ALBATROSS AND PETREL INTERACTIONS WITH AN ARTISANAL SQUID FISHERY IN SOUTHERN PERU DURING EL NIÑO, 2015–2017

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ABSTRACT

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We report on the occurrence of albatrosses (Diomedeidae) and petrels (Procellariidae) associated with an artisanal small-scale fishery (SSF) for Humboldt Squid *Dosidicus gigas* in waters of southern Peru during El Niño 2015–2016 and coastal El Niño 2017. We deployed as observers on a number of fishing trips to assess seabird interactions. White-chinned Petrels *Procellaria aequinoctialis* and Waved Albatross *Phoebastria irroata* were the most abundant species observed, followed by Salvin's *Thalassarche salvini* and Chatham *T. eremita* albatross, and Cape Petrels *Daption capense*. The majority of procellariid species (> 60% of total birds) visited while vessels were positioned over the continental slope. Salvin's and Chatham albatross, and White-chinned Petrels, were mostly absent during summer (only 5% and 15% of birds present, respectively), but Waved Albatross and Cape Petrels were present year-round. Thus, the prevalence of each of these species was disproportionate relative to expectation based on non-fishery surveys. All assessed species foraged on offal discards associated with the fishery (~17%), with a higher frequency of consumption among Salvin's (27%) and Chatham (21%) albatross; in contrast, Waved Albatross largely fed on pelagic fish at the surface. Bycatch rate was found to be low; one Chatham Albatross was hooked and released in a hand-held squid jig (0.042 By Catch Per Unit Effort [BPUE] per fishing trip, n = 16). Probably due to El Niño conditions, Waved Albatross were more abundant than expected (43.9% of albatross, and 2.8% of total seabirds observed) and were 1 300–1 400 km farther south than their usual southern limits. We report the first sighting of Southern Royal Albatross *Diomedea epomophora* in Peru. Bycatch in longline fisheries are a conservation concern, but the magnitude and constant growth of SSFs, especially for Humboldt Squid, needs to be further investigated.

Key words: El Niño, fishery interactions, Humboldt squid fishery, New Zealand albatrosses, offal discards, Waved Albatross

INTRODUCTION

The Humboldt Current along the west coast of South America, an upwelling driven eastern boundary current, is one of the most productive stretches of ocean on Earth, sustaining immense fisheries (Glantz & Thompson 1981). It has long been recognized as a seabird hotspot including both resident and wintering components of its avifauna (e.g., Murphy 1936), although it has recently seen major reductions in resident species' populations owing to massive industrial fishing for anchoveta *Engraulis ringens*, and thus depletion of a major forage species (Pauly & Tsukayama 1987). In recent times, the composition of the avifauna has been quantified through extensive surveys on oceanographic research vessels (e.g., Spear *et al*. 2003, Spear & Ainley 2008), and a number of migratory albatross and petrels have been recorded. For example, there are records of Salvin's *Thalassarche salvini*, Buller's *T. bulleri*, and Chatham *T. eremita* albatrosses from New Zealand (Spear *et al*. 2003, Spear & Ainley 2008, Deppe 2012, Quiñones *et al*. 2021a); the Black-browed Albatross *T. melanophris* (Robertson *et al*. 2014, Quiñones *et al*. 2021b) from Diego Ramirez Island, south of Chile; and the Cape Petrel *Daption capense*, White-chinned Petrel *Procellaria aequinoctialis*, and the Northern Giant Petrel *Macronectes halli* from the sub-Antarctic (Shirihai 2008, Van Den Hoff 2011, Thiers *et al*. 2014, Quiñones *et al*. 2021c). From the north, there are records of the Waved Albatross *Phoebastria irroriata* in Peruvian waters from Isla Española, Galápagos Islands (Anderson *et al.* 2008).

In waters off southern Peru, and further along the South American coast, the high productivity is generated by a complex interaction between the northward flowing cold Humboldt Current and the poleward Peruvian Chilean counter current (Chaigneau *et al.* 2013). Intense upwelling between Pisco (~14°S) and Atico (~16°S), Peru, occurs during spring-summer, driven by alongshore winds, bringing cold waters to the surface (Bakun & Mendelssohn 1989, Hill *et al.* 1998). Besides high densities of seabirds and marine mammals, high concentrations of another mesopredator, the Humboldt Squid *Dosidicus gigas,* are also present, mainly along the outer edge of upwelling areas.

While the purse seine fishery for anchoveta has had major indirect impacts by removal of seabird prey (e.g., Duffy 1983, Duffy *et al.* 1984, Pauly & Tsukayama 1987), industrial longliners have had a direct, negative impact on albatross and petrels owing to extensive bycatch (Tuck *et al*. 2001, Rolland *et al*. 2008). Small-scale fisheries (SSF) also exist but have been poorly quantified. A few surveys, through interviews with fisherman, have been carried out in Peruvian waters on the interaction of albatrosses and petrels with SSF (Jahncke *et al*. 2001, Mangel *et al*. 2012, Ayala *et al*. 2008, 2010). Intentional captures of the Waved Albatross have also been reported for human consumption by the longline SSF of Salaverry (08°S) (Alfaro-Shigueto *et al*. 2016).

Herein, we report the composition of seabird species associated with an artisanal SSF targeting Humboldt Squid in southern Peru by participating in fishing trips on squid vessels, and compare it to previous assessments of seabird composition carried out prior to the establishment of the SSF. We were aware that the fishery might negatively impact albatross numbers, given that the Waved and Chatham albatrosses are protected by Peruvian Law Nº 034-2004-AG administered by the Environmental Ministry. Due to the scale of the Humboldt Squid fishery, a potential negative impact on these threatened birds could be a significant issue. We aimed to provide inputs for management measures to reinforce the effective conservation of these protected species.

MATERIAL AND METHODS

Peruvian artisanal, small-scale Humboldt Squid fishery

This fishery is the second-most important fishery in Peru, after the industrial purse seine fishery targeting anchoveta (Paredes & de la Puente 2014, Csirke *et al*. 2018). The artisanal Humboldt Squid fishery represents 18.8% (n = 2 828 boats) of the entire SSF in Peru. It employs hand-line jigs at both sides of the vessel and operates in pelagic waters. Dimensions of the wooden boats average 8.9 m (range 2.3–20.4 m), with a hold capacity of 8.6 m^3; 86.7% of the boats have < 10 m^3 capacity (Paredes & de la Puente 2014). During the period 2001–2012, the majority (76%) of the fleet operated in the Piura region (04°–06°30′S); a second fleet (22%) operated in the southern region (15°45′S–18°S) (Sueiro & de la Puente 2013). Considering the 1999–2017 period, the total Peruvian catch reached 558 995 tons (in 2008), of which 95.4% (533 000 tons) were caught by the local artisanal fleet; in 2014, the entire take of 556 156 tons was caught by the local artisanal fleet (Csirke *et al*. 2018). This fishery product is exported and also used for local consumption.

Data collection

The Peruvian Marine Research Institute (IMARPE) conducted an onboard observer program of this fishery from October 2015 until April 2017, mainly in Lomas (15°34′S, 74°51′W), Atico (16°13′S, 73°36′W), La Planchada (16°24′S, 73°13′W), Caleta de Quilca (16°42′S, 72°26′W), and Matarani (17°S,72°06′W) harbors. Upon arrival at the fishing grounds, the observers opportunistically assessed the interactions of albatrosses and petrels during the manual retrieval of the squid jigs. Birds were sighted by naked eye or with the aid of 10 × 50 binoculars from sunrise to 09h00 and from 16h00 until sunset, i.e., the fishery operated in the crepuscular hours. Birds were counted by fixed points (Ralph *et al*. 1995) from the starboard side in a radius of 100 m within a quadrant of 180°. Counts lasted 10 min interrupted by 10-min breaks. Relative abundance was determined by the total number of individuals sighted of a given species; no birds were counted more than once.

For each sighting, we observed behavior as follows: (1) flying, birds traveling not engaged with foraging activity; (2) resting on the water; (3) feeding on pelagic waters, meaning feeding naturally at the sea surface; and (4) feeding on offal discards. In addition, we registered birds that were hooked with the squid jigs. To differentiate albatross and petrel species, we used the field guides of Shirihai (2008) and Howell & Zufelt (2019).

Data analysis

Habitat was defined using the bathymetry data from GEBCO platform (https://www.gebco.net/). For this, we use a raster of bathymetry, interpolated using the ArcToolBox with our sightings geographical position in WGS84 system coordinates. General Linear Models (GML) were used to test the differences between the types of behavior and habitat on the five most commonly observed species. Maps were made with ArcGIS using the base map tools for ocean bathymetry (Institutional License No. 358632). A seasonal analysis was carried out by means of the relative abundances: summer (January–March); autumn (April–June); winter (July–September); spring (October–December). The habitat of sightings was classified as follows: coastal waters (0–15 m); continental shelf (15–200 m), continental slope (201–4 500 m), Peru-Chile trench (> 4 500 m), and Abyssal plain (offshore, beyond the Peru-Chile trench). As a proxy of the El Niño Southern Oscillation (ENSO), the Peruvian Oscillation Index (POI) was employed (for details of the index, see Quiñones *et al*. 2010).

RESULTS

A total of 170 h of observations were completed in 16 fishing trips, encompassing 35 d of observation; the mean duration of fishing trips was 2.68 ± 1 d (range: 1–5 d; Table 1). The fishing activity was done in periods of low light using lamps to attract the squid. When the squid appeared, the squid jigs were thrown (depending on the number of operators) with or without bait (fish, squid) and, once squid were hooked, they were manually pulled to the boat (De Lucio *et al*. 2013).

TABLE 1
Habitat use of albatrosses and petrels: continental slope, Peru trench, and abyssal plain in waters off southern Peru

Year	Month	No. fishing trips	No. of seabirds	No. of albatross and petrels	POI[a]
2015	October	3	215	15	4.31 (*)
2015	November	1	76	3	3.60 (*)
2015	December	1	86	1	3.18 (*)
2016	January	1	49	1	2.99 (*)
2016	February	1	81	5	2.45 (*)
2016	June	1	147	16	0.89
2016	July	1	49	7	1.53 (*)
2016	August	1	104	9	1.94 (*)
2016	September	1	62	12	1.71 (*)
2016	October	0.5	18	5	0.70
2016	November	0.5	132	2	0.80
2016	December	1	41	1	1.01 (*)
2017	February	1.5	261	6	2.66 (*)
2017	March	0.5	29	0	3.06 (*)
2017	April	1	149	15	(*)

[a] Peruvian Oscillation Index (POI), as a proxy of El Niño Southern Oscillation (ENSO), with an asterisk indicating a positive (> 1.0) El Niño (Purca 2015).

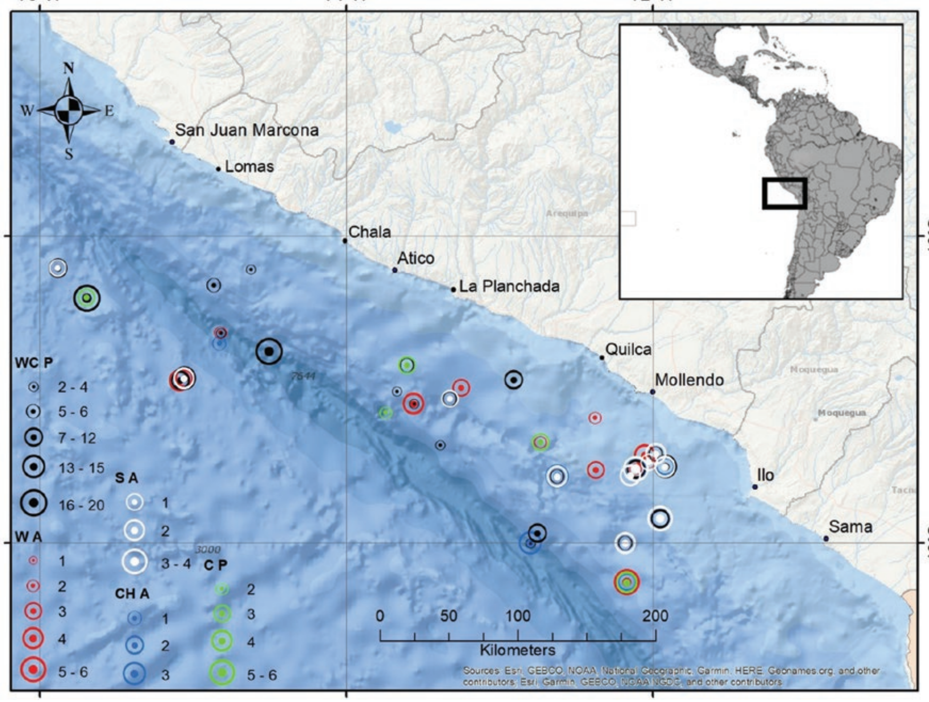

Fig. 1. Map of the study area in southern Peru (October 2015–April 2017), showing the sightings of the five most abundant species: White-chinned Petrel *Procellaria aequinoctialis* (WC P) in black; Waved Albatross *Phoebastria irroata* (WA) in red; Salvin's Albatross *Thalassarche salvini* (SA) in white; Chatham Albatross *T. eremita* (CH A) in blue; and Cape Petrel *Daption capense* (CP) in green.

A total of 300 birds of 11 species were sighted. The White-chinned Petrel was most numerous (*n* = 181, 60.3%), followed by Waved Albatross (*n* = 43 birds, 14.3%), Salvin's Albatross (*n* = 22. 7.3%), Cape Petrel (*n* = 21, (7%), and Chatham Albatross (*n* =19, 6.3%; Fig. 1). Other species were recorded in lower numbers (Table 2). The five main species (> 60% of individuals) (GML, *P* = 0.409) were encountered in waters of the continental slope: for Salvin's and Chatham albatross, 86% and 68% of individuals, respectively; for Cape Petrels, 76%; and for Black-browed Albatross (*n* = 5) and Northern Giant Petrels (*n* = 4), the figure was > 75%. Few birds were found over waters of the Peru–Chile Trench and Abyssal plain (Fig. 1, Table 2). The same habitat was exhibited by Buller's Albatross (*n* = 2), Southern Royal Albatross *Diomedea epomophora* (*n* = 1), Southern Giant Petrel *Macronectes giganteus* (n = 1), and Grey-headed Albatross *T. chrysostoma* (*n* = 1) (Fig. 1); all exhibited similar behavior (Fig. 3). A large percentage (~17%) foraged on offal discards, especially when in waters over the continental slope (Table 2). The Royal Albatross was sighted on 22 August 2016, at 17°34′S, 72°37′W, 84 km offshore Matarani.

The New Zealand albatrosses (Salvin's and Chatham albatrosses) were almost absent (5%) during summer, with over 40% occurring in autumn. In winter, Chatham and Salvin's albatross numbers represented > 50% and > 30% of sightings, respectively. In spring, Salvin's Albatross numbers represented > 20% of sightings and Chatham Albatross were absent. Waved Albatross were present year-round (> 20%), reaching 35% during spring. Cape Petrels were present year-round, with > 20% of sightings in each season. White-chinned Petrels were present in low numbers in summer (15%), around 25% in autumn and winter, and 35% in spring (Fig. 2). The behaviors were quite similar among the five main species (GLM, *P* = 0.069, r^2 = 68.5%). The behavior most often sighted was foraging on offal discards (Fig. 3). The Waved Albatross was the only species seen feeding on small pelagic fish at the surface.

One Chatham Albatross was hooked by a squid jig, which represented 0.042 BPUE per fishing trip (*n* = 16), and was released.

DISCUSSION

During extensive at-sea research vessel surveys of the Humboldt Current during 1980–1995, Spear & Ainley (2008, p. 127; hereafter A&S) documented the following general composition of the marine avifauna: "…93 species of seabirds, composed of 18 endemics (species that breed only in the study area, 20%), 10 residents (breed in the study area and elsewhere, 11%), 41 southern hemisphere migrants (breed outside of the study area, 45%), 18 northern hemisphere migrants (18%), and 6 migrants (7%) that breed in both hemispheres." Comparing the composition of the species in that larger-scale study offers some insight into the relative attractiveness of the squid boats, especially during El Niño when feeding opportunities are greatly altered (e.g., Murphy 1936, Pauly & Tsukayma 1987).

White-chinned Petrels were the second-most important procellarid during summer and the fifth-most important procellarid during winter in A&S; we found them mainly during autumn, winter, and spring over the continental slope (Fig. 1). For our study area, A&S reported that Salvin's Albatross was the 12th-most abundant procellarid during winter and the Chatham Albatross was too rare to be ranked. We found a seasonal pattern for both albatross species similar to that of White-chinned Petrels, showing their higher abundance in autumn-winter (Fig. 2). The abundance of these three

TABLE 2
Habitat use of albatrosses and petrels: mean depth (m, with sample size of surveys) and the number of birds recorded[a]

Habitat	Continental slope		Peru–Chile trench		Abyssal plain	
Species	**Depth (*n*, surveys)**	**Birds, *n* (%)**	**Depth (*n*, surveys)**	**Birds, *n* (%)**	**Depth (*n*, surveys)**	**Birds, *n* (%)**
White-chinned Petrel *Procellaria aequinoctialis*	2909 (15)	101 (56)	6206 (3)	27 (15)	4340 (4)	53 (29)
Waved Albatross *Phoebastria irrorata*	2083 (9)	28 (65)	5920 (2)	4 (9)	4340 (4)	11 (26)
Salvin's Albatross *Thalassarche salvini*	1735 (9)	19 (86)	-	-	4352 (2)	3 (14)
Cape Petrel *Daption capense*	2433 (4)	16 (76)	5739 (1)	2 (10)	4166 (1)	3 (14)
Chatham Albatross *Thalassarche eremita*	2096 (6)	13 (68)	6154 (2)	4 (21)	4489 (1)	2 (11)
Black-browed Albatross *Thalassarche melanophrys*	2906 (2)	4 (80)	6088 (1)	1 (20)	-	-
Northern Giant Petrel *Macronectes halli*	1745 (2)	3 (75)	6296 (1)	1 (25)	-	-
Buller's Albatross *Thalassarche bulleri*	2154 (2)	2 (100)	-	-	-	-
Southern Royal Albatross *Diomedea epomophora*	2565 (1)	1 (100)	-	-	-	-
Southern Giant Petrel *Macronectes giganteus*	1143 (1)	1 (100)	-	-	-	-
Grey-headed Albatross *Thalassarche chrysostoma*	3185 (1)	1 (100)	-	-	-	-

[a] Shown for each habitat is mean depth (m) and the number of cruises (*n*, surveys), number of birds and percentage (%) in Southern Peru, from October 2015 to April 2017. No birds were registered in the Continental shelf.

species was very low during summer because they frequent their breeding grounds in New Zealand during this period (Robertson & Van Tets 1982, Bell *et al.* 2017, Rexer-Huber 2017); presence during summer probably involved juveniles and sub-adults that could remain in southern Peru year-round. For instance, Salvin's juveniles were seen in large numbers in southern Peru during spring 2019 (Quiñones *et al*. 2021a)

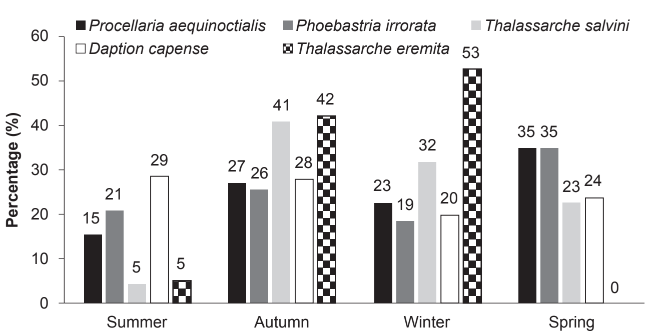

Fig. 2. Seasonal occurrence histograms (summer, autumn, winter, spring) of the five main species of seabirds (White-chinned Petrels *Procellaria aequinoctialis,* Waved Albatross *Phoebastria irroata,* Salvin's Albatross *Thalassarche salvini*, Chatham Albatross *T. eremita*, and Cape Petrels *Daption capense*) observed in Southern Peru, expressed as percentages.

The great majority of our sightings (59%) of albatrosses and petrels that had come from New Zealand (Salvin's; Chatham; Buller's; Royal's Albatrosses, White-chinned and Northern Giant Petrels) occurred in the winter-spring seasons, with lower numbers of sightings in autumn (Fig. 2). These high

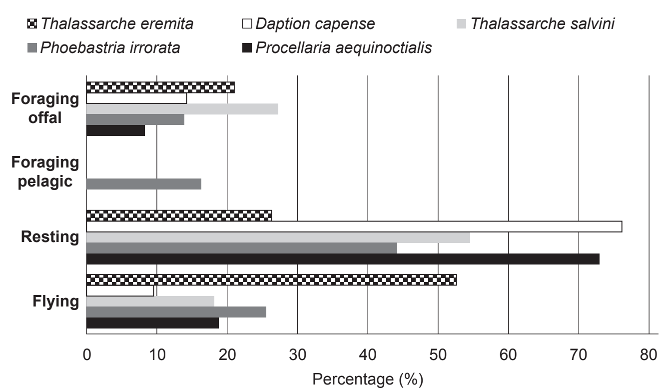

Fig. 3. Behavior histograms (flying, resting, foraging pelagic, and foraging offal) of the five main species of seabirds (White-chinned Petrels *Procellaria aequinoctialis,* Waved Albatross *Phoebastria irroata,* Salvin's Albatross *Thalassarche salvini*, Chatham Albatross *T. eremita*, and Cape Petrels *Daption capense*) observed in southern Peru, expressed as percentages.

incidences of sightings coincided with the timing of strong westerly winds in the South Pacific (Nakamura & Shimpo 2004). The long westerly migrations of albatross and petrels were likely related to the seasonally predictable prevailing westerly winds that dominate the South Pacific between 30°S and 60°S (Weimerskirch *et al*. 2000).

For birds migrating or dispersing from polar waters, the Cape Petrel occurred in moderate numbers, in accord with A&S, with Cape Petrels recorded as the least abundant procellarid and present only in winter. However, in our study, the species was present year-round, mainly over the continental slope (Fig. 1). In fact, during their wintering period, Cape Petrels disperse as far as the Galápagos in the eastern South Pacific (Wiedenfeld 2006). Conversely, during late spring-summer, our sightings of this species were lower, in accord with their breeding season much farther south (Weidinger 1998). It is possible that we detected Cape Petrels year-round during El Niño, because during such climatic events they are less prevalent and exhibit lower reproductive success at their southern breeding areas (Orjeira *et al*. 2013).

The Waved Albatross occurred in significant numbers throughout the study area and was the most sighted (43.9% of albatross observed) species in the 16°S–18°S area (Fig. 1). This contrasts with satellite tracking of adults from their two main breeding grounds in Galápagos. For example, the median-most southerly latitude values for birds breeding in Punta Ceballos (PC) was 7.18°S (range 1.38°S–12.77°S), and for Waved Albatross breeding in Punta Suarez (PS) was 7.98°S (range = 3.18°S–9.07°S) (Awkerman *et al.* 2014).

In the present study, Waved Albatrosses were reported at a mean latitude of 17.3°S, or 1300–1400 km further south of their usual southern limits. The species does sometimes reach Chilean waters, although there are only 13 records of such occurrences over a 33-yr period (1980–2013) (Suazo *et al.* 2017). In this study, in a short period of only 19 mo (October 2015–April 2017), we encountered

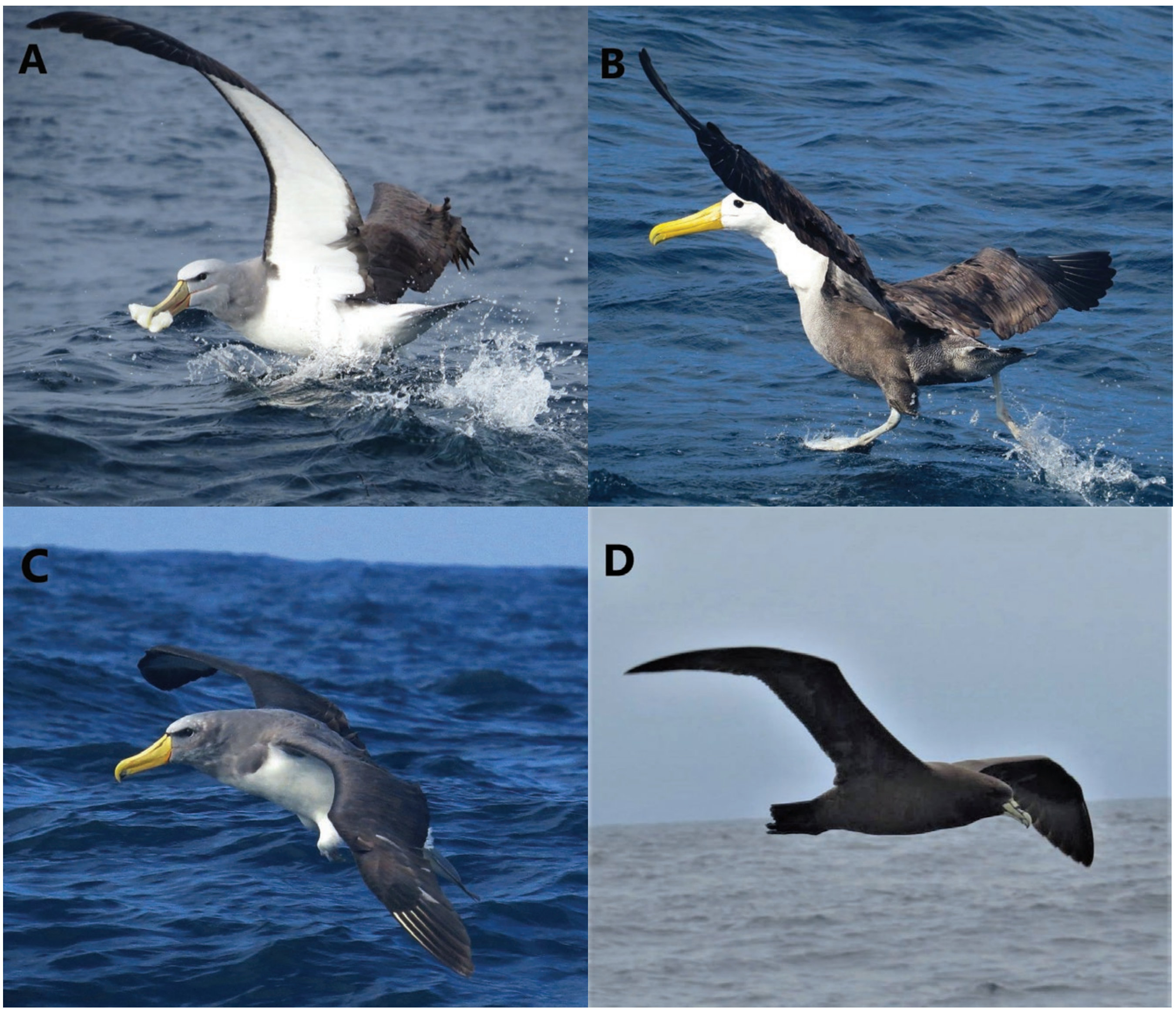

Fig. 4. Photographs of the main albatross and petrel species interacting with a Humboldt Squid artisanal fishery in southern Peru. (A) Salvin's Albatross *Thalassarche salvini*; (B) Waved Albatross *Phoebastria irroata*; (C) Chatham Albatross *T. eremita*; and (D) White-chinned Petrel *Procellaria aequinoctialis*. All photos were taken by Cristian Moreno.

43 individuals. It seems likely that the El Niño 2015–2017 and the coastal El Niño 2017 account for these increased sightings (Table 1). If El Niño reduced food availability to seabirds in the Humboldt Current (certainly shown to be the case; see above), the albatross likely dispersed more widely than is typical for this species. During the strong El Niño 1998, this species was registered as far as 30.3°S off central Chile (Mackiernan *et al*. 2001). Reduced food availability, and perhaps reduced breeding prevalence in the Galápagos, also explains why this species was present year-round in all seasons in this study, with no clear seasonal pattern (Fig. 2). This is contrary to the pattern in S&A, who also found this species to be the most sighted albatross, but with greater abundance in winter compared to summer. Note, though, that S&A participated in cruises that covered the entire Humboldt Current.

The great majority of the birds were observed resting on the water in the vicinity of the squid boats, probably waiting for offal discards, especially the Cape Petrel and White-chinned Petrel. The Cape Petrels regularly congregate in large flocks around fishing vessels, likely attracted to the fish oil scent (Birdlife International 2018). White-chinned Petrels also attend vessels in waters off the central and southern Chilean coast, e.g., 220 individuals were caught in the longline fishery targeting hake *Merluccius gayi* (Richard & Adasme 2019). A few Waved Albatross were observed feeding where there was a constant presence of Panama Lightfish *Vincinguerria lucetia* and juvenile Jack Mackerel *Trachurus picturatus murphyi* (IMARPE unpublished information).

The presence of a Royal Albatross in southern Peru constitutes the most northern report for this species in the eastern South Pacific. Unfortunately, we could not determine sub-species. However, this record represents a considerable northward extension with respect to their regular latitudinal ranges in southern and central Chile (Nicholls *et al*. 1994, Moore *et al*. 2005). S&A encountered Royal Albatross only in the southern portion of their Humboldt Current study region.

Previous quantifications of seabird-fisheries interactions in the Southern Hemisphere have concentrated on industrial longline fisheries (Abraham *et al.* 2019). There is spatial overlap between the oceanic distribution of albatross and petrel species, including those that we observed in the area (see S&A), with the longline SSF targeting Blue Sharks *Prionace glauca* and Shortfin Mako Sharks *Isurus oxyrhynchus*, with both of these artisanal fisheries being quite common in oceanic waters of southern Peru during autumn–spring (Adams *et al.* 2016, Csirke *et al*. 2018). The present study has identified the albatross and petrel species that interact with the Humboldt Squid SSF in southern Peru. In this scenario, and due to the magnitude and constant growth of this Humboldt Squid fishery (Csirke 2018), it is important to continue monitoring its impacts on seabird populations.

Regarding SSF, only preliminary bycatch evaluations have been carried out in Peru, and only on purse seine, longline, and gillnet fisheries, despite the large size of the Humboldt Squid SSF. For instance, there was a 350% increase in artisanal longliners in Peru from 1995 to 2005 (Alfaro-Shigueto *et al*. 2010). The potential for negative impacts on albatross and petrels may be high, and would be added to the impacts of direct take by intentional hunting, such as for the "critically endangered" Waved albatross in Peru (Alfaro-Shigueto *et al.* 2016). This study was the first to assess the possible impacts and interactions of the Humboldt Squid fishery on these threatened birds and identifies the seabird species that could be affected by the SSF.

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DECLARATIONS

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Conflicts of interest/Competing interests: This research has no conflicts or competing interests.

Ethics approval: Humboldt Squid sampling *Dosidicus gigas* followed the recommendations from Moltschaniwskyj *et al.* 2007. Albatrosses and petrels were only sighted and not sampled.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and material: The data set used in this study will be archived at the Instituto del Mar del Peru (IMARPE) digital repository.

Code availability: Not applicable.

Authors' contributions: JQ and CM designed the study. CM carried out the onboard sampling. JQ wrote the manuscript. Both authors have read and approved the manuscript.

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