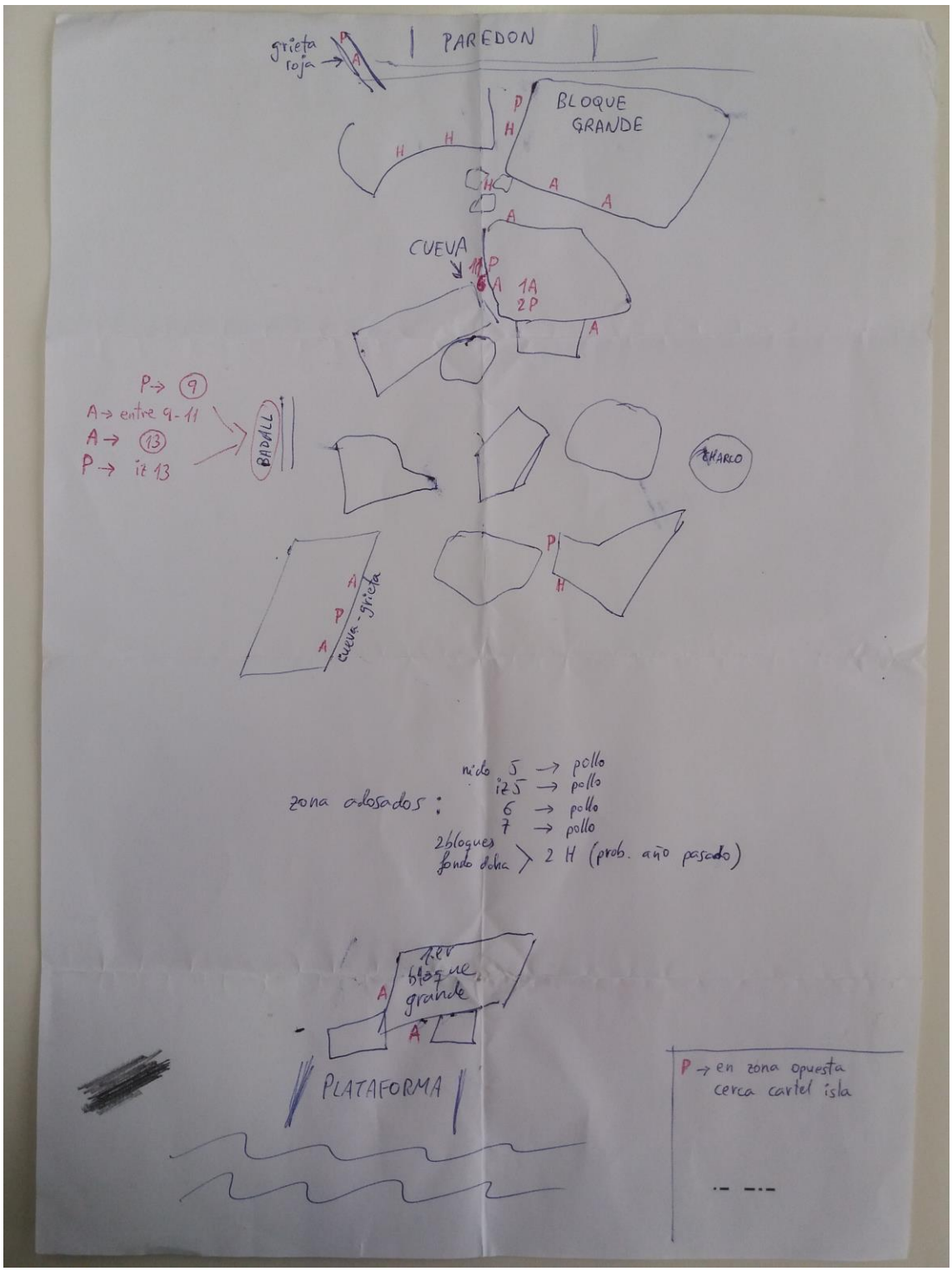

ANEXO 3

Publicaciones científicas

nature communications

Article

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Global assessment of marine plastic exposure risk for oceanic birds

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Plastic pollution is distributed patchily around the world's oceans. Likewise, marine organisms that are vulnerable to plastic ingestion or entanglement have uneven distributions. Understanding where wildlife encounters plastic is crucial for targeting research and mitigation. Oceanic seabirds, particularly petrels, frequently ingest plastic, are highly threatened, and cover vast distances during foraging and migration. However, the spatial overlap between petrels and plastics is poorly understood. Here we combine marine plastic density estimates with individual movement data for 7137 birds of 77 petrel species to estimate relative exposure risk. We identify high exposure risk areas in the Mediterranean and Black seas, and the northeast Pacific, northwest Pacific, South Atlantic and southwest Indian oceans. Plastic exposure risk varies greatly among species and populations, and between breeding and non-breeding seasons. Exposure risk is disproportionately high for Threatened species. Outside the Mediterranean and Black seas, exposure risk is highest in the high seas and Exclusive Economic Zones (EEZs) of the USA, Japan, and the UK. Birds generally had higher plastic exposure risk outside the EEZ of the country where they breed. We identify conservation and research priorities, and highlight that international collaboration is key to addressing the impacts of marine plastic on wide-ranging species.

Plastic pollution harms marine life worldwide[1], alongside other threats including fishing, climate change and invasive species[2]. Reports of entanglement and ingestion impacts are mounting[1,3,4], but there are large gaps in our understanding, including about factors affecting plastic encounter, ingestion rates, mortality and population-level impacts[4,5]. Marine plastic is unevenly distributed[6], accumulating in patches within ocean gyres and coastal regions[7,8], and often drifting thousands of kilometres in ocean currents[8,9]. Likewise, marine life is patchily distributed[10], and many species cross oceans and political boundaries[11,12]. With plastic production and waste generation continuing to increase[13], identifying at-risk species and populations is crucial for targeting conservation action and research[14–16] because the vulnerability of populations relates to exposure to a hazard, sensitivity to damage that impacts survival or reproduction, and the resilience of the population[17].

Many seabird species are sensitive to plastic pollution; they frequently ingest plastic[1], which can have lethal and sublethal impacts caused by chemical contamination[18] and physical damage or blockages[19]. Numerous factors affect the amount of plastic accumulated by different species including foraging behaviour, at-sea distribution and gut morphology[20–22]. Among seabirds, albatrosses and petrels can contain particularly high loads of plastic ingested directly or within their prey[1,20]. Many species rarely regurgitate indigestible items, except when feeding their chicks[23]. Petrels are particularly sensitive because they retain plastic for long periods due to their gut morphology[22], and small species (e.g., storm-petrels and gadfly petrels) can suffer greater physical damage or higher metabolic costs from ingesting plastic relative to larger species[5]. Petrels are a diverse group of 123 wide-ranging species that inhabit all the world's oceans, making them good sentinels for ocean health[2]. Many populations are

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unlikely to be resilient to hazards because over half (64) are listed as globally Threatened or Near Threatened by the International Union for the Conservation of Nature (IUCN), including 16 Endangered and 12 Critically Endangered species[2]. Moreover, we know little about the status of many of their populations or if they are impacted by plastic[2].

Assessing risk to petrel populations from plastic pollution requires a robust understanding of vulnerability to ingestion, for which exposure at sea is a key component[14]. Seabirds risk encountering plastic when they forage near sources associated with dense human populations[24], fisheries[25] and shipping lanes[26], or in mid-ocean gyres where floating debris accumulates[27–29]. Exposure risk can be characterised by estimating contact between organisms and hazards, or their co-occurrence, and a key goal in ecological risk assessment is to consider variation in the amount of time spent by animals in different parts of their range[30,31]. Plastic exposure risk has not been previously quantified using methods that account for the time spent in areas of different densities of plastic pollution, but lightweight tracking devices have recently provided unprecedented detail about the movements of petrels of all sizes[32], including the time spent in different foraging areas and across the annual cycle[33].

Here, we estimate relative marine plastic exposure risk for 77 petrel species at a global scale by calculating the spatio-temporal overlap between modelled floating plastic density and the space-use of tracked birds[14]. To inform conservation action and future research, we compare exposure risk across populations, seasons (breeding and non-breeding), Exclusive Economic Zones (EEZ) and areas beyond national jurisdiction (the high seas), and found substantial variation. We identified areas of high risk of exposure to plastic debris in the Mediterranean and Black seas, the northeast Pacific, the northwest Pacific, the South Atlantic and the southwest Indian Ocean. Our results also reveal that Threatened species have greater exposure risk. Because marine debris and seabirds cross multiple political boundaries, our results emphasise that efforts to reduce the amount of plastic waste in the ocean should not only focus on areas of high exposure risk. Improved international cooperation and collaboration are needed to address this global threat.

Results and discussion

Plastic exposure risk for petrels

We analysed 1,736,880 tracked locations for 7137 adults of 77 petrel species (64% of species within Oceanitidae, Hydrobatidae and Procellariidae, excluding the two *Macronectes* species), from 148 populations in 27 countries and Antarctica, between 1995 and 2020 (mean = 2012). For each population, we calculated monthly 95% utilisation distributions (UDs) that estimate time spent by tracked petrels in 10 km grid cells (i.e., smoothed density of 12-hourly tracked locations; Fig. 1a), and combined monthly UDs into seasons (breeding or non-breeding). If data were available from multiple populations of a species, we created species UDs weighted by approximate population size. We calculated a geometric mean of global marine plastic densities estimated by three published models[6,9,34] for micro- and macro-plastics (~0.333 mm–40 cm) combined for 2014 in 1 × 1° cells (Fig. 1b). We aggregated petrel UDs into 1 × 1° grid cells and created an all-species map by summing species UDs, weighting those tracked only in the breeding season and so not including the non-breeding part of the annual cycle at 0.5 (Fig. 1c). We divided the plastic and petrel grids by their respective cumulative sums so that the values of each global grid summed to one. We then multiplied each petrel UD by the plastic density to map spatial overlap as an indicator of estimated exposure risk[14] (e.g., Figure 1d). Summing the values across cells provided an exposure risk score, which we multiplied by 10^6 to provide an easy-to-use scale; this gave us monthly population-level scores ranging from 0.0007 to 1091.

We ranked species by plastic exposure risk score (Fig. 2a), ranging from 0.003 to 549 (mean = 28.0; median = 4.9, interquartile range = 1.8–14.5). Of particular concern are the 19 species scoring over 15.3 (the score any species would receive if plastic was evenly distributed worldwide), indicating they mostly use areas with above-average plastic density. These species include the Critically Endangered Balearic shearwater *Puffinus mauretanicus* and Newell's shearwater *Puffinus newelli*; the Endangered Hawaiian petrel *Pterodroma sandwichensis*; and the Vulnerable yelkouan shearwater *Puffinus yelkouan*, Cook's petrel *Pterodroma cookii* and spectacled petrel *Procellaria conspicillata* (Fig. 2a). The proportion of total exposure risk within each IUCN Red List category differs from the proportion of tracked species within each category, with a greater percentage of the exposure risk shared among Threatened species, particularly Critically Endangered species (Fig. 2b). The 20 highest-scoring species had greatest plastic exposure risk in five areas, both in coastal regions (Mediterranean/Black Sea, northwest Pacific) and ocean gyres (northeast and northwest Pacific, South Atlantic, southwest Indian oceans; Figs. 1d, 2a). Plastic exposure risk was low in upwelling zones (Humboldt and Canary currents) and polar regions (Fig. 1d). For some species, scores differed greatly among populations (Fig. 2a). For example, European storm-petrels *Hydrobates pelagicus* breeding in the Mediterranean had much higher scores (306–534) than elsewhere (1.0–1.4; Supplementary Fig. 1). There was no long-term trend in exposure risk scores for populations tracked in the same months for more than three years (Supplementary Fig. 2). By using tracking data to estimate the relative density of regularised bird locations, instead of using only estimated presence or absence, we explicitly consider spatio-temporal variation in seabird distributions, thus providing more detail on global plastic exposure risk for a subset of species than an analysis based on range maps, which inferred different geographic hotspots of plastic exposure risk[14].

Breeding and non-breeding season exposure risk

We calculated breeding and non-breeding plastic exposure risk scores for 107 populations of 60 species. The mean difference between seasons was 34.0, with little difference for most populations (median = 3.6), but substantial differences for some (maximum = 521.8; Fig. 3a). For example, Scopoli's shearwaters *Calonectris diomedea* breed on Malta in the Mediterranean and migrate to the eastern Atlantic Ocean where they had a much lower plastic exposure risk score (30.0) than during the breeding season (496.2). In contrast, yelkouan shearwaters also breed on Malta (517.5), but had a higher score during non-breeding (937.7) when they disperse within the Mediterranean and migrate to the Black Sea (Fig. 3a–c). Seasonal contrasts also varied among populations of the same species. For example, scores for Cook's petrels during non-breeding were much higher for birds breeding in northern New Zealand that migrate to the northeast Pacific (159.3), than those breeding in southern New Zealand that migrate to the Humboldt Current (0.8; Fig. 3a, d, e).

Exposure risk and ingestion

Plastic exposure risk, as indicated by our scores, is necessary but not sufficient for ingestion to occur and there are not yet enough suitable samples to quantify this process for most species. The amount of ingested plastic detected in seabirds is affected by foraging style, body size, tendency to regurgitate, gut morphology, prey type, age and breeding stage[20,22,23,28]. Few ingestion studies have used standardised protocols to sample different populations of the same species[4]. Furthermore, ingestion data are influenced by whether samples came from pellets[26] or regurgitates[18], or necropsies of birds that were found dead at a colony[29] or on beaches[35], recovered after attraction to light pollution[36], bycaught in fisheries[37], or taken for research[28] or human consumption[4]. Nonetheless, studies that compared ingestion for different populations of the same species using the same methods control for these factors, and so can be compared to our exposure risk scores. For example, flesh-footed shearwaters *Ardenna carneipes*

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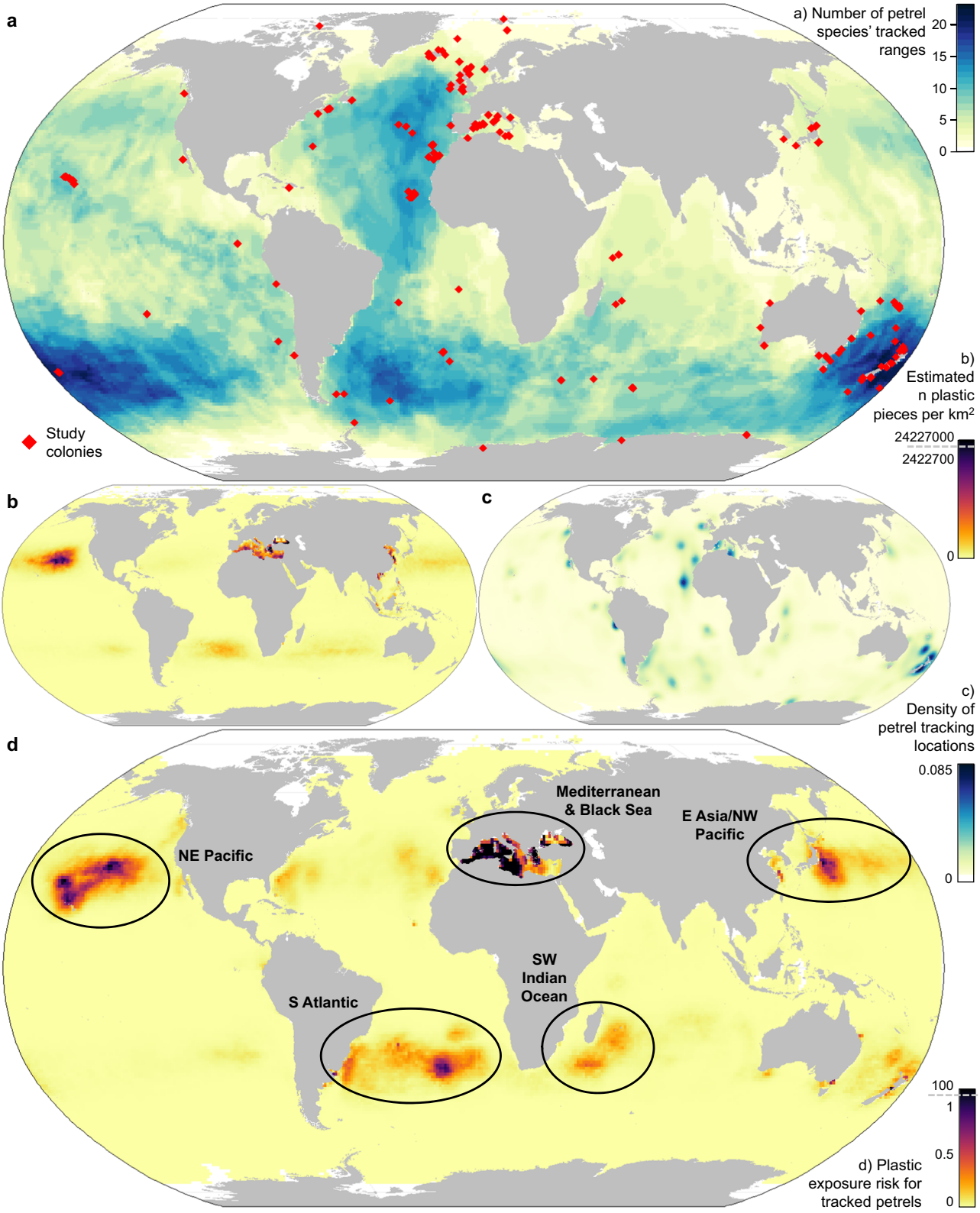

Fig. 1 | Mapping petrels and plastics. a Species richness based on presence within 95% utilisation distributions isopleth contours from tracking data for 77 petrel species. Red diamonds indicate the colonies from which tracking data were obtained. **b** Plastic density at the ocean surface, showing the square root of the number of plastic pieces (~0.333 mm–0.4 m) estimated per km^2 in each 1 × 1° grid cell. For visualisation only, the values are capped at 10% due to extreme values. **c** Summed 95% utilisation distributions for all species, with species weighted equally if year-round tracks were available or by 0.5 if tracks were only available for the breeding season. If we had data from multiple populations for a species, densities were weighted by approximate population size. **d** Exposure risk to plastic was calculated by multiplying the density value in each cell for plastics (scaled to sum to 1) by the value for petrels (scaled to sum to 1). For visualisation only, the values are capped at 1% due to extreme values, and all other values are shown on a linear scale. Black ellipses relate to the areas identified from the 20 species with the highest exposure risk scores (Fig. 2a). *n* = number. White = no data. Robinson Projection. Land polygons from Natural Earth. Source data for colony locations are provided as a Source Data file.

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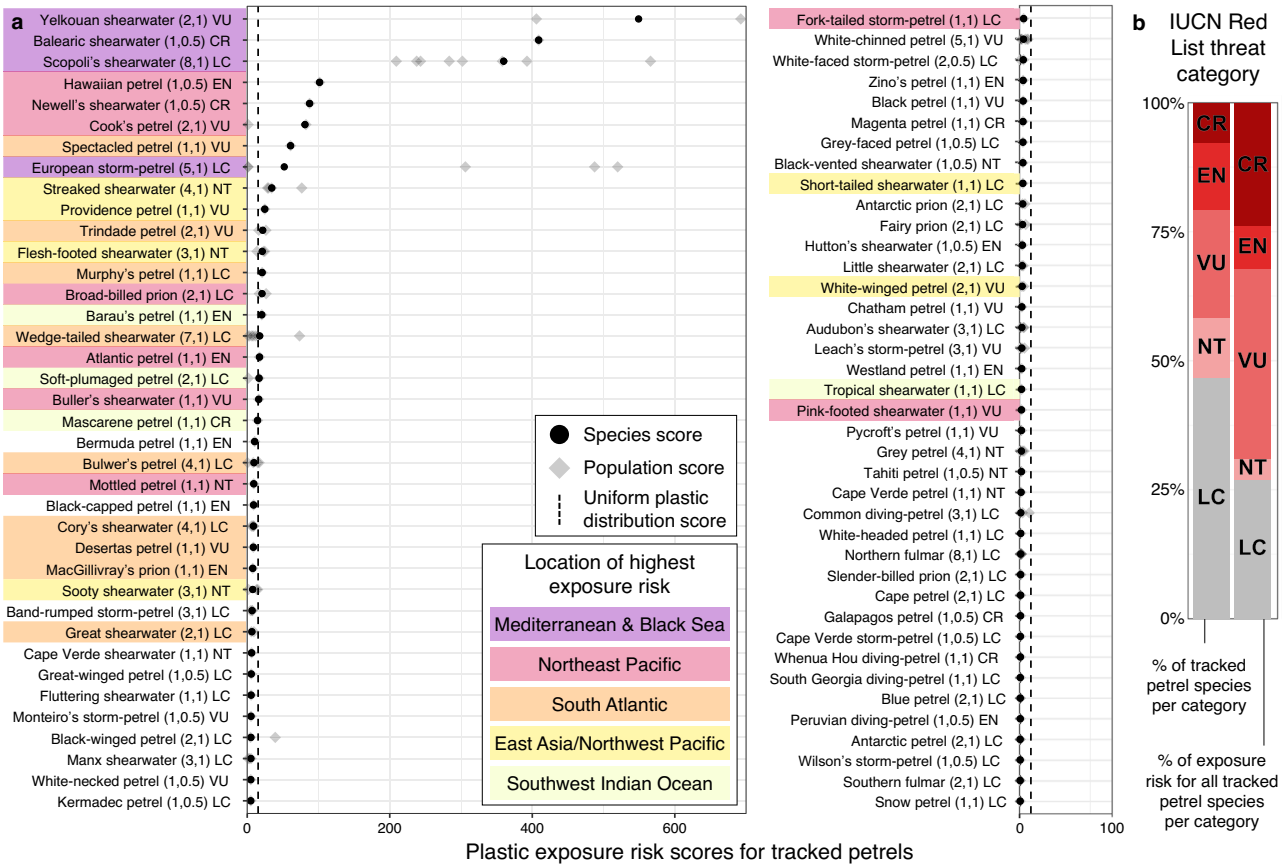

Fig. 2 | Plastic exposure risk scores for 77 petrel species. a Species are ranked by exposure risk from the top-left to the bottom-right. Colours represent the location that contributed most to the score for the five areas of highest exposure risk. Where there are multiple populations per species (grey diamonds), the mean of all populations (black circles) is weighted by the population size. The vertical dashed line indicates the theoretical exposure risk score if plastic was uniformly distributed across all cells (15.3). Values in parentheses are the number of populations, followed by 1 if the species was tracked in breeding and non-breeding seasons or by 0.5 if only tracked in one season. Two-letter codes indicate the IUCN Red List assessment threat category (Least Concern (LC; $n = 36$), Near Threatened (NT; 9), Vulnerable (VU; 16), Endangered (EN; 10), Critically Endangered (CR; 6)). **b** The percentage of tracked petrel species within each IUCN threat category and the percentage of total exposure risk attributed to species in each category. Source data are provided as a Source Data file.

sampled in eastern parts of their breeding range contained significantly more plastic[20], consistent with our higher scores during the non-breeding season for populations migrating to the northwest Pacific (New Zealand = 44.9; Lord Howe = 47.1) compared with those migrating to the eastern Indian Ocean (Western Australia = 13.6). Additionally, the Ecological Quality Objective for part of the North Sea target of <10% of northern fulmars *Fulmarus glacialis* containing ≥0.1 g of plastic was exceeded more in the North Sea than Arctic Canada[38], mirroring our exposure risk scores for those tracked from the UK (1.4) and Canada (0.25). There are clear examples of high ingested plastic loads in high exposure risk areas in the Mediterranean[37], northeast Pacific[39] and southwest Indian Ocean[36]. However, plastic loads are both low and high in areas with low exposure risk[40], indicating that birds may still be at risk while foraging in marine areas with low estimated plastic densities. Plastic has been ingested even by the species with the lowest exposure risk score of 0.003 (4% of 27 sampled snow petrels *Pagodroma nivea*, which forage around Antarctica, contained plastic[40]), indicating that the ubiquitous availability of plastic is concerning across all oceans worldwide, not only in areas where plastic aggregates.

Jurisdictions and policy

Plastic exposure risk for tracked petrels occurred mostly in the Mediterranean and Black Seas (Fig. 4a, b), where breeding European storm-petrels and Scopoli's, yelkouan and Balearic shearwaters are at risk, with high plastic loads recorded[37,41]. Elsewhere, the high seas are used by 75 of our 77 tracked species, and accounted for 25% of global plastics exposure risk, mainly within oceanic gyres. The US EEZ accounted for a high proportion of the exposure risk, noticeably northeast of Hawai'i, followed by the EEZs of Japan, and the UK, mainly around the Overseas Territories of Tristan da Cunha and Bermuda (Fig. 4a, b). The New Zealand EEZ ranked highly despite low plastic levels due to the exceptionally high petrel occurrence and diversity. Moderate plastic exposure risk scores (0.15–1.00% of total) occurred in the EEZs of France, Australia, Brazil, Portugal, Mauritius, China, Russia, Argentina, Madagascar, Bahamas, and Mexico (Fig. 4a).

Our results indicate that mitigating plastic pollution in the breeding country's EEZ alone would not adequately protect most species throughout the annual cycle. We identified links between the countries within which each tracked petrel population breeds (including overseas territories) and the jurisdictions where those populations were exposed to plastic (Fig. 4c). Exposure risk primarily occurred outside the breeding country's EEZ (theoretical EEZ in the Mediterranean because actual EEZs are not clearly defined), except for 7 of the 29 highest-scoring populations (e.g., wedge-tailed shearwaters *Ardenna pacifica* in the USA, and streaked shearwaters *Calonectris leucomelas* in Japan). Of the 29 highest-scoring populations, 25 were exposed to plastic in multiple EEZs. For example, streaked shearwaters breeding in South Korea were exposed in China, Malaysia, the Philippines, South Korea, Indonesia and Vietnam (Fig. 4c). Exposure risk

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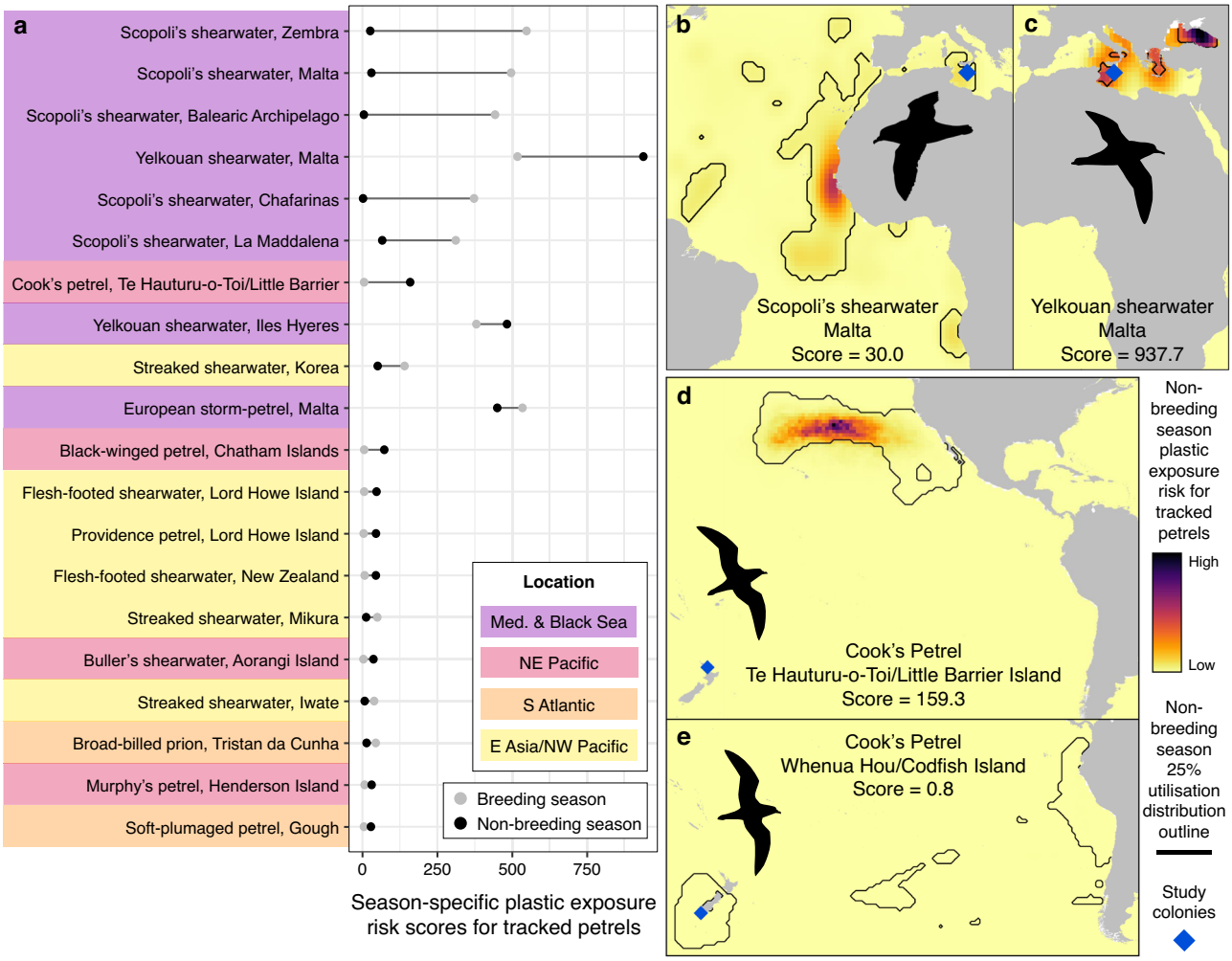

Fig. 3 | Season-specific plastic exposure risk scores. a Scores during breeding (grey circles) and non-breeding seasons (black circles) for the 20 populations with the greatest differences between seasons (grey lines). **b** Non-breeding season plastic exposure risk for Scopoli's shearwaters (non-breeding score = 30.0, breeding season score = 496.24) and **c** yelkouan shearwaters (non-breeding = 937.7, breeding =517.5) for tracked from Malta, and for Cook's petrels breeding either at **d** Te Hauturu-o-Toi/Little Barrier Island (non-breeding = 159.3, breeding = 5.5) or **e** Whenua Hou/Codfish Island (non-breeding = 0.8, breeding = 2.1). Black lines indicate the outline of the most used area in the non-breeding season (top 25% of the utilisation distribution). Land polygons from Natural Earth. Source data are provided as a Source Data file.

was greatest in the high seas for 15 of the 29 highest-scoring populations, particularly those breeding in the USA, New Zealand, UK, Brazil, Australia, France, and Mauritius (Fig. 4b). For each petrel population, we provide the percentage of exposure risk occurring in each EEZ and the high seas to facilitate targeting mitigation and policy efforts towards key areas (Supplementary Data 1).

Marine vertebrates and plastic debris are globally distributed and highly mobile, and cross political boundaries within and beyond national jurisdictions[11]. Therefore, mitigating plastic pollution from marine and terrestrial sources will require efforts targeted across multiple jurisdictions and the high seas[42]. International cooperation, collaboration, resource mobilisation and information exchange are key to addressing marine plastic pollution[43] by limiting still-increasing plastic waste production[13], improving waste management, and cleaning up existing plastic. The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V prohibiting plastic waste discharge from vessels entered into force 31st December 1988[44], but plastics from marine sources still affect seabirds[26] and account for at least 22% of ocean plastics[45]. Ghost fishing gear is a priority because it presents deadly entanglement risk[25] and food web contamination after degradation at sea. Pollution from vessels could be reduced with more resources and incentives for monitoring and managing waste, and enforcing MARPOL and local regulations, particularly among developing countries[46]. A coordinated approach for plastic waste management could be achieved, for instance, through a global-scale treaty on plastics[43], which could operate in synergy with MARPOL and other relevant bodies and frameworks, such as the Convention on Biological Diversity, Convention on the Conservation of Migratory Species, Agreement on the Conservation of Albatrosses and Petrels, Regional Seas Conventions and Action Plans.

Research priorities

Greater use of standard methods for future ingestion studies would facilitate comparison and help identify the drivers of plastic ingestion[4,47]. The relationship between exposure risk, ingestion and impact could be examined by concurrently sampling ingested plastic and tracking movements[41,48], and measuring physiological impacts. Interspecific differences could be clarified by systematically comparing plastic loads in species that have similar geographic ranges and exposure risk scores. Crucially, it is unclear for which species or populations plastic ingestion reduces survival or productivity and how much exposure they can tolerate; so, studies of population-level impacts and how to separate these from known causes of population declines will be vital[2,5]. Four species with high plastic exposure risk

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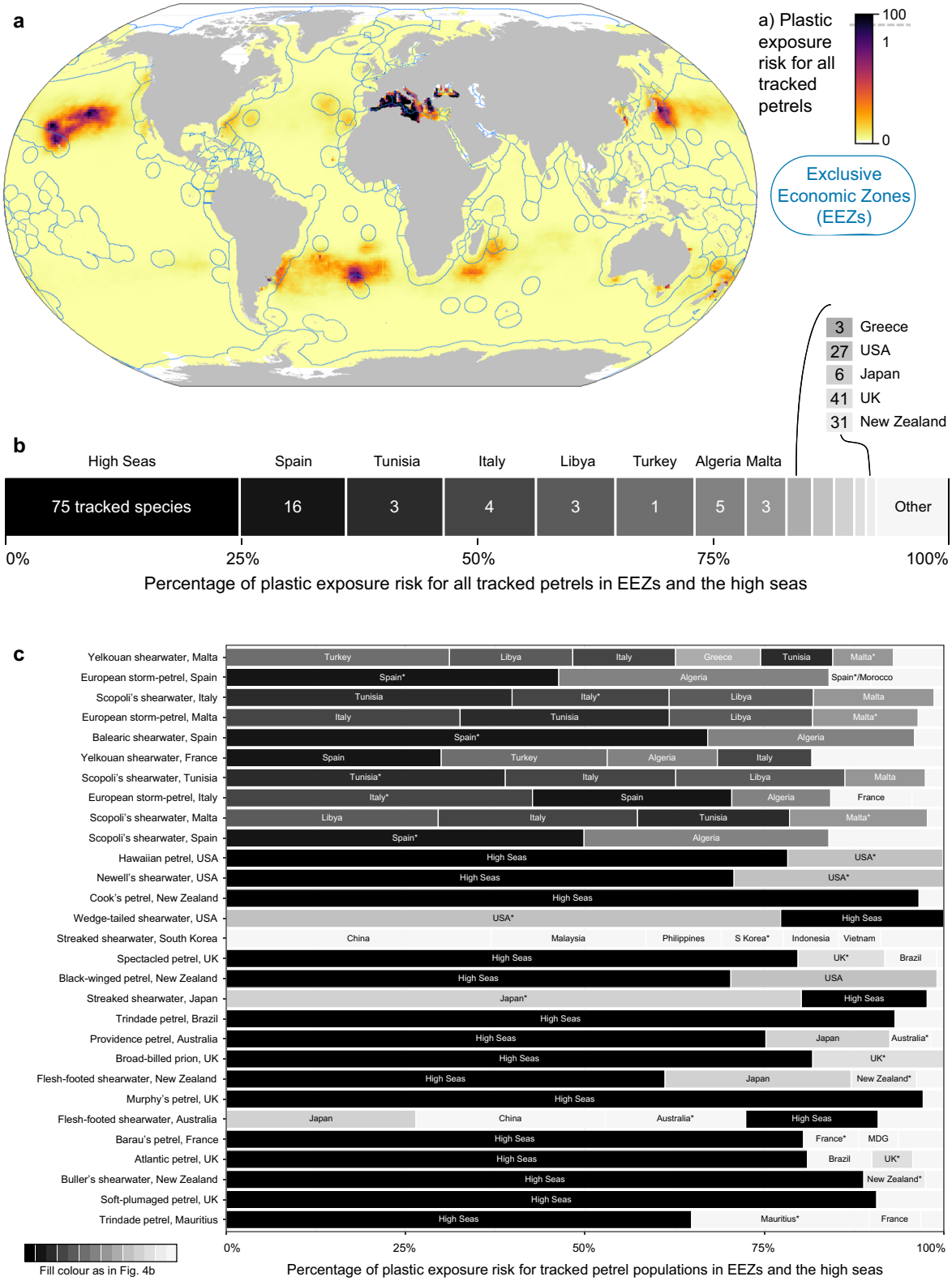

Fig. 4 | Plastic exposure risk for petrels in different jurisdictions. a Map of plastic exposure risk for 77 petrel species in the Exclusive Economic Zones (EEZs) of each country (including overseas territories) and the high seas (Areas Beyond National Jurisdiction). In the Mediterranean, theoretical EEZs are used. For visualisation only, the score is capped at 1% due to extreme values in the Mediterranean and Black Seas. **b** The percentage of plastic exposure risk score attributed to the high seas and each EEZ/theoretical EEZ accounting for >1% of total exposure risk, labelled with the number of tracked species using each area (values are provided in Supplementary Table 1). **c** For the 29 petrel populations by country with the highest exposure risk scores (ranked from high to low), bars show the proportion of the exposure risk score in each jurisdiction that accounts for over 5% of the total exposure risk, with unlabelled bars containing all others. Bars are coloured according to b. Overlapping territorial claims are shown as claim 1/claim 2. MDG = Madagascar. Asterisks(*) indicate that the EEZ matches the breeding country. Land polygons from Natural Earth. Source data are provided as a Source Data file.

scores but no ingestion data in a recent review[1] are key research priorities: Hawaiian petrel and streaked shearwater within the main high-exposure risk areas, and Bermuda petrel *Pterodroma cahow* and Desertas petrel *Pterodroma deserta* elsewhere. Comparable ingestion data from different tracked populations of the same species with contrasting migration patterns (e.g., Cook's petrel; Fig. 3d, e) would be particularly valuable.

Our tracking data covered almost all of the world's oceans and all ocean regions within the ranges of 70% of analysed species, broadly matching seabird biodiversity in general[10], but also reflecting known spatial biases in research effort, notably towards the Atlantic Ocean and latitudes south of 40°S[32] (see Supplementary Table 2 for spatial coverage gaps). Our study included tracking data for all four petrel species that breed in the Mediterranean, but we identified 14 species that occur in other high-exposure risk areas, making them priorities for tracking studies (Supplementary Table 3). Additionally, both petrel tracking and ingestion data are sparse in coastal waters around east and southeast Asia, where high plastic densities occur, and the South Pacific and North Atlantic gyres, where moderate plastic densities occur[10,32] (Fig. 1). We identified priority species for future research in each of these regions (Supplementary Table 4). Sample sizes varied substantially among species, from 3 to 960 individuals (median = 35, mean = 93), so additional tracking for some species could be beneficial (Supplementary Data 2). Furthermore, tracking immature birds or adults when deferring breeding could reveal differences in exposure risk[33]. Our method could also be applied to global-scale, multi-species tracking datasets[12] for other marine megafauna, such as turtles and marine mammals, for which plastic pollution is also a threat[1].

Collecting more data on plastic density, identifying sources, and developing density models to provide better spatial coverage at a higher resolution would aid targeted mitigation strategies, and enable a better understanding of the effects of spatial scale on plastic exposure risk. The models that produced the plastic density estimates used in our analysis involved interpolating over wide areas, whereas observed plastic densities tend to be more patchy[49]. There were limited plastic data, particularly for southeast Asia[6], where a recent survey recorded high plastic levels[50]. The South Pacific has a high petrel species richness, but few samples were used to inform the plastic density models[6]. The plastic density model estimates covered most of the Arctic and Antarctic oceans, but had more missing values near the poles than in other regions (Fig. 1b), although the Southern Ocean is not thought to contain much plastic[6]. However, plastic accumulates around Svalbard in the Arctic[51], which although only important for northern fulmars among petrels, could affect other taxa. Marine species also feed at different depths and so it would be valuable to examine how plastic varies vertically[52]. Repeated plastic sampling across longer timescales would improve temporal matching between plastic and seabird data and allow investigations into long-term changes in plastic exposure risk[53]. We provide example versions of the code used to produce our results to facilitate future research on different tracking or plastics datasets[54].

Methods

In brief, we collated tracking data for petrels and computed gridded utilisation distributions (UDs) at a monthly scale. We then combined gridded distributions of marine plastic density and multiplied them by the petrel UDs to map estimated exposure risk. For each map, we summed the plastic exposure risk values in all cells to provide a score representing relative estimated exposure risk. We combined maps and scores to investigate variation in exposure risk between breeding and non-breeding seasons, among populations and species, and across Exclusive Economic Zones (EEZs) and the high seas. Steps for processing and analysing the data are described in detail below and represented graphically in Supplementary Fig. 3. All data handling was carried out in R[55] and R scripts are provided, along with example data and templates[54].

Petrel tracking data collation and processing

We collated tracking data that were collected using Global Positioning System (GPS) loggers, Platform Terminal Transmitters (PTTs) and Global Location Sensor (GLS) loggers deployed on adult petrels (Table S1; Oceanitidae, Hydrobatidae and Procellariidae). We searched for published and unpublished tracking data for all petrel species between March and August 2020, excluding the two giant petrel species *Macronectes giganteus* and *M. halli* because our analyses focused on marine areas and they regularly feed on land[56]. We obtained data for 77 species (64% of the 121 target species) from the Seabird Tracking Database (www.seabirdtracking.org), ZoaTrack (www.zoatrack.org)[57], Movebank (www.movebank.org)[58], and individual researchers (represented by authors of this study or detailed in the Supplementary Acknowledgements). We collated 1,736,880 tracked locations for 7137 individuals tracked from 27 countries and Antarctica. Datasets varied in terms of number of colonies per species, and numbers of individuals, years, and months tracked per population (Supplementary Data 2) and species (Supplementary Data 3).

We standardised tracking datasets to contain the following fields in the same format: latitude, longitude, datetime, species, colony name, colony latitude, colony longitude and device type. For GLS, we removed locations around the equinoxes (March equinox: −21, +7 days; September equinox: −7, +21 days) as they are unreliable[59], unless latitudes were estimated using additional information such as sea surface temperature prior to our analysis. For GPS and PTT data, we filtered locations for unrealistic speeds (>90 km/h), and visually checked maps and removed locations that were clear outliers. We removed locations within 5 km of the colony for GPS data or within 15 km of the colony for PTT data, but not for GLS locations due to large location error for these devices. We linearly interpolated and resampled GPS and PTT datasets to the sampling frequency for GLS of two locations per day.

We grouped data for each species into 148 breeding populations determined according to jurisdiction, the distance between colonies, and overlap in at-sea distributions based on the tracking data, i.e., if distributions overlapped substantially (at a 1 × 1° scale) and colonies are in close geographical proximity and in the same country, we considered colonies to belong to the same population.

Density of tracked petrel locations

For each population, we pooled all locations for all individuals across all years by month, and then removed months with fewer than five locations. For each month, we reprojected tracked locations onto a Lambert azimuthal equal area projection centred around the geometric mean of all locations. We estimated kernel densities of tracked locations to compute a 95% UD, a common home-range metric, which, because the sampling frequency was standardised, represented the estimated time spent by all tracked petrels in that population within that month. We used the adehabitatHR R package[60], using a cell size of 10 km^2 and a smoothing factor of 200 km (based on the magnitude of error in estimating locations from GLS[33]). We trimmed all cells that fell over land (Natural Earth land 1:10 m polygons version 5.1.1 downloaded from www.naturalearthdata.com/) because these species do not forage in terrestrial environments and it is extremely rare for them to travel over land, so any locations are most likely due to device error[33]. We then reprojected the resulting rasters back to a latitude and longitude projection (WGS84).

Of the 148 tracked populations, 108 (61 species) were tracked both in the breeding and non-breeding seasons. For these populations, we collated published information on the timing of breeding at a monthly scale (Supplementary Data 4) for each species or, where possible, each population. We also labelled months as breeding or non-

breeding based on the tracking data. Locations were not always available for all months, with March and September often excluded from GLS datasets due to the uncertainty in light-based geolocation around equinoxes. We first calculated the distance between each location at sea and the breeding colony. For each population, we calculated the mean distance from the colony for each month, and a mean of those monthly means. If the mean for a month was greater than the population-specific mean across all months or if no individuals travelled within 200 km (chosen due to the approximate 200 km error common when using GLS devices) of the colony, this month was classified as non-breeding. To ensure there was only one breeding and one non-breeding season, if the classification of one month differed from the previous and following months, it was reclassified. We used published values except in cases when a month was labelled as breeding, but the tracking data showed that the subset of tracked birds did not attend the colony during that month, in which case, we used the label identified by the distance-to-colony method. Breeding and non-breeding months, therefore, do not necessarily represent the general phenology of the species, but instead reflect the behaviour (distance from the colony) of the majority of tracked individuals in that month. A sensitivity analysis showed that plastic exposure risk scores calculated using published breeding schedules were highly correlated with those estimated using the tracking data, Kendall's tau = 0.98 ($z = 13.879$, $p < 0.001$) for the breeding season, and tau = 0.97 ($z = 10.810$, $p < 0.001$) for the non-breeding season.

Plastic density distribution

We used estimated global marine plastic density (count per km^2) in 1 × 1° grid cells, from publicly available outputs from three published Lagrangian particle tracking models (Maximenko[34], Lebreton[9], and van Sebille[6]). The model estimates combined floating micro and macroplastics from ~0.333 mm to 40 cm, with different size classes having similar estimated distributions[7]. Although petrels can ingest plastic flexible plastic pieces 40–60 cm long, they generally consume smaller pieces[61]. The three models estimated plastic density using records from ~12,000 surface trawls. They provided particularly good spatial coverage in the northeast Pacific, northwest Atlantic and Australian waters, but particularly poor coverage at the poles, the waters around Southeast Asia, the northwest Indian Ocean, and the South Pacific[6]. The models simulate the movement of plastic particles through multiple years and then create a static probability grid for a single time point (2014) based on where particles spent most time up until 2014 (equivalent to a utilisation distribution). We do not expect interannual variation in plastic distribution to be substantial in comparison to the spatial scale of between-season seabird movement because plastics travel passively, take decades to break down, and have been released throughout the study period. Each model uses the trawl data along with weather conditions, ocean circulation models, and plastic sources and sinks to inform the movement of plastic particles and predict the number of particles in each sampled and unsampled 1 × 1° grid cell. The Maximenko model assumes particles can wash ashore and originate from a uniform input across the ocean surface[34], the van Sebille model assumes no sinks for plastic and plastics originate at the coast[6], and the Lebreton model assumes no sinks for plastic and plastics are sourced from river mouths[9]. None of the models incorporate sinking through the water column[52], ingestion by marine organisms[1], or fragmentation processes. For each ocean basin and model, a prediction value was compared to observed plastic counts, providing regression coefficients used to scale the model plastics distribution and predict plastic concentrations within all cells[6]. Each model represents observed ocean plastic concentrations well[6], with observations generally falling within 1–2 orders of magnitude around the model estimate. Further details on the methods used to model plastic density, including on how regression coefficients were used and validated, are provided in Maximenko et al.[34], Lebreton et al.[9], and van Sebille et al.[6]. Despite the variation in sampling effort, the model outputs generally agree with subsequent surveys in the Mediterranean[62], southeast Pacific[63] and southeast Asia[50].

We took the geometric mean (as opposed to the arithmetic mean) of the Maximenko[34], Lebreton[9], and van Sebille[6] models to avoid bias in our plastic density layer toward the highest estimate from any individual model because the models have log scale variability between their estimates. Additionally, because the ocean is in constant flux, concentrations at any given location are constantly changing[53], assuming a lognormal distribution of concentrations through time, the geometric mean will be a better estimate of the central tendency and closer to the median concentration than the arithmetic mean[64]. The model outputs varied in spatial coverage in coastal and polar regions (Supplementary Fig. 4), and when one of the models did not have an estimate within a cell, we used the geometric mean of the other models, or the estimate from the only available model. If there was no estimate from any model, this was marked as NA, which occurred mostly in the Arctic and the Antarctic, and in some coastal areas where the marine area was less than the 1 × 1° grid size. The model outputs were centred around 180°E. Values in cells at 0–1°W were incorrectly estimated so these were imputed from the mean values in the three adjacent cells east and west (177–180°E and 1–4°W).

Plastic exposure risk scores

We aggregated the monthly 10 × 10 km petrel 95% UDs for each population[33] onto the same 1 × 1° global grid of the plastic density data. All petrel UDs and the plastic density grid were divided by the respective cumulative sum for each grid so that the values of each entire raster grid summed to one. We estimated exposure risk as the mathematical product of the petrel and the plastic values in each grid cell[14]. This gives equal weight to the number of plastic pieces in each cell and the density estimate for bird tracking locations in each cell. We assume that estimated density of bird tracking locations at equal time intervals is strongly related to the time spent at risk of exposure to plastic debris, because areas where seabirds spend more time are very likely to be where foraging is concentrated[65], as a result of area-restricted searching behaviour[66–68]. We then summed all cell values and multiplied all scores by 1,000,000 to reduce the number of decimal places to produce a single score for that month (ranging from 0.0007 to 1091). For comparison, we calculated a theoretical score of 15.3, which represents what the exposure risk score would be for any species if all global grid cells contained the mean plastic density (i.e., assuming that plastic was evenly distributed across the world's oceans). We combined monthly grids to produce grids for each population, breeding or non-breeding season (if data were available for non-breeding months) and species. Scores for each population are the mean of all tracked months, and scores for each season are the mean of all months in that season (Supplementary Data 5). We used the mean to allow comparison between species with different numbers of tracked months. Maps for most populations are in Supplementary Fig. 5. For the 33 species for which we had multiple tracked populations, we searched for published population estimates (Supplementary Data 6). We calculated species-level scores as the mean of scores for each population weighted by the population size and multiplied by 0.5 if the population was only tracked during the breeding season (Supplementary Data 7).

We tested how robust our results were in relation to population size estimates, sampling frequency and tracking year. Population estimates for some species have large uncertainty, so we tested the correlation between species-level scores calculated with and without weighting by population size using Kendall's tau because scores are not normally distributed. They were highly correlated (tau = 0.83; $T = 483$, $p < 0.001$), so our results are unlikely to be affected by uncertainty in population size estimates.

To investigate possible effects of sampling frequency, we reprocessed the tracking data without subsampling all datasets to 12-hourly intervals. We identified 44 populations for which all data were derived from GPS or PTT devices. For each track, we calculated the median interval between successive locations and recorded the maximum median for each population, and if this was less than 6 h, we regularised tracking locations at that frequency (intervals ranging from 1 min to 5 h, median = 1 h, mean = 82 min). We performed kernel density estimation with the higher-frequency datasets using a smaller 50 km smoothing factor[33] for the remaining 39 populations and used them to calculate exposure risk scores for each population. The scores estimated using the higher and lower resolution data were highly correlated (tau = 0.90, $T = 703$, $p < 0.001$), so we conclude that 12-hour sampling intervals and 200 km smoothing parameter are sufficient for a study of this scale.

Birds were tracked between 1995 and 2020 with a mean tracking year of 2012. Among the 148 populations, 139 (94%) were tracked within 5 years of 2014 (2009–2019), the year for which plastic density was estimated. Given petrels are long-lived and generally faithful to breeding sites[69] and foraging areas during both breeding and non-breeding seasons[70–73], we assumed that distributions were unlikely to vary substantially across the study period. Data on long-term trends in plastic ingestion by seabirds have not shown substantial increases during the study period[27,74,75]. A subset of 13 populations had been tracked with geolocators for the same set of months across more than three years (Supplementary Fig. 2). For these, we calculated an exposure risk score for each year and then tested the effect of population and year using a generalised linear model with a Gamma distribution (due to positive continuous right-skewed response variable). We checked model fit by simulating residuals using the DHARMa R package[76].

We recorded the most recent IUCN Red List assessment threat category[77], where 36 species were Least Concern (LC), 9 Near Threatened (NT), 16 Vulnerable (VU), 10 Endangered (EN) and 6 Critically Endangered (CR). Red List status categories from the year each species was first tracked remained the same for 71 of the 77 species, and we used the most recent assessment for the 6 species for which changes have occurred. Three were genuine changes relating to altered threats or conservation action (Westland petrel *Procellaria westlandica* from VU in 2016 to EN in 2017; Chatham petrel from CR in 2008 to EN in 2009 to VU in 2015; yelkouan shearwater from LC in 2004 to NT in 2008 to VU in 2012), while three were not genuine changes because they related to improved evidence for assessment (flesh-footed shearwater from LC in 2012 to NT in 2016; streaked shearwater from LC in 2012 to NT in 2015; spectacled petrel from CR in 2005 to VU in 2007)[77,78]. We calculated the proportion of the total of all exposure risk scores attributed to species in each threat category.

Spatial patterns in plastic exposure risk

We used the ranked species scores to identify global-scale high - exposure risk areas by recording the region in which each species had the highest scores. We created an all-species map by summing results for each species, with those tracked in both breeding and non-breeding seasons given a weight of 1, while the 16 species that were tracked only in the breeding season were given a weight of 0.5 to avoid undue bias towards breeding colonies. We also divided the all-species distribution grid by the cumulative sum so that all values sum to one and multiplied this by the plastic density grid to produce an exposure risk map. We then overlapped this all-species map with EEZs and the high seas, obtained as an open-source polygon layer[79]. Because national jurisdictions in the Mediterranean are not yet clearly defined or are subject to dispute, we used theoretical EEZs, which are defined as 200 nautical miles from the coastline or the median point between two coastlines unless treaties and agreements have been submitted to the UN[80]. We calculated the proportion of the global risk of exposure to plastic for all petrels in each EEZ/theoretical EEZ and in the high seas. For joint regimes and overlapping claims, the score was divided evenly between the involved sovereigns. To record the links between the breeding country and the jurisdictions of plastic exposure risk, we calculated the proportion of plastic exposure risk for each population by country in each EEZ/theoretical EEZ and in the high seas[11] (Supplementary Data 1).

Spatial coverage and research priorities

To assess spatial coverage and identify research priorities for tracked species, we compared the distribution of the tracking data for each species with the estimated range maps[77]. We assessed whether major populations (>1% of the global population or 200 pairs) of each tracked petrel species were missing from any of 10 major ocean areas (NW/NE/SW/SE Atlantic, NW/NE/SW/SE Pacific, Indian or Southern Oceans) according to the SeaVoX Salt and Fresh Water Body Gazetteer (https://www.marineregions.org/). Our tracking data covered all ocean regions within the published estimated ranges of 54 of the 77 species considered (70%). Our data compilation also revealed the main gaps in coverage for the remaining 23 species (Supplementary Table 2).

To identify research priorities for high exposure risk areas identified in this study, we used range maps to identify species or populations for which tracking data were not included in this study, but range maps indicated they may overlap (Supplementary Table 3). We recorded ingestion frequency of occurrence as the percentage of individuals found to contain plastic and the number examined as reported in Kühn & van Franeker[1]. We also carried out this process for areas for which plastic density is high and range maps showed that petrel species may use these areas, but no tracking data were available for our study (Supplementary Table 4).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The plastic exposure risk data generated in this study and the plastic density data used in this study are provided in the Supplementary Data files, available at https://github.com/BirdLifeInternational/petrels-plastics and have been deposited in the Zenodo database at https://doi.org/10.5281/zenodo.7852143. The seabird tracking data are available under restricted access because the data were collected for other purposes that vary between datasets and revealing the exact locations of sensitive species may put them at risk. Access can be obtained by making a request to the owners of each dataset using the mechanisms provided by each database. Zoatrack (https://zoatrack.org/) dataset IDs: 57, 93, 102–112, 159, 253, 254, 762, 817. Movebank (https://www.movebank.org/) dataset IDs: 944960474, 200628745, 241140274. SEATRACK (https://seapop.no/en/seatrack/) for relevant northern fulmar data. U.S. Geological Survey data release: https://doi.org/10.5066/P9NTEXM6. Seabird Tracking Database (https://www.seabirdtracking.org/) dataset IDs: 434, 438, 439, 448, 466, 467, 506–511, 517, 518, 554, 555, 561, 571, 607, 609, 610, 627, 628, 634, 635, 637, 639, 658, 659, 662, 663, 667, 668, 670, 672–678, 683, 684, 686, 694–696, 704–706, 708–715, 736, 741, 783–786, 788, 789, 826, 827, 829–831, 836–842, 844, 854, 858–872, 879, 883–886, 888–893, 900, 945, 946, 949, 951–954, 959–963, 966, 967, 970–983, 986–998, 1004, 1028, 1029, 1031–1033, 1055–1061, 1081, 1083, 1084, 1086–1091, 1120, 1121, 1140–1142, 1233–1236, 1238, 1239, 1258, 1259, 1279, 1280, 1282, 1285–1289, 1298, 1314, 1317, 1326, 1343–1347, 1360–1362, 1375, 1386, 1401, 1404, 1409, 1410, 1413–1415, 1422–1425, 1440, 1443, 1449, 1452, 1453, 1460, 1461, 1463, 1481, 1482, 1485–1488, 1494, 1497–1500, 1520–1523, 1541, 1544, 1546, 1549–1551, 1553–1558, 1562–1570, 1574–1577, 1579–1582, 1585–1592, 1594–1600, 1602, 1603, 1606–1608, 1610, 1618, 1619, 1621–1625, 1630, 1665, 1668–1672, 1690, 1711–1717, 1738, 1908–1923,

2036–2038, 2042, 2044–2046–2049, 2051–2056, 2059, 2060, 2063–2066. Source data are provided with this paper.

Code availability

R code used to produce the analysis can be accessed at https://github.com/BirdLifeInternational/petrels-plastics with the version on the date of publication archived at https://zenodo.org/record/8033861[54].

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Competing interests

The authors declare no competing interests.

Additional information

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