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3 **GPS tracking devices reveal foraging strategies of Black-legged Kittiwakes**

4

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12

13 Black-legged Kittiwakes *Rissa tridactyla* are the most abundant gull species in
14 the world but some populations have declined in recent years, apparently due
15 to food shortage. Kittiwakes are surface feeders and thus can compensate for
16 low food availability only by increasing their foraging range and/or devoting
17 more time to foraging. The species is widely studied in many respects, but
18 long-distance foraging and the limitations of conventional radio telemetry
19 have kept this vital activity largely out of view. Development of GPS loggers
20 is advancing rapidly. With devices as small as 8 g now available it is possible
21 to use this technology for tracking relatively small species of oceanic birds
22 like kittiwakes. Here we present the first results of GPS telemetry applied to
23 Black-legged Kittiwakes in 2007 in the North Pacific. All but one individual

24 foraged in the neritic zone north of the island. Three birds performed foraging
25 trips only close to the colony (within 13 km), while six birds had foraging
26 ranges averaging about 40 km. The maximum foraging range was 59 and the
27 maximum distance traveled was 165 km. Maximum trip duration was 17 h
28 (mean: 8 h). An apparently bimodal distribution of foraging ranges affords
29 new insight on the variable foraging behaviour of Black-legged Kittiwakes.
30 Successful deployment of GPS loggers on kittiwakes holds much promise for
31 telemetry studies on many other species of similar size and encourages this
32 new approach for further studies.

33

34 Key words: Black-legged Kittiwake, *Rissa tridactyla*, foraging, Gulf of Alaska,
35 telemetry

36

37 Seabirds spend most of their time at sea and are difficult to observe when not
38 attending nests during breeding. Research is therefore biased toward land-based observations,
39 with the at-sea biology of smaller species generally limited to counts of travelling and
40 foraging birds from research vessels. Such studies are time- or area-restricted and unable to
41 give detailed insights into the foraging behaviour of individuals (Weimerskirch et al. 2005).
42 However, knowledge of foraging behaviour is essential to understanding both the ecological
43 roles of seabirds and constraints acting upon them in marine ecosystems (Monaghan 1996;
44 Wilson et al. 2002). The most productive and cost-effective way to study the flight and
45 foraging behaviour of birds at sea employs electronic devices attached to individuals (Daunt
46 et al. 2003; Garthe et al. 2007; Grémillet et al. 2004; Wilson et al. 2002). A variety of loggers

47 and techniques have been developed in the last 40 years (Grémillet et al. 2000; Hamer et al.
48 2007; Weimerskirch and Wilson 2000). The newest tracking devices to come on line are GPS
49 receivers, unlimited in range and capable of much higher resolution and accuracy than
50 satellite transmitters or conventional radio telemetry (Hulbert and French 2001; Hünerbein et
51 al. 2000). As with most new technologies, the first GPS data loggers were too heavy to deploy
52 on all but very large-bodied seabirds such as albatrosses (Diomedidae; (Waugh et al. 2005;
53 Weimerskirch et al. 2002) and gannets (Sulidae; (Grémillet et al. 2004). The latest equipment,
54 with package sizes in the range of 8-12 g, bring small and medium-sized seabirds (c. 300 g
55 and larger) into the scope of possible applications.

56 Black-legged Kittiwakes (*Rissa tridactyla*), widely distributed in north temperate to
57 arctic regions of the northern hemisphere, are the most abundant and one of the most
58 thoroughly studied gull species in the world (Hatch et al. 2009). Detailed knowledge of
59 foraging ecology is still lacking, however, as the species is highly pelagic, especially in
60 winter, and foraging activity is difficult to observe. Kittiwakes stay closer to the coast while
61 breeding, returning frequently to their nests to change incubation duties or deliver food to
62 their chicks (Daunt et al. 2002; Hatch et al. 2009; Suryan et al. 2000), but even then their
63 foraging trips often take them out of range of telemetry techniques that rely on fixed receiving
64 equipment (Camphuysen 2005; Wanless et al. 1992). Kittiwake body mass averages about 430
65 g (Pacific) or 390 g (Atlantic) (Hatch et al. 2009), thus telemetry devices exceeding 20 g (~ 5% of
66 their body weight) are not recommended (Caccamise and Hedin 1985; Calvo and Furness 1992;
67 Phillips et al. 2003).

68 Kittiwakes are regarded as useful indicators of marine environmental change in the
69 North Atlantic and North Pacific oceans (Frederiksen et al. 2007; Gill et al. 2002; Wanless et

70 al. 2007). Many colonies have declined in numbers and productivity in the last 20-30 years
71 (Daunt et al. 2002; Hatch et al. 2009), probably because of reduced availability of their
72 principal food — small, schooling fish such as sand lance *Ammodytes* spp., capelin *Mallotus*
73 *villosus*, and juvenile cods (Gadidae) (Frederiksen et al. 2008; Harris and Wanless 1990;
74 Hatch et al. 1993b; Suryan et al. 2006), which they capture by dipping or surface plunging
75 (Hatch et al. 2009; Hoyo et al. 1996). As obligate surface feeders, kittiwakes are affected by
76 changes in both the abundance and vertical distribution of their food (Furness and Tasker
77 2000; Hatch et al. 1993b). Breeding kittiwakes may compensate for food shortage by
78 spending more time foraging and/or ranging farther from the colony, although this could have
79 disadvantages like higher vulnerability to nest site competition and predation on eggs or
80 chicks.

81 Here we report on the first use of miniature GPS data loggers to characterize the
82 foraging behaviour of Black-legged Kittiwakes. The work was conducted during the breeding
83 season of 2007 at Middleton Island in the north-central Gulf of Alaska, where population
84 monitoring and studies of breeding ecology, behaviour, and physiology have occurred since
85 the mid 1970s (Gill et al. 2002; Hatch et al. 1993b; Hatch et al. 1993a; Roberts and Hatch
86 1993). Data on foraging trip durations from this colony are available from one prior study
87 (Roberts and Hatch 1993) that employed direct observations of nest attendance in 1988, when
88 the colony was much larger than at present. There is concern about the status and viability of
89 this colony, which has declined more than 90% — from 83,000 pairs to 6,200 pairs — over
90 the last 26 years (Hatch et al. 2009). Understanding the decline will require a thorough
91 understanding of the birds' foraging habits, both during and outside the breeding season.
92 Knowledge of their foraging habits could reveal possible food shortness caused for example

93 by competition with other seabird species, oceanographic anomalies, or fishing activities.

94

95 **Methods**

96

97 Middleton Island (59.4° N, 146.3° W) is close to the steep submarine terrain of the
98 continental slope (about 10-15 km south) and faces a broad expanse of unsheltered continental
99 shelf to the north (Fig. 1). Thus, both neritic and deep ocean habitats are readily available to
100 breeding kittiwakes.

101 Kittiwakes sampled in the study nested on a U.S. Air Force radar tower,
102 decommissioned and derelict since the 1960s, to which artificial nest sites have been added
103 for research purposes. The tower supported 910 nesting pairs in 2007, most using wooden
104 ledges viewable from inside the building through sliding panes of one-way mirror glass (Gill
105 and Hatch 2002). Birds were snared around the leg with a wire hook passed through a slot in
106 the wall beneath each window. Individuals chosen for logger deployment were actively
107 incubating or rearing chicks. Chick-rearing birds had one or two chicks aged 1-40 days. All
108 birds in the study were marked with a unique combination of steel and plastic colour bands
109 for individual recognition. Every nest was checked each morning for egg or chick status and
110 for the presence of adult birds.

111 Tracking devices were deployed between 1 July and 11 August 2007. We captured 14
112 adult kittiwakes and deployed GiPSy[®] data loggers (11 g; L 50 x W 22 x H 10 mm)
113 manufactured by TechnoSmart. The loggers were programmed to use a 5-min sampling
114 interval. GPS data stored in the device memory and used for the analysis included date, time,
115 latitude, longitude and speed. The devices were attached to feathers in the middle of the back

116 with TESA[®] tape (Wilson et al. 1997). Before deployment, each bird was weighed to the
117 nearest 5 g using a spring balance. The loggers were 2-3% of mean body mass (397 g, range
118 345-500 g). Mass was the only measurement taken upon first capture to minimize handling
119 time. Additional measurements (bill length, head-bill length, wing length) and banding were
120 taken upon recapture if data were not already available from previous studies. Measurements
121 were used to determine the sex of the birds (Jodice et al. 2000). Handling time (capture to
122 release) was approximately 10 min for deployment and 3-15 min for logger removal, banding,
123 and measurements as needed. In 28 captures and recaptures, 15 birds returned to their nest
124 within 15 min (5 of them immediately), 4 birds within 31 min, and 3 birds more than 1 h after
125 capture. Return time for 6 birds was undetermined due to a lack of nest observations. We
126 deployed 12 of the 14 loggers in the late afternoon or evening, which allowed us potentially to
127 capture information on nighttime foraging. We used 106 unmanipulated nests on the tower as
128 a control group to compare breeding success between equipped and non-equipped birds.

129 Flight paths were plotted in ArcView[®] 3.2 from the positional data obtained.
130 Maximum foraging range was defined as the most distant position in a straight line from the
131 colony. Distance travelled refers to the summed distances between positions from start to end
132 locations of each foraging trip. Elapsed time from start to end of a trip is trip duration. Start
133 and end of a trip were defined using GPS data. Trips started when a positional fix was 300 m
134 away from the colony and subsequent positions were progressively farther away. In
135 calculating mean velocity (ground speed), we used only flight speeds greater than 10 km h⁻¹,
136 excluding one outlier of 119 km h⁻¹. Speeds less than 10 km h⁻¹ were probably associated with
137 swimming or feeding (Weimerskirch et al. 2006).

138 Loggers were switched on at deployment — no delayed start was possible — and due

139 to battery depletion or occasional large gaps in data collection, not all foraging trips were well
140 documented from start to finish. In calculating the mean maximum range, mean distance to
141 colony and mean trip duration we included only complete trips, but estimated values are also
142 reported for individual trips that were incomplete. The missing portion of a track line was
143 extrapolated directly back to the colony, which underestimates the distance travelled by an
144 unknown, but probably modest amount. Extrapolated track lines were then used to correct the
145 trip duration of incomplete trips using a mean flight speed of 33 km/h (as measured in this
146 study; see below). Statistical analyses were carried out in R 2.8.0. and SPSS 11.5.

147

148 **Results**

149

150 All 14 instrumented birds were recaptured after 1-7 days. Two birds had shed the
151 logger by pulling out the feathers to which it was attached, although we did not observe birds
152 pecking at or trying to remove the logger. Two loggers failed to record data for unknown
153 reasons. Among the remaining sample of 10 kittiwakes, one bird incubated for nearly 2 days,
154 thus depleting its logger battery before leaving the nest. We used data from 9 successful
155 deployments (5 females, 4 males) for analysis of foraging patterns.

156 We obtained data for 16 foraging trips, 7 of which were complete (Table 1). Four birds
157 made one foraging trip, three made two trips, and two birds made three foraging trips during
158 the working period of the logger. Loggers recorded between 24 and 626 positional fixes
159 within a foraging trip (mean 123, SD 144).

160 The main foraging area was north of the colony, encompassing the continental shelf
161 area between Middleton Island and Prince William Sound (Fig. 2). Birds stayed mostly over

162 waters less than 200 m deep. One bird made repeated visits to the shelf slope south and east of
163 the island but did not access the abyssal zone beyond (Fig. 2a, 2c). One bird visited the
164 nearshore area of Hinchinbrook Island at the entrance to Prince William Sound (92 km from
165 Middleton).

166 On 9 of the 16 foraging trips, which we categorize as “short” trips, kittiwakes stayed
167 within 13 km of the breeding site, in contrast to the remaining 7 trips — “long” trips that
168 exceeded 35 km from the colony (Fig. 3). Among the completed trips, the maximum range
169 from the colony was 59 km, with a mean foraging range of 25.5 km (SD 22.2 km). However,
170 one incomplete trip had a maximum range from the colony of at least 91.8 km (Table. 2). The
171 maximum total distance travelled by a kittiwake on a completed trip was 164.7 km (mean
172 72.5 km, SD 58.4 km). When incomplete trips are taken into account the total maximum
173 distance travelled per trip was at least 306.3 km.

174 Trip duration varied from 1.5 h to 16.8 h (mean 7.9 h, SD 5.8 h) for complete trips,
175 whereas one incomplete trip exceeded 33 h for incomplete trips. We found a positive
176 relationship between trip duration and total distance travelled per foraging for complete trips
177 trip (Spearman’s $r_s = 0.835$, $P < 0.01$) but no significant relationship between foraging trip
178 duration and maximum distance to colony. Because of the small sample size of complete
179 foraging trips, statistical tests between males and females were not applicable.

180 Most trips occurred solely during daylight, but overnight trips were conducted by one
181 female and two males. In one instance the bird appeared to spend the night in or near another
182 portion of the colony on Middleton, whereas two overnight trips likely entailed foraging, as
183 the birds travelled far from the colony (Table 2). Nonetheless, the birds were mostly inactive
184 at night as indicated by rates of movement $< 10 \text{ km h}^{-1}$ (Fig. 2b).

185 Mean flight speed during foraging trips was 33 km h⁻¹ (maximum 87 km h⁻¹, SD 13
186 km h⁻¹) (Fig. 4). Kittiwakes spent only about a third (35%) of their foraging trips engaged in
187 sustained directional flight. The remaining 65% of the time budget consisted of periods of
188 inactivity or other behaviours not characterized by directional flight (speeds < 10 km h⁻¹).

189 We found no evidence that GPS loggers influenced breeding performance of the
190 subjects. Breeding success (number of chicks fledged/number of eggs laid) of instrumented
191 birds (0.5) was similar to that of controls (0.44) and there were no differences in mean chick
192 mass between groups at three stages of development: newly hatched chicks, mid-chick stage
193 or chicks near fledging (Table 3).

194

195 **Discussion**

196

197 Foraging patterns were highly variable among Black-legged Kittiwakes sampled on
198 Middleton Island in 2007, with a tendency towards bimodality in the distances travelled on
199 foraging trips. The longest and most far-ranging excursions were overnight trips, but even day
200 trips tended to range either less than 10 km or more than 40 km from the island. It may be that
201 shorter trips were used for chick-provisioning, while the longer trips were important for self-
202 feeding by adults, as suggested for chick-rearing Procellariiformes (Congdon et al. 2005;
203 Weimerskirch et al. 2001). Further study is needed to confirm that possibility in kittiwakes.
204 The disjunct distribution of foraging distances could also reflect prey distribution, as the main
205 prey of kittiwakes during chick rearing at Middleton, capelin and sand lance (Gill and Hatch
206 2002), may be available at different distances from the island.

207 Foraging trips that included a night at sea generally lasted much longer than trips

208 performed only during daylight (Coulson and Johnson 1993; Hamer et al. 1993; Roberts and
209 Hatch 1993). The importance of nighttime foraging was noted on Middleton in 1988, when
210 62% of overnight trips resulted in chick feeding upon return of the adult, while 35% of
211 daytime absences resulted in chick-feeding (Roberts and Hatch 1993). Overnight trips may in
212 general access distant foraging areas. Two of three overnight trips recorded in 2007 were
213 among the three most distant trips. Among birds tracked at night, the recorded flight speeds
214 $<10 \text{ km h}^{-1}$ indicated that hours of darkness were often spent in relative inactivity, probably
215 drifting on the surface, as was also observed by (Hamer et al. 1993) in Shetland. However,
216 birds “on water” might also engage in feeding by picking up small prey items, such as
217 euphausiids or polychaetes, likely available at the surface at night.

218 Foraging ranges of breeding kittiwakes are variable from one location to another.
219 Ranges (\pm SE) of 41 ± 3 km (Shoup Bay), 26 ± 5 km (Icy Bay), and 21 ± 5 km (Eleanor
220 Island) were reported for three colonies in Prince William Sound (Ainley et al. 2003). The
221 maximum foraging distance from the Shoup Bay colony was 120 km (Suryan et al. 2000).
222 Values reported here for Middleton Island (mean range of all trips: 26 km, maximum: 59 km)
223 are intermediate relative to Prince William Sound, whereas radio telemetry in Great Britain
224 (Sumburgh Head, Shetland) found that kittiwakes usually travelled more than 40 km from the
225 colony in 1990, beyond the range of receiving equipment (Wanless et al. 1992). In the
226 following year, more than 95% of foraging trips stayed within 5 km of the Sumburgh Head
227 colony, a reversal attributed to improved food availability (Hamer et al. 1993). Elsewhere in
228 Britain, maximum ranges of 73 ± 9 km from the Isle of May and 55.5 km from the Farne
229 Islands were estimated from flight duration and speed (Daunt et al. 2002; Pearson 1968).
230 Kittiwakes breeding at Helgoland in the German Bight were seen at a distance of 10-35 km

231 from the colony (aerial and ship based transect counts). Only single birds were observed at
232 distances up to 70-80 km (Dierschke et al. 2004). Those relatively short foraging distances
233 may be explained by low competition for prey — good feeding conditions around the island,
234 small size of the colony, and its isolation from other colonies of the same species

235 Our mean trip duration (7.9 h) was longer than that observed by (Roberts and Hatch
236 1993) on Middleton Island in 1988 (mean 4.1 h for daytime trips that culminated in chick-
237 feeding). Shorter trips are also reported from other colonies in Alaska and in Great Britain.
238 Mean trip durations of 3.4-6 h were found among kittiwakes in Prince William Sound (Ainley
239 et al. 2003; Suryan et al. 2000). Kittiwakes from the Isle of May spent 6.1 h (Humphreys et al.
240 2006) and 5.5 h (Daunt et al. 2002) at sea, and foraging trips were shorter still in two other
241 Scottish colonies — 3.4 h (Hamer et al. 1993) and 2.8 h (Coulson and Johnson 1993).
242 However, trip durations averaged more than 6 h during a year of reduced prey availability
243 (Hamer et al. 1993; Wanless et al. 1992). Our mean trip duration of nearly 8 h therefore
244 suggests poor food availability near Middleton Island in 2007. Flexible time budgets, as a
245 means of coping with low food availability, are also known from other colonies of kittiwakes
246 and murre (*Uria lomvia* and *U. aalge*) in Alaska (Harding et al. 2007; Kitaysky et al. 2000).

247 With one exception, kittiwakes foraged only in a northerly direction from the colony,
248 over the continental shelf and within the 200-m depth contour. We expected the shelf edge, a
249 potentially rich feeding habitat close to the island, to be a greater attraction than it was.
250 However, upwelling along the shelf edge is not as strong in summer as in winter (Weingartner
251 et al. 2005), which may explain the absence of kittiwakes in that area during July and August.
252 Observations on diet suggest a different situation in April, prior to egg-laying. Prey
253 regurgitated by kittiwakes in the first several weeks after returning to Middleton Island in

254 spring consist mostly of lanternfishes (Myctophidae) and small squids (S. A. Hatch, unpubl.
255 data). The birds presumably obtain this prey from deep ocean habitat of the continental slope
256 and abyssal ocean south of the island. Myctophids and squids are important components of
257 the mesopelagic community that migrate vertically to the ocean surface at night (Beamish et
258 al. 1999; Sinclair and Stabeno 2002). Myctophids, in particular, are high-energy prey (Van
259 Pelt et al. 1997) whose availability to kittiwakes before and during early breeding stages on
260 Middleton is thought to influence breeding success (Gill and Hatch 2002). Such prey are seen
261 also during incubation in some years (Gill and Hatch 2002). In this study we sampled two
262 birds late in incubation, one of which went to the shelf edge east of Middleton while the other
263 made the most distant foraging trip observed, on a northwesterly heading to Hinchinbrook
264 Island. More sampling is needed to clarify the relative importance and seasonality of deep
265 ocean versus neritic foraging by kittiwakes from Middleton.

266 Pennycuick (1987; 1997) and Götmark (1980) observed air speeds for kittiwakes of
267 about 47 and 54 km h⁻¹, respectively. Our observed mean flight speed of 33 km h⁻¹ was lower
268 than those speeds and matches better with the minimum power speed of Pennycuick (1987;
269 1997). But flight speeds varied greatly during foraging trips. Speed of flight to and from
270 foraging areas ranged from about 20-60 km h⁻¹, while birds searching for food had flight
271 speeds up to 20 km h⁻¹. It seems that birds changed between minimum power and maximum
272 range speeds (Pennycuick 1987, 1997) while flying to and coming back from foraging areas.
273 Whether this behaviour was weather dependent should be investigated.

274 In conclusion, we affirm the utility of GPS data loggers in elucidating the movements
275 and marine habitat use of seabirds previously excluded from such investigations because of
276 their small body size. Kittiwakes exhibited flexible foraging behaviour—short and long

277 foraging trips that appeared to change in relative frequencies over the course of chick rearing.
278 Although the sample was limited to 16 foraging trips, seven of them complete, we gained
279 much insight into the foraging behaviour of Black-legged Kittiwakes from Middleton Island.
280 Nearly all foraging trips were over the continental shelf, in northerly direction of the colony.
281 Thus, we believe the sample typifies the behaviour of most birds in this colony, but further
282 investigations are desirable. Interannual and within-season variation have yet to be fully
283 investigated.

284 Future applications of this powerful new technology promise many valuable insights
285 on the foraging strategies of kittiwakes and other oceanic birds of similar size. GPS data
286 loggers are able to track seabirds at distances from the colony that are out of range of
287 conventional radio telemetry. In addition, they are unaffected by weather conditions, an
288 important constraint on ship or aerial transect counts.

289

290

291 **Zusammenfassung**

292

293 GPS-Logger offenbaren Nahrungssuchstrategien der Dreizehenmöwen

294

295 Die Dreizehenmöwe (*Rissa tridactyla*) ist die weltweit häufigste Möwenart, aber viele
296 Populationen haben in den letzten Jahren abgenommen, was vermutlich auf
297 Nahrungsverknappung zurückzuführen ist. Dreizehenmöwen suchen ihre Nahrung an der
298 Wasseroberfläche und können deshalb geringe Nahrungsverfügbarkeit nur durch ein
299 Ausweiten ihres Nahrungssuchgebietes und / oder einen erhöhten Zeitaufwand kompensieren.

300 Diese Möwenart ist schon in vielen Aspekten ihrer Biologie untersucht wurden, aber durch
301 ihre weiten Nahrungssuchflüge und die Einschränkungen durch die konventionelle
302 Radiotelemetrie konnten diesen Aktivitäten bisher nur wenig untersucht werden. Die
303 Entwicklung von GPS-Loggern schreitet schnell voran. Mit neuen Geräten, die nur noch 8 g
304 wiegen, ist es jetzt auch möglich relativ kleine Seevogelarten, wie die Dreizehenmöwe, mit
305 dieser Technologie auszustatten und zu untersuchen. Hier präsentieren wir erste Ergebnisse
306 der GPS-Loggereinsätze auf Dreizehenmöwen aus dem Jahr 2007 aus dem Nordpazifik. Mit
307 Ausnahme von einem Tier sind alle Vögel in der neritischen Zone nördlich der Insel auf
308 Nahrungssuche gegangen. Drei Vögel suchten nur in unmittelbarer Nähe zur Kolonie (<
309 13 km) nach Nahrung, während sechs weitere Tiere eine durchschnittliche Entfernung von
310 40 km zeigten. Die maximale Entfernung zur Kolonie betrug 59 km und die maximale
311 zurückgelegte Distanz während eines Nahrungssuchfluges betrug 165 km. Der längste
312 Nahrungssuchflug dauerte 17 h (Mittelwert: 8 h). Die maximalen Distanzen zur Kolonie der
313 Nahrungssuchflüge machen eine bimodale Verteilung sichtbar, was neue Einsichten in das
314 variable Nahrungssuchverhalten von Dreizehenmöwen liefert. Die erfolgreiche Ausstattung
315 von Dreizehenmöwen mit GPS-Loggern verspricht auch Erfolg mit Telemetriestudien bei
316 vielen anderen Arten ähnlicher Größe und gibt neue Ansätze für weitere Untersuchungen.

317

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319

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327

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468 *Mar Ecol Prog Ser* 228: 241-261
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471 Table 1. Summary of deployments of GPS data loggers attached to Black-legged Kittiwakes on Middleton Island, Alaska during the breeding
 472 season in 2007.

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Bird no.	Nest	Sex	Brood stage	Date		No. of trips	
				deployment	recapture	complete	incomplete
1	D-15	female	incubating	02 Jul	04 Jul	battery empty before left the nest	
2	B-10	male	incubating	05 Jul	10 Jul	0	1
3	B-6	male	incubating	08 Jul	10 Jul	0	2
4	D-15	male	incub./chick rear.	11 Jul	14 Jul	no data recorded	
5	B-14	female	chick rearing	11 Jul	14 Jul	no data recorded	
6	D-17	female	chick rearing	14 Jul	16 Jul	1	2
7	B-16	female	chick rearing	14 Jul	17 Jul	logger lost	
8	D-4	male	chick rearing	17 Jul	01 Jul	1	0
9	D-13	male	chick rearing	19 Jul	20 Jul	1	0
10	B-4	female	chick rearing	21 Jul	23 Jul	1	1
11	D-3	female	chick rearing	25 Jul	27 Jul	1	1
12	D-2	female	chick rearing	27 Jul	28 Jul	0	1
13	B-4	male	chick rearing	29 Jul	05 Aug	logger lost	
14	C-1	female	chick rearing	08 Aug	11 Aug	2	1

491 Table 2. Foraging behaviour of Black-legged Kittiwakes from Middleton Island, Alaska during the breeding season in 2007. Range indicates
 492 maximum straight-line distance from the colony. Total distance travelled is distance covered during one foraging trip. Complete/incomplete
 493 indicates whether the whole trip was recorded from nest-leaving through return to the colony. Diel period distinguishes overnight and day
 494 trips.

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Bird no.	Sex	Brood stage	Trip duration (h)	Range (km)	Total dist. travelled (km)	Complete/ incomplete	Diel period of trip	
							day only (d)	overnight (n)
2	male	incubating	6.5	9.8	51.2	incomplete	d	
3	male	incubating	2.1	1.4	3.9	incomplete	d	
6	female	chick rearing	33.0	91.8	306.3	incomplete	n	
			2.5	3.8	9.7	incomplete	d	
			12.8	59.0	164.7	complete	n	
8	male	chick rearing	4.6	47.2	100.5	incomplete	d	
			16.8	35.2	92.5	complete	n	
			7.2	49.5	129.7	complete	d	
9	male	chick rearing	7.2	49.5	129.7	complete	d	
			2.1	4.9	14.7	complete	d	
10	female	chick rearing	2.1	4.9	14.7	complete	d	
			8.8	63.6	179.0	incomplete	d	
11	female	chick rearing	3.8	5.6	18.7	incomplete	d	
			4.2	12.5	35.0	complete	d	
12	female	chick rearing	6.9	36.1	121.4	incomplete	d	
14	female	chick rearing	4.1	3.0	6.7	incomplete	d	
			1.5	6.4	15.5	complete	d	
			10.4	10.9	55.4	complete	d	

496 Table 3. Comparison of breeding success (number of chicks/number of eggs laid) and chick
 497 growth at three stages of development between logger birds and non equipped Black-legged
 498 Kittiwakes in 2007 on Middleton Island, Alaska. Numbers in parentheses are sample sizes.

	Logger birds	Non-equipped birds	Statistics (GLM)
no. chicks / no. eggs laid	0.5 (n=13)	0.4 (n=95)	$t = 0.617, P = 0.538$
mean chick mass in g (0 days)	36.5 (n=16)	35.7 (n=85)	$t = 0.664, P = 0.508$
mean chick mass in g (20 days)	300.3 (n=12)	319.3 (n=75)	$t = 1.107, P = 0.271$
mean chick mass in g (35 days)	413.9 (n=8)	422.0 (n=69)	$t = -0.538, P = 0.592$

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508 Figure Legends

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510 Figure 1. Study area in the Gulf of Alaska showing the locations of Middleton Island and

511 Prince William Sound (PWS). Middleton lies about 80 km south of the Alaska mainland.

512 Depth contours indicate the position of the continental slope.

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514 Figure 2. Foraging tracks of Black-legged Kittiwakes from Middleton Island during the

515 breeding season in 2007. Maps show Middleton Island (MDO), the entrance to Prince

516 William Sound (PWS), Hinchinbrook Island (HI), and bathymetry in meters. (a) All foraging

517 trips (16) performed by nine instrumented birds. (b) Two long-distance, overnight trips (two

518 different birds) shown in more detail. Circles indicate resting areas at night, white dots are

519 positional fixes obtained by the GPS logger, and arrows indicate direction of movement. (c)

520 Two examples of shorter trips shown in more detail. Symbology as in (b).

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522 Figure 3. Maximum foraging distances (km) for all recorded foraging trips from Middleton

523 Island in 2007, sorted chronologically.

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525 Figure 4. Flight speeds of Black-legged Kittiwakes from Middleton Island recorded by GPS-

526 data loggers during the breeding season in 2007. Flight speeds $\leq 10 \text{ km h}^{-1}$ are not depicted

527 for reasons explained in the text.

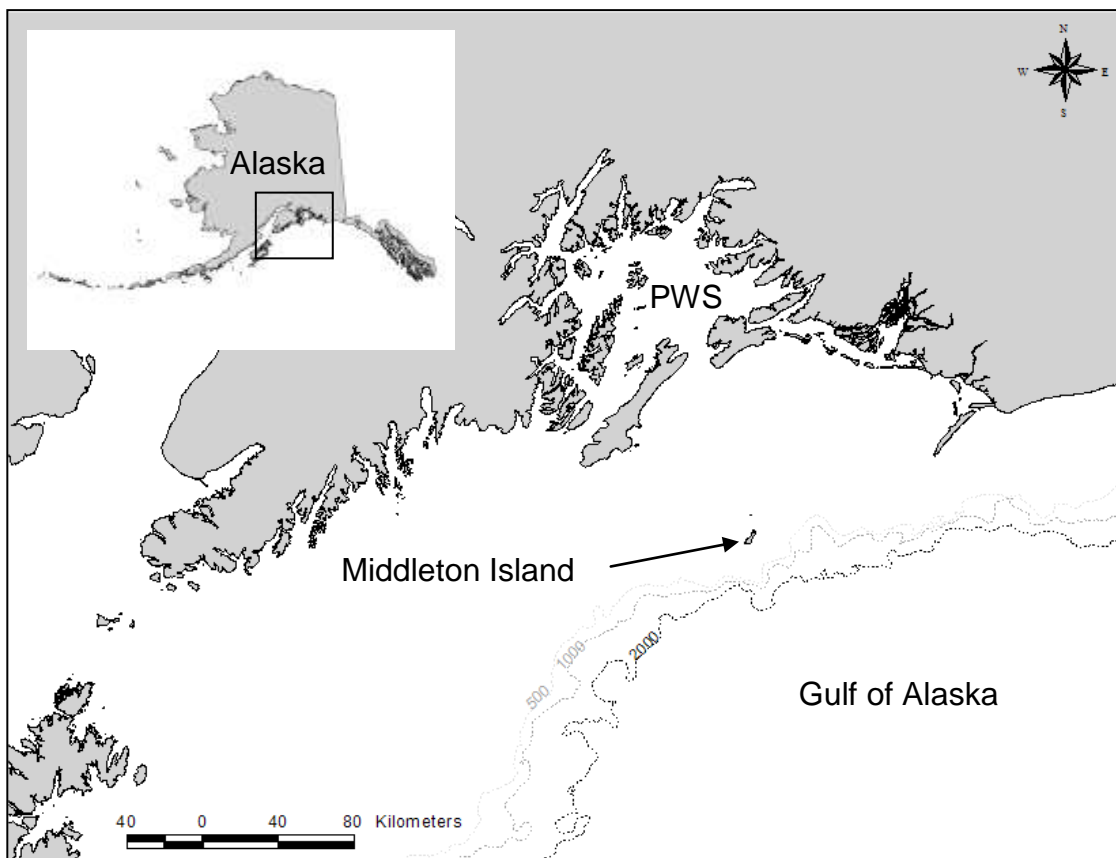


Figure 1

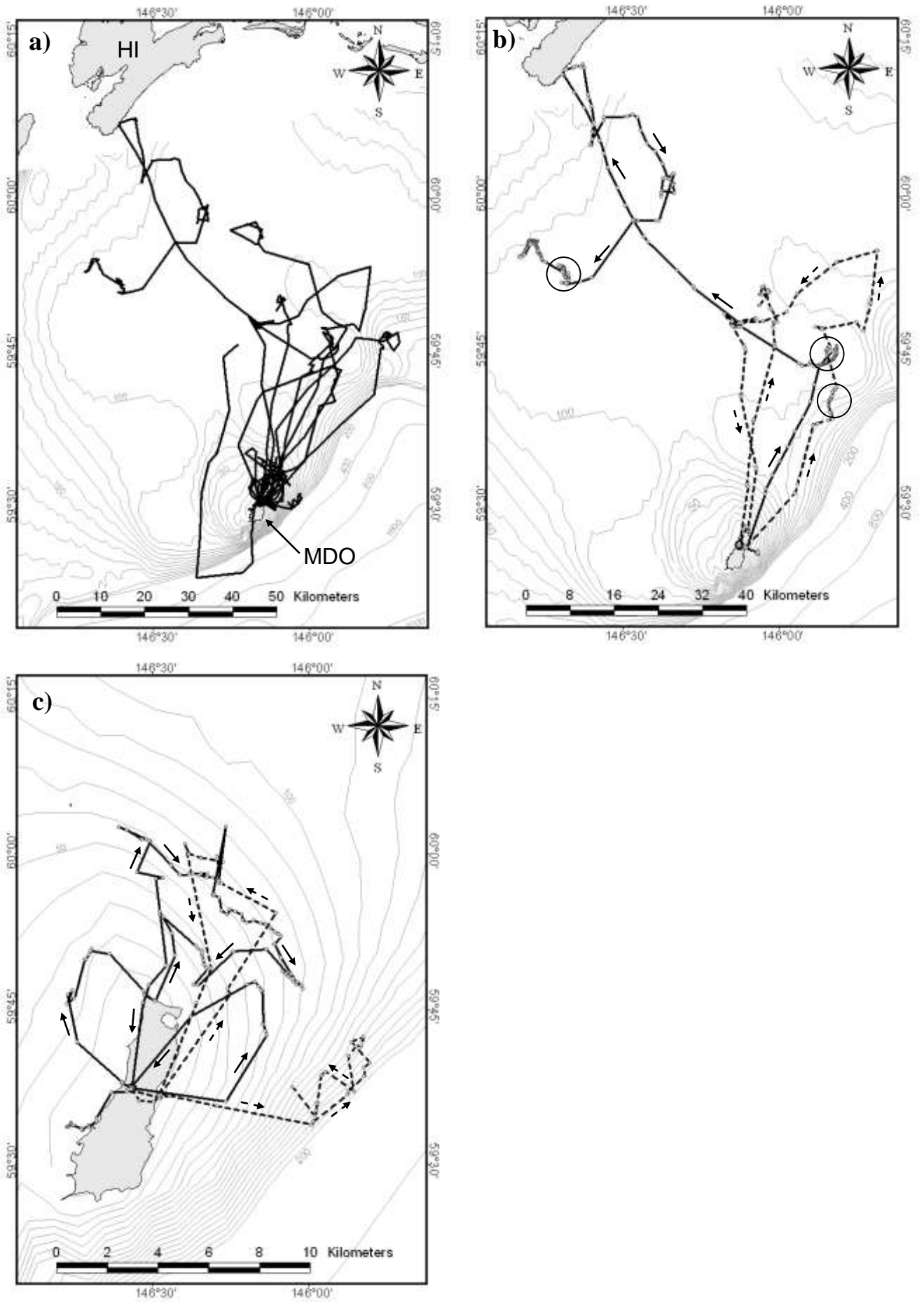


Figure 2

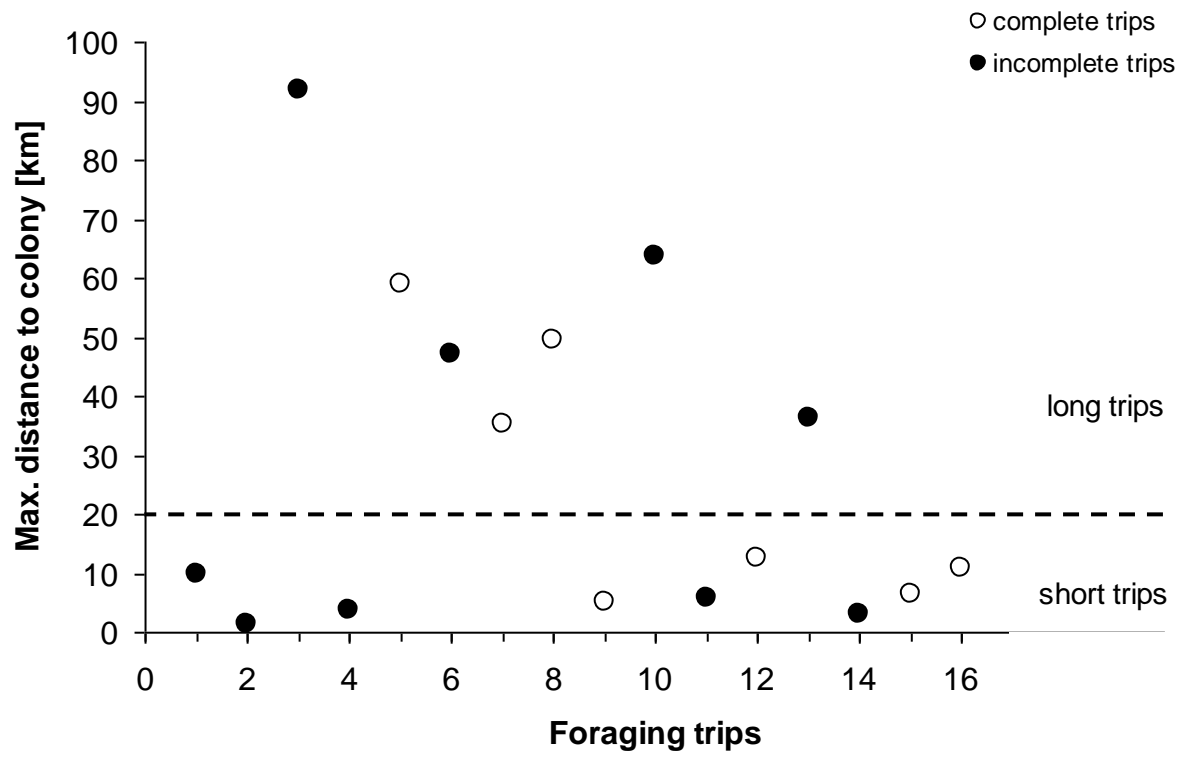


Figure 3

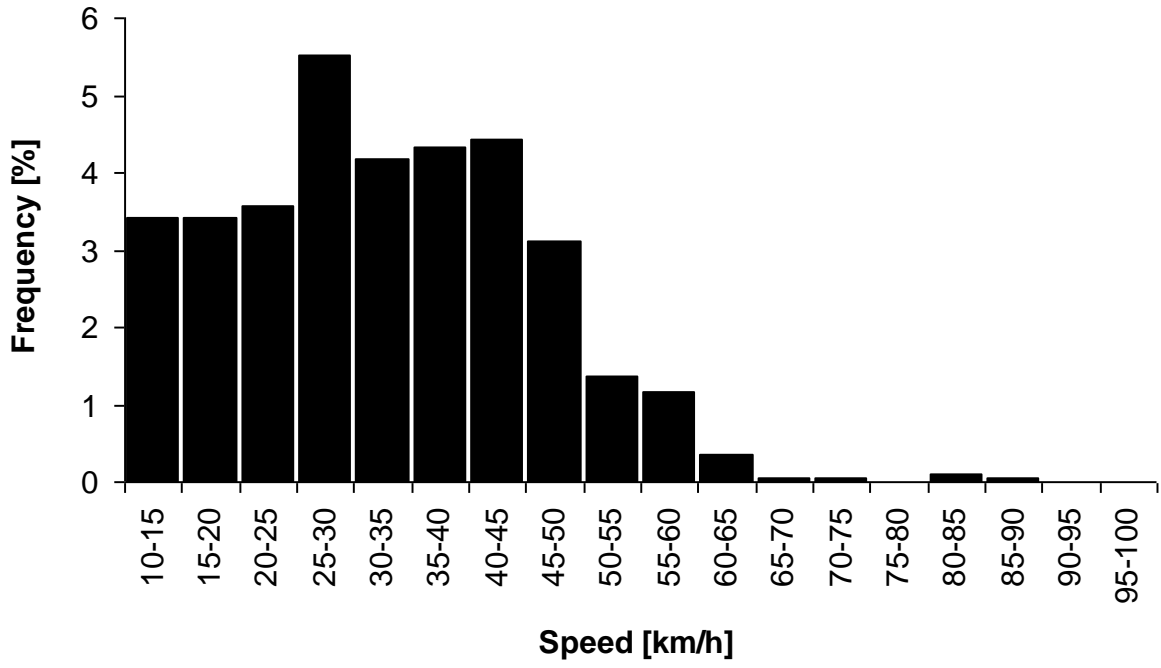


Figure 4