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Use of Social Information in Seabirds: Compass Rafts Indicate the Heading of Food Patches

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Abstract

Ward and Zahavi suggested in 1973 that colonies could serve as information centres, through a transfer of information on the location of food resources between unrelated individuals (Information Centre Hypothesis). Using GPS tracking and observations on group movements, we studied the search strategy and information transfer in two of the most colonial seabirds, Guanay cormorants (*Phalacrocorax bougainvillii*) and Peruvian boobies (*Sula variegata*). Both species breed together and feed on the same prey. They do return to the same feeding zone from one trip to the next indicating high unpredictability in the location of food resources. We found that the Guanay cormorants use social information to select their bearing when departing the colony. They form a raft at the sea surface whose position is continuously adjusted to the bearing of the largest returning columns of cormorants. As such, the raft serves as a compass signal that gives an indication on the location of the food patches. Conversely, Peruvian boobies rely mainly on personal information based on memory to take heading at departure. They search for food patches solitarily or in small groups through network foraging by detecting the white plumage of congeners visible at long distance. Our results show that information transfer does occur and we propose a new mechanism of information transfer based on the use of rafts off colonies. The use of rafts for information transfer may be common in central place foraging colonial seabirds that exploit short lasting and/or unpredictably distributed food patches. Over the past decades Guanay cormorants have declined ten times whereas Peruvian boobies have remained relatively stable. We suggest that the decline of the cormorants could be related to reduced social information opportunities and that social behaviour and search strategies have the potential to play an important role in the population dynamics of colonial animals.

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Introduction

Anim[redacted]l li ing o ga he ing in g[redacted] p a ce ain pe iod of hei [redacted]fe can[redacted] e pe onal info ma ion ob ained [redacted]om en i onmen al [redacted] e and ocial info ma ion f om he beha i[redacted] of congene o make deci ion [1,2]. The bala[redacted]nce be een pe onal and ocial in[redacted] ma ion in deci ion making[redacted] e i likel o eflec he op imal ad[redacted] men o[redacted] e[redacted]loi he mo [redacted]eliable info ma ion. Toda e idence i ac[redacted] m[redacted] la ing ha he[redacted] e of[redacted] ocial [redacted]info ma[redacted]ion i [redacted]common in na[redacted] e [3,4] ha he la ge g[redacted] p h[redacted] ld fa[redacted] he [redacted] e of ocial info ma ion and imp o[redacted] e he abili o make co ec deci ion compa [redacted]d i h malle [redacted]g[redacted] p [5].

The igh of [redacted] nd ed of h[redacted] and o million of eabi d ga he ing oge he[redacted] in o a[redacted] ingle col[redacted]n ha al a fa cina ed ob e [redacted] , and im[redacted] la ed q[redacted] e ion ab[redacted] he in e e of o man indi i[redacted] al concen a ing a he ame place. Apa f om a [redacted]ca e [redacted]h[redacted]e con ain on acce ibili o ne i e o food e[redacted] ce oc[redacted] , colonie a[redacted]e con ide ed a an efficien a eg o limi p eda ion [6], [redacted] he e a e man ela ed co (di ea e , ec opa a i e infec ion, compe i ion fo food o ne ing i e [7]. Befo e he concep[redacted] of ocial info ma ion a de eloped [4], Wa d and Zaha i [8] [redacted] gge ed ha colonie ma e e a a i e of info ma ion e change ab[redacted] he loca ion of [redacted]food, al o kno n a he info [redacted]ma ion cen e h po he i (ICH[redacted] Bec[redacted] e ea bi d el on food e[redacted] ce ha a e pa chil di i[redacted] ed, i h loca ion b[redacted]ing highl a iable in [redacted]ace and ime [6,9[redacted]], b eeding in colonie c[redacted] ld p[redacted] ide he oppo[redacted] ni [redacted] o indi i[redacted] al o ob ain info ma ion ab[redacted] he loca ion of fa[redacted] able foo[redacted] pa che b a ching he beha i[redacted] [redacted]f o he indi i[redacted] al hen[redacted] e[redacted] ning f om, o lea ing fo feeding g[redacted] nd . The empi i[redacted]al [redacted] die ha ha e e ed hi h po he i came o mi ed conc[redacted] ion (ee e [redacted]e in Richne[redacted] and Heeb (1995) [10]). Ho e e , mo [redacted]mpi ical [redacted] die ha e fo[redacted] ed [redacted]n he[redacted] demon a ion ha indi i[redacted] al [redacted]ollo f om he colon [redacted] cce [redacted] l fo age hea[redacted]ling o feeding g[redacted] nd , he ea info ma-ion e change ma o[redacted] [redacted] [redacted]ide h[redacted] colon [redacted]nd be ba ed on he ob e a ion of he e[redacted] ning [redacted] cce [redacted] l indi i[redacted] al [11,12].

Se e al al e na i e h po he e , ela ed o he ICH, ha e [redacted]een p opo ed [redacted] e plain he[redacted]ad an age of b eeding in la ge g[redacted] p , ba ed on [redacted] el i[redacted]di i[redacted] al elec ion. The local enhancemen h po he i [13,14] [redacted] gge ha he inc ea e in den i of bi d [redacted]fo aging f om a col[redacted]n imp o e he p obabili [redacted] of di co e ing [redacted] np edic abl di i[redacted] ed food pa c[redacted]e . The ec[redacted] i men cen e [redacted] po h[redacted] i [10,15] p edic ha comm[redacted] nal feeding i impo an[redacted] fo [redacted] cce [redacted] l fo aging a feeding pa che , he efo e bi d ec[redacted] i congene a colonie . O he i e indi i al ma impl e pe onal info ma ion ba ed on pa fo aging e pe ience and memo [16] o e n o fo aging g nd . Thi a eg i ela i el common hen eabi d ea ch fo e ce pa iall agg ega ed in a p edic able a [9].

Mo e ecen modelling die ha e gge ed ha he diffe en h po he e ela ed o ICH a e p obabl no e i e, and ld be on ide ed in a common f ame o k [17], and ha eabi d ma e a mi e of ea ching a egie [18]. The efo e he ma e ocial info ma ion a ell a pe onal info ma ion o a o ma i i e food b gh o he off p ing and minimi e ime pen comm ing and ea ching [19,20]. Ho e e , he e i a need fo mo e mpi ical die , in pa i la ho e ba ed on he d of i di i al beh i f om he colo o food pa he . The e die a e diffi l o nde ak in na al condi ion , i h he ad ance in eleme minia i a i n ha e opened p ne me hod o empi icall add e he e e ion [21].

ana co mo an and Pe ian boobie a e he main ano o ce b eeding along he Pe ian coa . The concen a e in ge colonie ha hi o icall ld g p nd ed of ha and of indi i a in a ingle colon , ep e en ing one of he o ld' mo pec a la agg ega ion of eab d [22]. The el mainl on Pe ian ancho ([23,24] ha ha ained, n il ec n l , he o ld la ge ingle- pecie fi he [25]. The black p maged co mo an , ne in e mel den e colonie and a e ocial fo age fo ming endle co nn mo ing f om colonie o feeding g nd he ea he hi e p maged boobie b eed in la ge, le den e colonie [22,26]. O e he pa 50 ea , ana co mo an ha e d ama icall dec ea ed f om c.21 million bi d a i ical anal e e e pe fo med[redacted] ing he [redacted]Package *circular* e ion 0.3-8 (Co ela ion Coefficien fo Ang la Va iable , Wa on o ample Te of Unifo mi) in R.

Results

When ea ing chick [redacted] ano bi d a e pical cen al place fo age , making fo aging ip f om he ne o [redacted]a ch fo food a [redacted] ea. When one pa en fo age [redacted] ea, he pa ne [redacted] a d he chick [redacted] n il i i elie ed b [redacted]e [redacted] ning membe of h[redacted] pai . Bo h pecie fo aged ic l [redacted] ing he da ime. Indi i[redacted] al acking ho ha bo h boo[redacted]ie and[redacted] co mo an [redacted] e o di inc i e mo [redacted]men . The bo h[redacted] e 'Re[redacted] n T ip ', lea ing he colon o a pa i[redacted] a bea ing ha i kep[redacted] n il he each[redacted] feeding one[redacted]and [redacted]hen e[redacted] n aigh o he colon , making he [redacted] a d and e[redacted] n [redacted] e pa allel, i h an angle $<10°$ (Fig. 1). The al o bo h[redacted] e 'Looping T ip ' he eb bi d cha[redacted]ge di ec ion e e al ime befo e feeding (o no) and hen[redacted] e[redacted] n o[redacted]he colon f om a bea ing diffe en f om ha aken [redacted] ing he [redacted] a d pha e, i h an angle $>10°$ (Fig. 1). Feeding [redacted]one a e clea l i ible, a indica ed b ci cling o e a pa i[redacted] la e ic [redacted]d a ea, di[redacted]ing ac i el , i ing on he a e [redacted]and aking of[redacted] in [redacted] cce i e ba (Fig. 1). Feeding one e e f[redacted] nd in all Re[redacted] n ip e cep one and in 81.19% of Looping ip ($\chi^2_1 = $[redacted].3, P = 0.0211) indica ing [redacted]ha in mo ip bi d[redacted] ha [redacted]e enco[redacted] n[redacted]ed a p e pa ch. [redacted] he mo e, all bi d cap[redacted] ed [redacted] af e e[redacted] ning f om he ea e[redacted] gi a ed fi he [redacted]ancho[redacted]ie mainl) co[redacted]nfi ming ha mo bi d e[redacted] n onl af[redacted] a[redacted] cce [redacted] l fi hing. Re[redacted] n T ip ep e en 62% of ip fo G[redacted] ana co mo an and onl 39.8% fo boobie ($\chi^2_1 = 5.8$, P = 0.0163). The [redacted] a ion of fo aging ip a longe fo [redacted]co mo an han fo boobie (Mi ed ANOVA, 2.0±0.8 h e [redacted] .1.2±0.5 h $F_{1,39} = 32.9$, [redacted]P<0.001) and a longe [redacted]o Looping T ip han fo Re[redacted] n T ip ([redacted].3±0.8 h e [redacted] 1.7±0.6 h fo co m[redacted]an and 1.4±0.6 h e [redacted] 0.9±0.3 h fo boobie). The ma i[redacted] m ange [redacted] a imila fo he o pecie (20.2±11.5 km fo bo[redacted]bie e [redacted] 18.9±6.1 fo co mo an , $F_{1,[redacted]9} = 0.5$, P = 0.480), [redacted] [redacted]Looping T ip had longe ange han Re[redacted] n T ip (21.1±9.7 e [redacted] 16.6±5.8, $F_{1,39} = 10.4$, P = 0.004). In bo h pecie , feeding one e e ne e a he ame loca ion f om one ip o he ne[redacted] e cep in one ca e fo each pecie , i h [redacted]ong di ance be een [redacted] cce i e feeding one (di ance be een [redacted] cce i e feeding one = 19.9±11 km fo co mo an and 16.9±12.2 fo boobie $F_{1,29} = 0.5$, P = 0.461). The [redacted] a no diffe ence he[redacted]he e con ide di ance be een [redacted] cce i e fo aging one [redacted] ing he ame [redacted]a , o f om one da o he ne .

The bea ing [redacted]aken b indi i[redacted] al acked bi d depa i[redacted]g f om he colon o e[redacted] ning f om he feeding one o of g[redacted] [redacted] of bi d ob e ed e e mainl di ec ed o a d no h, e and [redacted] h, i h fe ip heading o he ea (Fig. 2), and do no diffe be e[redacted]n pecie (Wa on o ample e , U = 0.922, P = 0.187). Indi i[redacted] al bi d end o change[redacted]di ec ion f om one ip o he ne (Fig. 1). Fo GPS acked G[redacted] ana [redacted]o mo an , he e i no co ela ion be een he b[redacted]a ing hen e[redacted] ning o he i land and he bea ing of[redacted] he ne [redacted] a d ip (Table 1) confi ming ha bi d do no e[redacted] n o he ame feeding one f om one ip o he ne . Fo boobie he e i a [redacted]endenc fo bi d o [redacted]ke he ame di ec i[redacted]n han ha of he e[redacted] n p[redacted] of he p e i[redacted] ip, onl hen [redacted] cce i e ip e e ca ied [redacted] he ame da (Table 1).

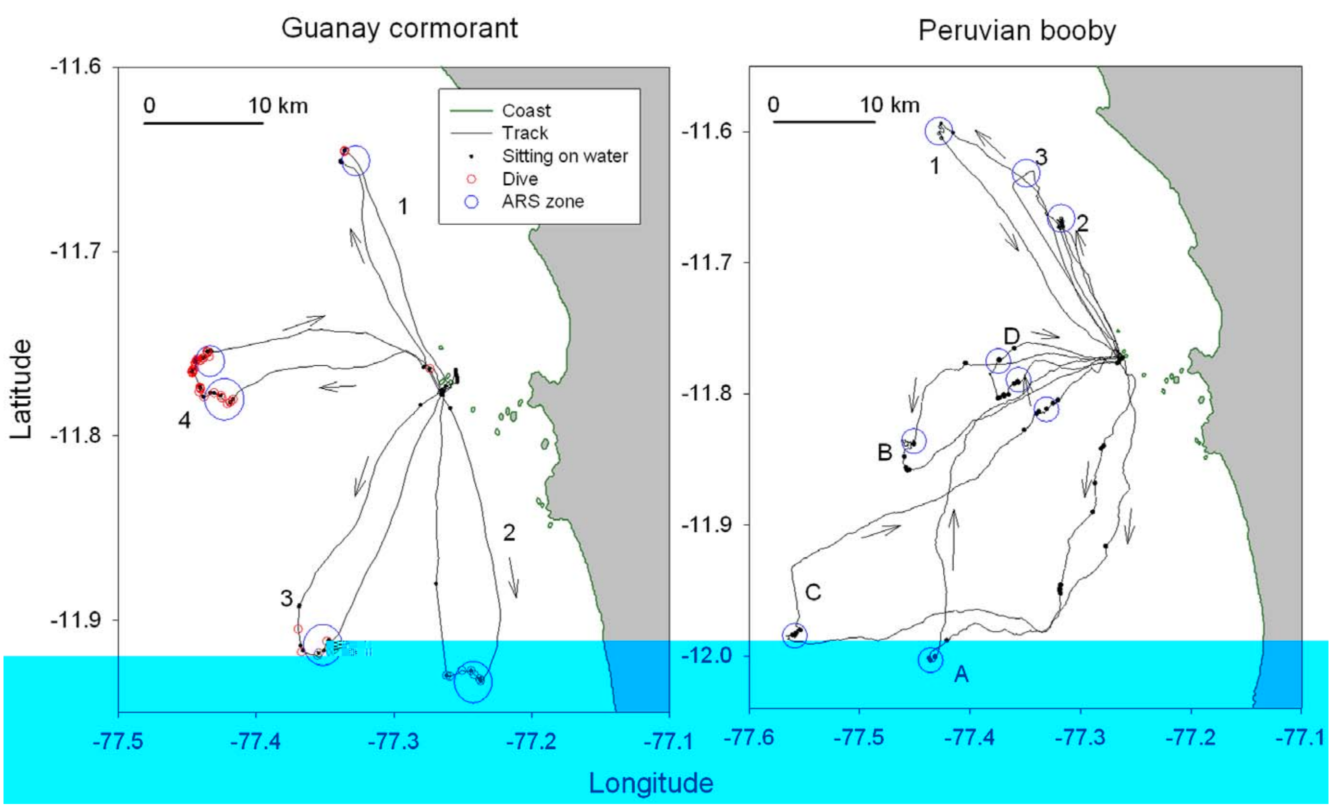

Figure 1. Foraging trips of Guanay cormorants (left) and Peruvian boobies (right) tracked with GPS. Left: four successive return trips of a Guanay cormorant (1–4). Right: three successive return trips of a Peruvian booby (1–3) and four successive tracks (A–D) of a second individual Peruvian booby (looping course A and C, return trip B and D). Arrows indicate the flight direction; dots indicate sitting on the water, small red circles the deep diving events, blue circles zones of area restricted search (ARS).
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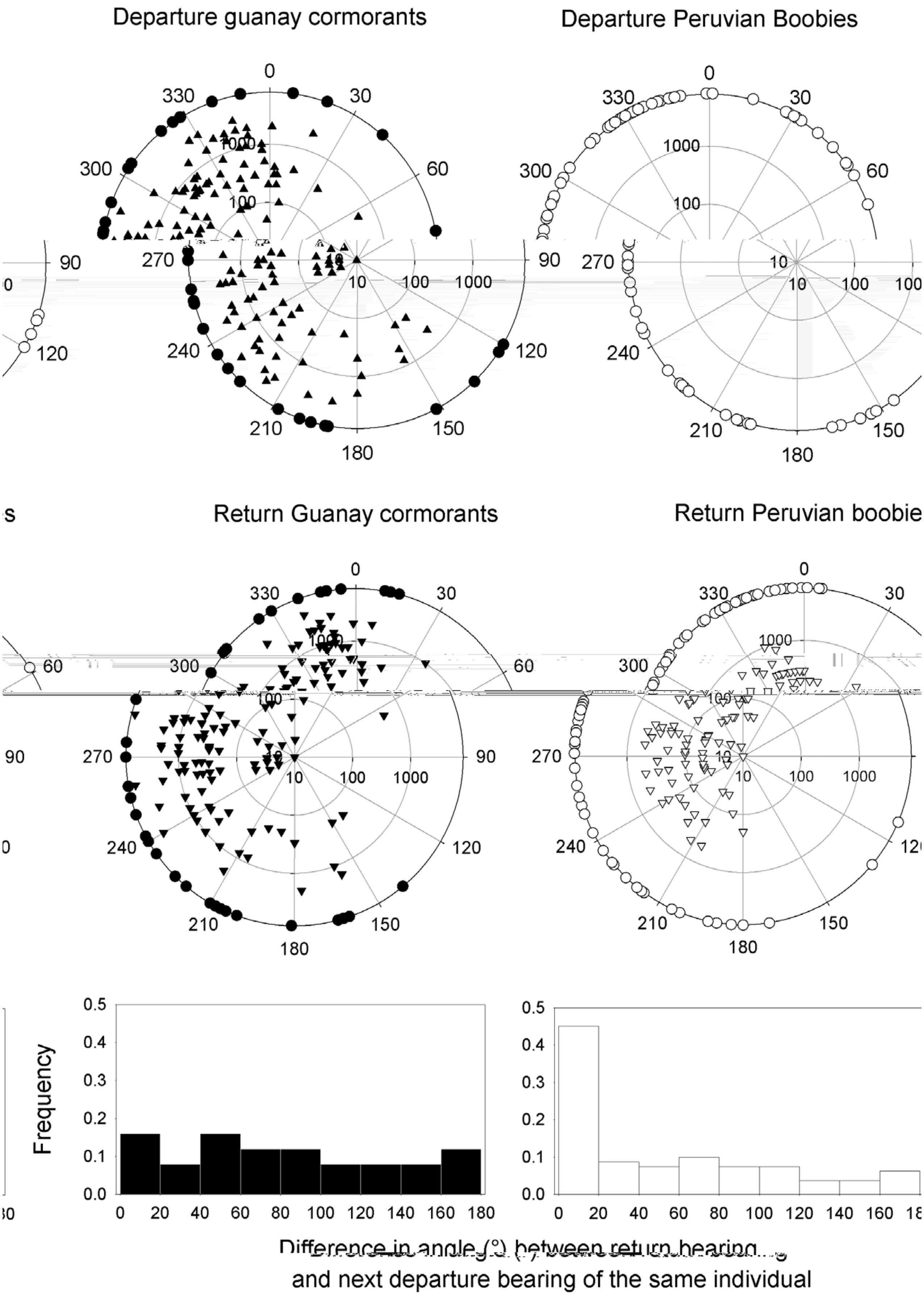

Departure guanay cormorants
Departure Peruvian Boobies
Return Guanay cormorants
Return Peruvian boobie
Frequency
Difference in angle (°) between return bearing
and next departure bearing of the same individual

Figure 2. Bearings taken by groups according to the centre of the island and difference in angle between the return bearing and the departure bearing of Guanay cormorants and Peruvian boobies. Upper four figures: Bearing (in°) taken by groups according to the centre of the island and size of groups (from 10 to 10,000) of Guanay cormorants (black) and Peruvian boobies (white) leaving the island (▲) and returning to the island (▼). The circles indicate the bearings at departure and when returning taken by individuals tracked with GPS. Lower two figures: difference in angle between the return bearing and the departure bearing during the next foraging trip of individuals tracked with GPS.
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Indi id al acking of G ana co mo an ho ha af e depa ing he colon , bi d ci cle he i land and hen land on a e 300 m-2 km off he i land fo a fe econd befo e heading fo a pa i la di ec ion (Fig. 3a). Thi e eo ped beha io ha been ob e ed in all acked bi d . Ob e a ion f om he an age poin confi m ha bi d ci cled a o nd he i land in mall g o p , and hen joined he af . A an ime hi af g o ped an a e age 305±163 indi id al on he a e (ange 50-1000). Rema kabl he e a onl a ingle af a o nd he i land a once, b o e ime i po i ion con in o l changed (Fig. 4). The af fo med one- o ho af e n i e, emained p e en h o gh he da and a ed ani hing 1-2 h befo e n e hen no mo e bi d e e lea ing (Fig. 4). Since bi d a e con in o l landing, haking ing and aking off, he af can be een f om a long di ance f om he colon a a poin of foaming a e (Fig . 3, 5). Indi id al bi d on a ed in he af fo 5-30 econd and hen ook off in la ge g o p , q ing one af e he o he , all in he ame di ec ion, fo ming long col mn of cce i e g o p , eg la l nin e p-ed p o he ho i on. In e e ingl , depa ing g o p in col mn fle j abo e he ea face, he ea e ning g o p in col mn fle a an al i de of 10-30 m abo e ea face. The af a aligned i h he col mn of bi d e ning f om he ea, pecificall i h he la ge e ning g o p (Ci la Co ela ion coefficien , = 0.610, F = 4.6, P<0.001, Fig. 3). Raf ing off he colon a depa e doe no occ in Pe ian boobie : he depa ed oli a il o in mall g o p of a fe bi d , and e ned alone o in mall o medi m i ed g o p (Fig. 2), of en incl ded in he la ge fo ma ion of G ana co mo an . The bea ing of he la ge g o p of co mo an and boobie e e ongl co ela ed (Ci la Co ela ion, = 0.981, F = 6.6, P<0.001).

Discussion

The fi , and mo impo an , e l of hi d indica e clea l ha Info ma ion T an fe does occ in a colonial eabi d h o gh a pecific ignalling beha io , b fo ming a compa af . The nc ion of hi af appea o be a ignal ha i ell i ible f om he colon o f om bi d ha a e ci cling in fligh he i land (Fig. 3b), poin ing he heading o be aken o bi d lea ing he colon . B ing hi compa af , G ana co mo an el en i el on he info ma ion ob ained f om e ning congene . The efo e he af pla he ole of a ignal o he congene [15]. I i ema kable o no e ha an G ana co mo an lea ing he colon join he compa af befo e heading fo feeding g o nd . j befo e landing and f om he af he a e p obabl able o de ec he bea ing of he incoming col mn ha a high in he k . Th G ana co mo an e ocial info ma ion made a ailable f om he la ge col mn e ning f om a di an p e pa ch. Thi i po ible onl beca e he majo i of he e ning bi d ha e been cce f l in a p e pa ch ha he ha e eached ei he di ec l b a Re n T ip, o af e a longe ime ea ching h o gh a Looping T ip. B a oon a he ha e had fo nd a food pa ch, he e ned in a aigh line o he colon making he heading of he e ning col mn a eliable ocial info ma-ion. The ocial info ma ion i an fe ed h o gh he compa af and pda ed con in o l h o gh he alignmen of he compa af o he e ning la ge col mn (i.e. p obabl he mo cce f l g o p).

Af e a ending hei chick a he colon , bi d a e elie ed b hei pa ne and e n a ea, b joining fi he compa af . The efo e he a e able o e he mo ecen info ma ion a ailable f om congene e ning f om a fo aging pa ch. B compa i on if he had o el on hei o n memo of hei p e io ip, he info ma ion o ld be le pda ed, beca e of he ime pen a ending he chick. Thi ma che he heo of info ma ion cen e ha p edic ha he o a ion of a food pa ch ho ld allo a lea one e n ip [8]. Fo G ana co mo an , he ba ic condi ion eq i ed fo a colon o ope a e a an info ma ion cen e a e filled, i.e. food pa che a e epheme al a la a lea e e al ho . Colon membe can ea il de ec cce f l fo age , no di ec l f om he colon b f om he nea b compa af [7,8,10]. Thi fo aging a eg ha p obabl been elec ed fo he e ploi a ion of food e o ce ho e di ib ion and a ailabili acco ding o he cen al place colon ma change apidl o e ime. Th e cha ac e i ic appl o he main p e of g ano bi d , he Pe ian ancho , an e emel ab ndan epipelagic fi h, pa chil di ib ed in pace and in ime [32]. The loca ion of pa che a ailable fo g ano bi d p obabl changed con in o l a gge ed b he con in o change in fligh di ec ion f om one ip o he ne in he ca e of G ana co mo an , b i al o applie o boobie . When bi d follo ing col mn a i e on a p e pa ch ha ha been deple ed, he di pe e f om he e and ea ch fo ano he p e pa ch and hi p obabl e l in Looping T ip . Bi d e n o he colon f om

Table 1. Circular correlation coefficients between angles for Guanay cormorants and Peruvian boobies fitted with GPS.

	Foraging flight bearings	Guanay cormorant			Peruvian boobies		
Test for:							
		Coeff	**Stat**	**P**	**Coeff**	**Stat**	**P**
Parallelism	Departure trip 1 vs Return trip 1	0.90	4.8	<0.001	0.781	6.6	<0.001
Persistence	Departure trip 1 vs Departure trip 2	0.178	0.9	0.362	0.02	0.2	0.862
Predictability (all days combined)	Return trip 1 vs Next Departure trip 2	0.202	1.0	0.311	0.189	1.4	0.147
Predictability (same day only)	Return trip 1 vs Next Departure trip 2	0.296	1.1	0.265	0.305	2	0.052

doi:10.1371/journal.pone.0009928.t001

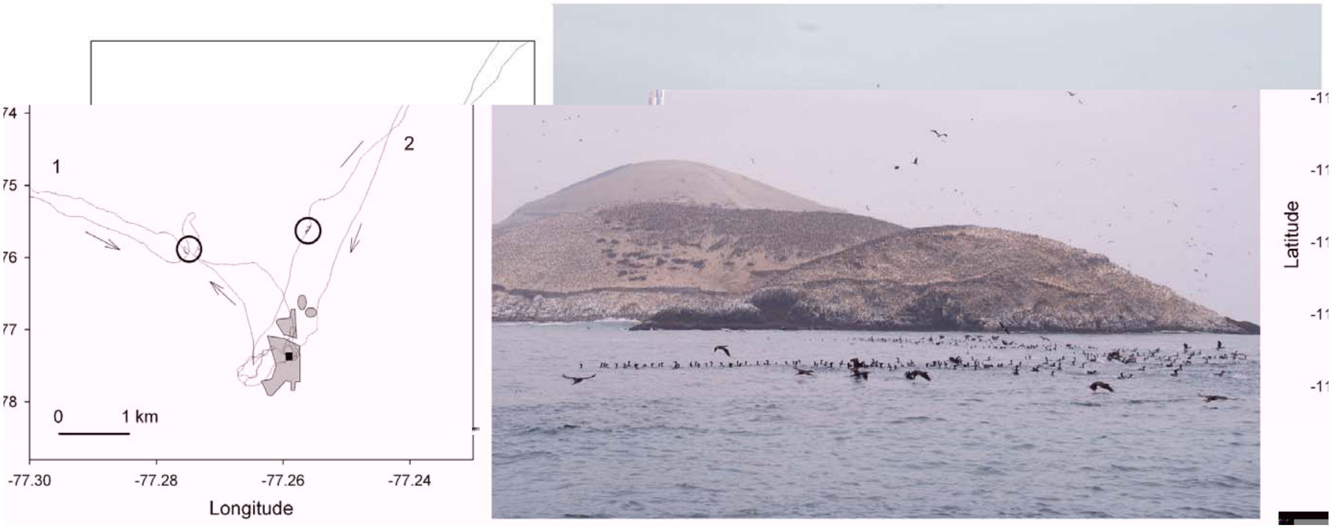

Figure 3. Movements of a Guanay cormorant in the vicinity of the colony and view from the sea of a compass raft. (Left) Fine scale movements of a Guanay cormorant tracked by GPS at 1 sec interval in the vicinity of Isla Pescadores (in grey). Two successive foraging trips (1 and 2) from the nest (black circle). The location of the compass raft visited after departure from the colony is indicated by a circle (circle) and the arrows indicate flight direction. (Right) Photograph taken from the sea of a compass raft, with the colonies of seabirds on Isla Pescadores in the back ground.
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hi ne pa ch, i.e. f om a diffe en bea ing, ha i de ec ed b he compa af hich h n change di ec ion o ad o he ne bea ing of inc ming c mn .

The beha i of c e ing b fo e heading o feeding g nd ac a a ec i men di pla no nlike o he comple ignalling pe fo med b Ra en o a ac congene [33]. In eabi d , he ignalling h gh af ing c ld ha e e ol ed f om he nece i fo bi d o d ink and a h hei p mage af e a hif a he colon nd ba ing o b ooding chick . In G ana co mo an hi nc ion i a he a ginal ince a mino i of he bi d joining he ompa af ac all ei he a he o d ink befo e aking off. The e of af fo info ma ion an fe p obabl oc i o he eabi d pecie . Indeed man pecie of colonial eabi d ch a alba o e , alcid o ganne fo m af off he colonie befo e

Figure 4. Changes in the bearings according to the centre of the island of the compass raft (circle) and of the departing (▲) and returning (▼) groups of Guanay cormorants during two consecutive days. In some cases, when opposing arrows overlay, they appear as a star.
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Figure 5. View from the summit of the island showing part of a large aggregation of nesting guano birds on Isla Pescadores, with compass raft at sea. The photograph shows part of the seabird aggregations dominated by Guanay cormorants (black plumage), with Peruvian boobies (white plumage) on the edge of the mains groups of cormorants.The black arrow indicates the location of the compass raft at sea.
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heading fo he ea, [redacted] he an fe of [redacted]nfo ma ion[redacted] h[redacted] gh af ha been o e looked o fa . In M[redacted] e [redacted] ge [12] [redacted] gge ed ha info ma ion an fe migh[redacted] no be pa ed in he colon i elf. He no ed ha 69% of he [redacted] coming bi[redacted]d pla hdo n f om he colon befo e heading o he ea and he [redacted] gge ed ha bi d i ing on he ocean in he icini of he colon migh be ell po i ioned o gain info ma ion on he loca ion of p e pa che [12,34]. Ob e a ion on[redacted]alba o e al o indica e ha befo e depa ing fo he ea, bi d g[redacted] p in a compa af off he colon b[redacted]fo e aking off in mall g[redacted] p , of en follo ing a leading indi i[redacted] al (H.W. pe . ob e a ion). Sea ching a egie ma al o be diffe en [redacted]hin he ame pecie acco ding o [redacted]he i e. Fo e ample in [redacted]m e , compa af a e p obabl [redacted] ed hen pa che[redacted] a e [redacted] np edic able [12] [redacted] memo and local enhancemen a e[redacted] ed hen p e loca ion i p edic able and eliable o e longe pe iod of ime [18]. Theo e icall h[redacted] coe i ence of diffe en ea ch a egie in he ame pe[redacted]e h[redacted] ld [redacted]eld o a able a eg [17].

A econd impo an e[redacted] l of hi [redacted] d ho ha o highl colonial pecie , b eeding on he ame i e and feeding on he ame p e , can ha [redacted] diffe en ea ching a egie . When lea ing he colon[redacted] , indi i[redacted] al of [redacted]ach pecie ba[redacted] hei deci ion o ake a pa i[redacted] la bea ing b [redacted] ing diffe en [redacted] e , ei he b a ching congene and he compa af , o b [redacted] ing memo i ed pe onal ob e a ion . The e i ence of o diffe en ea ch a egie i p[redacted]obabl ela ed o he a each[redacted] pecie e ploi p e pa che . [redacted] ana co mo an ha[redacted]e a da k p[redacted] mage ha ma[redacted]ke hem c[redacted]p ic a di ance and fo m co[redacted] mn o each feeding g[redacted] nd . [redacted]The [redacted] e [redacted]ocial [redacted]i hing ha e[redacted] i e fo aging [redacted]in imm[redacted]en e g[redacted] p fo [redacted] cce [redacted] l [redacted] n ing. The [redacted] e [redacted]n la ge [redacted] mbe [redacted] nde fi h hoal [redacted] dep h 10. 5[redacted] m (H.W.[redacted] np bli hed [35]) o d i e fi h o[redacted] he [redacted] face [26]. T[redacted] he el mainl [redacted]on ocial info ma ion and[redacted] e colonie a ec[redacted] i men cen e, ec[redacted] i ing congene h[redacted] gh he compa af . We did no find e idence of info ma ion an fe be een co[redacted] pecific in boobie hich [redacted]d no fo m a[redacted] off he colonie . Pe[redacted] ian boobie ha e a hi e p[redacted] mage, con pi[redacted] a a long di ance hen in fligh o p[redacted] nging, hich p obabl fa [redacted] local enh[redacted]ancemen [36,37]. The lea e colonie oli a il o in mall g[redacted] p and el [redacted] mainl on pe onal info ma ion hen making a deci ion a[redacted] heading. The onl [redacted]feed on p e [redacted]a ailable clo e o he [redacted] fac[redacted] (a e age 2 m, ma im[redacted] m 6 m H.W. [redacted] np bli hed da a) and can [redacted] n oli a il ([redacted]e . ob , [26]). While off[redacted]ho e he can cong ega[redacted] in la ge [redacted] mbe [redacted] h[redacted] gh he ec[redacted] i men of o he indi i[redacted] al ha [redacted] obabl [redacted] e ne o k fo aging [7,37]. The ob e a ion ha Pe[redacted] ian boobie end o head o [redacted] d he di ec[redacted] ion aken [redacted] hen he e[redacted] ned o he co[redacted]on e e al h[redacted] ea lie , [redacted] gge he[redacted] e of pe onal info ma ion [redacted] ch a a me[redacted]no ba ed ea ch a eg [31]. Ho e e , he almo ne e [redacted]e[redacted] n o he ame feeding i e f om one ip[redacted] o he ne , and[redacted] co[redacted] ld ake hi heading and ea ch a neighb[redacted] ing pa ch beca[redacted] e[redacted] he o iginal one i deple ed o no longe a ailable.

We f[redacted] nd no e idence ha info ma ion on di ec ion be[redacted] ing of food pa che ma be ob ained f om o he pecie a o a[redacted] nd he colonie . Since boobie le[redacted] e he colon oli a il i [redacted] a no po ible o e [redacted] h[redacted] he he[redacted] e he compa af o [redacted]he co[redacted] mn of co mo an , [redacted] a e[redacted] l ho ha boobie [redacted]e[redacted] n f[redacted]om he ame di ec i[redacted]n han co mo an , of en in mall g[redacted] p inc[redacted] ded in he la ge co[redacted] mn of co mo a[redacted] . Ho e e off ho e h[redacted] e a e e e al piece of e idenc[redacted] ha [redacted] gge ha ome pecie [redacted] ch a boobie join [redacted]eeding g[redacted] p of co mo an and ha p[redacted] nging boobie con i[redacted] e an a ac i e ignal fo e e al eabi d pecie [26].

[redacted]Hi o icall [redacted] ana co mo an [redacted] ed o be en ime mo e ab[redacted] ndan han Pe[redacted] ian boobie [redacted] no ada bo h pecie ha e imila po[redacted] la ion i e, [redacted] i h 2 millio[redacted] bi d of each pecie [27]. In [redacted] he ea l e[redacted] ie h cen[redacted] e e al [redacted] ho e e imp e ed b he [redacted] nb oken co[redacted] mn of [redacted] ana co mo an [redacted] heading f om he colon o he feeding g[redacted] nd [22]. The e[redacted] c ion of ancho ie o[redacted]k in he 1970 ha p obabl led o [redacted]he c a h of he co mo an po[redacted] la ion a[redacted] hi ime [27]. i ha con i[redacted] ed o decline e e ince, he ea Pe[redacted] ian boobie , ho feed on he ame p e , ha e emained able. The diffe en end gge a de e a ion of condi ion o he han food a ailabili fo co mo an no fo Pe ian boobie , af e he 1970 c h. The diffe en ea ch a egie and eliance on pe onal e ocial info ma ion ma be in ol ed in he diffe en end ob e ed. Indeed, if en i on-men al condi i n change, a ea ch a eg ma become le o imal and e l in pop la ion decline. The ea ch a eg of ana co mo an elie on ocial nfo ma ion, he e of compa af aligned o nb oken co mn e ning f om a feeding g nd and on l ge p e pa che . Thi a eg i p obabl le op imal if co mn a e no longe con in and p e pa che le al n an and ho la ing. The efo e malle i e pop la ion make e of ocial in o ma ion and d ci ion-mak ng le efficien [5]. Con e el Pe ian boob e c ld be le cep ible o change in al ndance of e eca e of hei oli a il ea ching beha i . The e e l nde ine he po en ial impo ance of ocial info ma ion fo he e o ion of life-hi o ie [1,38]) and fo p edic ing he e pon e of pop la ion o en i onmen al a iabili [39]. Thi i al o impo an o con ide in he con e of longe e m e o iona change ince o e he la 10 cen ie ancho ie , and p obabl hei eda o , e e m ch le al ndan han he a e no ada [40] gge ing he need fo a apid adap a ion o he e pec i e e of pe onal e ocial info ma ion.

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Author Contributions

Concei ed and de igned he e pe imen : HW. Pe fo med he e pe i-men : HW SB JS JCM. Anal ed he da a: HW. Con i ed eagen / ma e ial /anal i ool : HW JS EG. W o e he pape : HW SB.

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