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1 **Contemporary premature feather loss (PFL) among common tern chicks in Lake Ontario:**
2 **the return of an enigmatic developmental anomaly**

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11

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Abstract

24 In July 2014, we observed premature feather loss (PFL) among non-sibling, common tern *Sterna*
25 *hirundo* chicks between 2 and 4 weeks of age at Gull Island in northern Lake Ontario, Canada.
26 Rarely observed in wild birds, to our knowledge PFL has not been recorded in terns since 1974,
27 despite the banding of tens of thousands of tern chicks across North America since then. The
28 prevalence (5% of chicks) and extent of feather loss was more extreme than in previous reports
29 but was not accompanied by other aberrant developmental or physical deformities. Complete
30 feather loss from all body areas (wing, tail, head and body) occurred over a period of a few days
31 but all affected chicks appeared vigorous and quickly began to grow replacement feathers. All
32 but one (recovered dead and submitted for post-mortem) most likely fledged 10-20 days after
33 normal fledging age. Secondary covert feather samples were collected from PFL chicks (n=6;
34 including shed feathers and re-growing live feathers) and normal individuals (n=8; plucked live
35 feathers) and were analyzed for corticosterone concentrations.
36

37 There was striking temporal association between the onset of PFL and persistent strong
38 southwesterly winds that caused extensive mixing of near-shore surface water with cool, deep
39 lake waters. We found no evidence of feather dystrophy, concurrent developmental
40 abnormalities or nutritional shortfall among affected chicks. Thus, the PFL we observed among
41 common terns in 2014 was largely of unknown origin but may have been caused by unidentified
42 pathogens or toxins welling up from these deep waters along the shoreline.

43 PFL was not observed among common terns at Gull Island in 2015, although we did observe
44 similar feather loss in a herring gull *Larus argentatus* chick in that year. Comparison with
45 sporadic records of PFL in other seabirds suggests that PFL may be a rare, but non-specific
46 response to a range of potential stressors. Its reemergence in penguins, and now gulls and terns,
47 may indicate widespread environmental changes that could lead to health risks for birds and
48 other wildlife.

49 Introduction

50 In July 2014 we observed premature feather loss (PFL) among common terns *Sterna hirundo* at
51 Gull Island in northern Lake Ontario, Canada. This condition, whereby developing chicks lose
52 their wing, tail, head and body feathers has rarely been documented in wild birds (although
53 feather loss has been well studied in domestic poultry; Hughes 1985, Leeson and Walsh 2004).
54 To our knowledge, PFL has only been reported for terns in coastal, eastern North America and at
55 Indian Ocean breeding islands between 1970 and 1974 (Gochfeld 1971, 1975, Hays and
56 Risebrough 1972, Feare 1974). At that time, it was cautiously associated with contaminant
57 burdens, chiefly mercury and polychlorinated biphenyls (PCBs) (Hays and Risebrough 1972,
58 Gochfeld 1980), and pathogenic organisms and their toxins (Bourne et al. 1977). However,
59 researchers were unable to rule out the possibility of other stressors (such as trauma, cancers,
60 allergens, infections, and genetic factors) (Gochfeld 1971).

61 Colonial seabirds and waterbirds are recognized as indicators of aquatic environments (Kushlan
62 1993, Piatt et al. 2007, Durant et al. 2009) in two main capacities: population-level/demographic
63 effects and physiological/biochemical effects (Kushlan 1993). In most cases, physiological and
64 biochemical endpoints are quicker to quantify and more widely used (Kushlan 1993, Furness and
65 Camphuysen 1997, Burger and Gochfeld 2004). However, gross physiological endpoints, such as
66 cases of aberrant or retarded development (including feather loss, e.g. Hays and Risebrough
67 1972) or reduced growth rates (e.g. Lyons and Roby 2011) may be more easily quantified,
68 especially when birds are easy to catch (such as waterbird chicks prior to fledging age). While
69 these do not necessarily permit absolute diagnosis, they allow immediate detection (although not
70 clear causality) of rare events and can help to narrow down potential causal factors (e.g. Bourne
71 et al. 1977).

72 Substantial feather loss can be induced in poultry by periods of starvation, nutritional
73 restrictions, as well as a consequence of feather pecking, shock molt or Psittacine Beak and
74 Feather Disease (Spearman 1980, Hughes 1985, Leeson and Walsh 2004, Møller et al. 2006).
75 However, it is rarely reported in wild birds except for some pathogenic infections (e.g. in
76 psittacines; Ha et al. 2007; but see Table 1). In North America, PFL in common terns was
77 reported locally in the vicinity of Long Island, New York, as well as a few locations in coastal
78 Connecticut and Massachusetts between 1970 and 1974 (Hays and Risebrough 1972, Nisbet
79 1972, Gochfeld 1980), but to our best knowledge, and despite tens of thousands of common terns
80 being banded in the interim, no further cases have been reported anywhere subsequently (M.
81 Gochfeld and I.C.T. Nisbet pers. comm.).

82 The re-emergence of PFL in common terns may be of conservation concern and, given their role
83 as indicators of the aquatic environment, may indicate acute health risks for birds and other
84 wildlife in the Lake Ontario region. Here, we describe the chronology and progression of PFL at
85 Gull Island, Ontario, and review associated evidence to narrow down potential causes of this
86 aberrant development. We aim to increase awareness of this phenomenon among ornithologists

87 and the wider scientific community to ensure timely reporting of future occurrences that may
88 lead to a better understanding of its underlying causes.

89 **Materials & Methods**

90 Since 2008, we have studied the reproductive biology of common terns annually at Gull Island,
91 Presqu'île Provincial Park, ON, Canada (43°59'N, 77°45'W) under appropriate authorizations
92 (see Acknowledgements). Following standard protocols (Arnold et al. 2015), each year nearly all
93 chicks were banded and chicks from all study nests (~80 – 130) were recaptured and weighed
94 regularly (every ~1-4 d) from hatching until fledging. In 2014, chicks were recaptured near-daily
95 until 24 July and then weekly until 20 August.

96 On discovery of premature feather loss (PFL) in multiple individual chicks at Gull Island, we
97 took a range of photographs (head, tail, wing, body) and also measured wing length (maximum
98 wing chord) and tail length (maximum length of longest outer tail feather) at each subsequent
99 recapture using a 300 mm wing rule. The same was done for a sample of normally developing
100 tern chicks during this time period. For corticosterone analysis, secondary coverts (5-6/bird on
101 average) were obtained (by plucking) from most chicks exhibiting PFL (n=6 chicks; 5 with
102 regrowing feathers and 1 with original feathers) and from normal (control) chicks (n=8; original
103 feathers) during this period. Mainly regrowing feathers were available from PFL chicks as
104 protocols were developed following initial identification of this condition. The carcass of one
105 subsequently dead PFL chick was sent to D. Campbell, of the Canadian Wildlife Health
106 Cooperative, Ontario Veterinary College for post-mortem.

107 Secondary covert feathers were analyzed for corticosterone as per the method of Bortolotti et al.
108 (2008). Briefly, the calamus was removed and the remaining feather was cut into small pieces and
109 extracted with methanol overnight at 50°C. After centrifugation at 13,000 rpm for 20 minutes, the
110 supernatant was transferred to a fresh tube and re-extracted with 1 ml methanol. The methanol
111 fraction was evaporated to dryness overnight before final reconstitution in 200 µl steroid diluent.
112 The sample was analyzed using a corticosterone EIA kit (Assay Designs product no. 900-097) as
113 per the manufacturer's protocol. Data are presented as pg corticosterone/mm feather.

114
115 Repeated mass measurements from eight chicks that exhibited PFL were used to construct a
116 composite growth curve for comparison to larger samples of normally developing chicks.
117 Median wing and tail growth rates (slopes of measurements within individuals) for chicks
118 exhibiting PFL and normal chicks were compared using Mann Whitney U-tests. For these
119 analyses, only chicks with multiple measurements and of similar age (24 d – 33 d) were included
120 in analyses (6 PFL chicks and 3 control chicks).

121 Local, hourly weather data from the Trenton, ON, weather station (44°7'N, 77°32'W; 21 km to
122 the northwest) were downloaded from Environment Canada (<http://climate.weather.gc.ca/>). From
123 these we calculated daily (24 h) means from 1 May to 31 July for air temperature, relative

124 humidity, wind speed, wind direction, visibility and standard atmospheric pressure, and also
125 minimum nighttime temperatures and maximum daytime air temperatures. Lake surface
126 temperature was retrieved from Environment Canada (<http://weather.gc.ca>) for the nearest near-
127 shore, weather buoy (Ajax, ON, Station 45159, 43°46' N 78°59' W, 105 km E of Gull Island).

128 Analyses were conducted in R (R Core team 2015). All means are reported with ± 1 SD, all
129 medians with quartiles [upper, lower].

130 **Results**

131 Premature feather loss (PFL) was first discovered in two non-sibling, common tern chicks at
132 Gull Island on 5 July, 2014. Initial symptoms noted at this time were missing feathers on the
133 head and body, similar in extent to that sometimes resulting from territorial aggression by
134 neighboring adults or chicks (but without the associated laceration, bruising or hemorrhaging).
135 However, by 8 July these two chicks had lost down, primaries and most feathers from all areas of
136 the head, body, tail and wings, and in one chick, pin feathers were already growing back in
137 places (Fig 1). On this same day, two other chicks exhibited PFL symptoms for the first time.
138 Between 9 July and 11 July a further 3 chicks were found with PFL and we noted a final case in
139 this month on 24 July. However, we also discovered an unbanded, medium-sized chick
140 (estimated as 13-15 d of age) exhibiting PFL on 15 Aug (which is excluded from the analyses
141 that follow). Although many affected chicks were from 2- or 3-chick broods, none had siblings
142 that showed signs of PFL.

143 No evidence of feather dystrophy was found in the dead PFL chick sent for post-mortem
144 analysis, reducing the likelihood that this PFL resulted from a viral infection (such as that from
145 Circovirus and Papovavirus) (D. Campbell, pers. comm.). It also showed no obvious signs of
146 infection or abnormality in heart, lung, liver or kidney tissues (D. Campbell, pers. comm.). There
147 was a high level of cellularity in the pulp of the feathers, but the significance of this is unclear
148 (D. Campbell, pers. comm.).

149 Corticosterone concentrations were above the limit of detection (0.5 pg/mm) for all feather
150 samples analyzed. There were no significant differences between the levels of corticosterone
151 measured in the feathers of the control birds and the PFL birds (Figure 2).

152 The mean age of chicks when first exhibiting PFL was 18 (± 3.7) d (range: 15 – 26 d).
153 Comparison between normal plumage development and that of chicks exhibiting PFL is shown
154 in Fig 1. Although growth in mass for chicks exhibiting PFL appeared normal initially, from
155 about 10 d of age until normal fledging age (~25 d) masses were generally lower than the colony
156 average (Fig 3). Although median rates of both wing and tail growth were slightly higher for
157 PFL chicks than normal chicks at similar ages, these differences were not statistically significant
158 (wing: PFL = 5.5 [4.3, 6.2] mm/d (n = 6), Normal = 4.0 [2.8, 5.3] mm/d (n = 3), W = 5, P =
159 0.38; tail: PFL = 3.8 [2.9, 4.9] mm/d (n = 6), Normal = 3.3 [2.2, 3.5] mm/d (n = 3), W = 3, P =
160 0.17).

161 The seven surviving chicks that exhibited PFL in July were last seen between 21 and 42 d of age
162 (mean: 29.1 ± 6.5 d). Mean body mass at their last recapture date was $119.3 (\pm 9.2)$ g, effectively
163 identical to the colony average for birds of fledging age (118.3 ± 8.1 , $n = 29$). Mean wing length
164 of the PFL chicks was $125 (\pm 23)$ mm when last seen (well before actual fledging). Using the
165 observed rates of daily wing growth (slope of maximum chord) we projected fledging dates for
166 each of these chicks as the date at which wing lengths would have equaled 180 mm (the smallest
167 wing length for a normal, fledged common tern chick in 2014). The earliest and latest projected
168 fledging dates for the PFL chicks were 26 July and 20 Aug (mean: 2 Aug ± 9 d), respectively.
169 During a visit to the colony on 11 Aug, we estimated there to be between 15 and 25 active
170 common tern broods in the colony at this time.

171 The period in which PFL was first detected in common tern chicks (and three days immediately
172 prior to it; 2 – 10 July) was characterized by plummeting near-shore, lake surface temperatures
173 (Fig 4a) and falling air temperatures (Fig 4b) as well as stronger southwesterly winds (Fig 4c &
174 d) and rising atmospheric pressure (not shown). Minimum nighttime temperatures and maximum
175 daytime temperatures were highly correlated with mean air temperature ($r_{89} = 0.82$ and $r_{90} =$
176 0.99 , respectively) and showed the same response (not shown). However, there were no obvious
177 changes in relative humidity or visibility at this time (also not shown).

178 Discussion

179 The premature feather loss (PFL) that we observed in common tern chicks at Gull Island in 2014
180 is similar in two ways to that described by researchers working on the Atlantic coast of North
181 America in the early 1970s. Firstly, we only observed it in chicks when they were between 2 and
182 4 weeks of age, the same age as noted by Hays & Risebrough (1972) and similar to Gochfeld
183 (1971) [3-5 weeks], although in this latter case PFL was restricted to chicks closer to normal
184 fledging age (Gochfeld 1971, Gochfeld pers. comm.). Secondly, in all our cases, shed feathers
185 were replaced in all areas of the body but chicks appeared otherwise healthy and vigorous
186 (Gochfeld 1971, Hays and Risebrough 1972). In fact, our PFL chicks, although they
187 consequently had shorter wings and tails than normal chicks (Fig 1), showed no reduction in
188 feather growth rates following feather loss. This is unsurprising, since feather growth appears
189 highly conserved (e.g. under conditions of nutritional stress; Bize et al. 2006, Lyons and Roby
190 2011).

191 There are a few interesting differences between the PFL we observed and that previously
192 documented both in terns and other birds (Table 1). Complete feather loss (Fig 1) is the extreme
193 among terns in previous reports, as some birds only lost primaries and/or tail feathers (Gochfeld
194 1971, 1975, Hays and Risebrough 1972, Feare 1974, Bourne et al. 1977). Similar complete
195 feather loss and regrowth has been observed in other species, e.g. greater black-backed gulls
196 (*Larus marinus*), African (*Spheniscus demersus*) and Magellanic (*S. magellanicus*) penguin
197 chicks (Kane et al. 2010). The incidence of PFL at our colony in 2014 was 5% (9/167) of all
198 chicks, higher than that reported for common terns (0.5 – 1.1%; Hays and Risebrough 1972,

199 Gochfeld 1975), although similar rates have been noted for other terns and gulls (Feare 1974,
200 Roy et al. 1986) and even higher incidences in rehabilitated penguins (Kane et al. 2010). Unlike
201 all other reports for terns, we did not observe concurrent developmental abnormalities (e.g.
202 crossed-bills, absence of down, aberrant limb development; Feare 1974, Gochfeld 1975, Bourne
203 et al. 1977) in PFL chicks or any other common tern chicks at our site. Lack of concurrent
204 abnormalities is, however, consistent with contemporary reports among penguins (Kane et al.
205 2010, Barbosa et al. 2015, Grimaldi et al. 2015). Colony-wide hatching success also did not
206 appear any different from in previous years (Arnold & Oswald unpublished data), suggesting an
207 absence of gross embryonic deformity (such situations were previously linked with PFL; Hays
208 and Risebrough 1972). Interestingly, previous studies in the lower Great Lakes between 1971
209 and 1974 detected a high prevalence of deformity among common tern chicks (including one
210 chick at Presqu'île Provincial Park) but no cases of PFL (Gilbertson et al. 1976).

211 Although high mortality among chicks developing PFL has been previously reported (Hays and
212 Risebrough 1972) or assumed (Gochfeld 1980, Kane et al. 2010), we only recovered one dead
213 chick with this condition despite intensive searching. Dead chicks can desiccate and decompose
214 quickly (Gochfeld 1971); however, we visit each nest on a near-daily basis at this site and thus,
215 recover nearly all chicks that die at this late stage of development. Given this, and the seemly
216 vigorous condition of PFL chicks when last seen (our intensive searches finished on 24 July for
217 logistic reasons), we expect that many of these chicks eventually fledged. This would not be
218 completely unprecedented since successful fledging of tern chicks that exhibit PFL during
219 development has been previously reported (Hays and Risebrough 1972).

220 While growth rates of wings and tails of common tern chicks recovering from PFL in 2014
221 appeared normal, PFL chicks had lower masses than normal chicks between 10 d of age and
222 normal fledging age (~25 d). Although some of this may be directly due to the absence of
223 plumage, the maximum differences we observed (~30 g on average at 18 d of age; Fig 3) likely
224 exceeded the weight of lost plumage. As chicks recovering from PFL appeared vigorous and
225 highly aggressive in some cases, this is unlikely to result from a competitive disadvantage during
226 provisioning events (e.g. Oswald et al. 2012) but instead a preferential channeling of energy to
227 feather regrowth. Such a relationship between PFL and growth has been previously documented
228 for penguins (Kane et al. 2010) but not terns (Gochfeld 1971). PFL did not appear to affect the
229 known tendency for tern chicks to overshoot adult mass and subsequently lose mass at this site,
230 as the proportion of PFL chicks exhibiting this growth trajectory (25% [2/8 chicks]) was similar
231 to that previously reported (34-38%, Arnold et al. 2015).

232 There was no difference between the normal and PFL chicks in terms of corticosterone levels in
233 secondary covert feathers, although values were slightly higher for feathers from PFL chicks (Fig
234 2). It is important to note that feather corticosterone represents a measure of chronic stress
235 (accumulation of corticosterone in the feather over time) (Bortolotti et al. 2008) and therefore an
236 acute stress event, such as that potentially behind the observed feather loss, may not be detected,
237 especially in regrowing feathers.

238 Other reports of PFL have been for chicks late in the breeding season (Gochfeld 1971) but at
239 Gull Island in 2014, PFL was first observed in early July (mean hatching date across all chicks in
240 2014 was 30 June) and an active colony persisted well into mid-August. There was a striking
241 association between the timing of occurrence of onset of PFL at Gull Island in 2014 and
242 plummeting (up to 13 C°) near-shore, lake surface temperatures, falling air temperatures, and
243 strong southwesterly winds (Fig 4). Sustained strong winds may cause substantial mixing of
244 cold, deep lake waters with warmer surface waters which, after a period of warm lake surface
245 temperatures, can bring anoxic bacteria (such as Type E *Clostridium botulinum*) to the surface,
246 causing botulism outbreaks (Perez-Fuentetaja et al. 2004, Chun et al. 2013). However, we did
247 not see much evidence of botulism among ring-billed gulls *L. delawarensis* or Caspian terns
248 *Hydroprogne caspia* at this time (we have never encountered botulism in common terns at Gull
249 Island), and systematic beach surveys at the Park did not report any unusual mortality events. It
250 is possible, however, that the cooler, deep waters that mixed with near-shore waters contained, or
251 vectored, sediment contaminated with pathogenic organisms or historical pollutants. In the early
252 1970s, there was evidence that PCBs might be responsible for gross deformities in chicks in
253 Lake Ontario (although not PFL) (Gilbertson et al. 1976) and elsewhere (Ludwig et al. 1996), but
254 research has largely debunked this idea (Kuiken et al. 1999). Contaminant levels in common tern
255 eggs have declined following legislative action (Weseloh et al. 1989) and recent monitoring (via
256 long-term monitoring of contaminants in herring gull eggs) has not indicated a return to
257 problematic contaminant levels of these legacy organohalogen contaminants (Hebert 2000,
258 Jermyn-Gee et al. 2005). Since PFL in 2014 was observed within a matter of days after falling
259 near-shore lake temperatures (Fig 4), this largely precludes bioaccumulation of contaminants
260 (PCBs [Hays and Risebrough 1972] or mercury [Gochfeld 1980]) as causal agents (C. Custer,
261 pers. comm.).

262 Exposure to as yet unknown toxins or pathogens between 2 and 10 July 2014 seems the most
263 likely current explanation of PFL in common tern chicks at Gull Island. Most affected chicks
264 were between 1-2 weeks of age during this time period, although one chick was hatched at this
265 time and the egg of another chick that developed PFL in August was laid at this time. Thus, it is
266 possible that the causal agent persisted in the environment or was communicated to the
267 developing embryo from the parent. As in most other cases of PFL, chicks showing this
268 condition had normal siblings, suggesting a low rate of transmission and an absence of a strong
269 genetic link (Roy et al. 1986, Kane et al. 2010, Barbosa et al. 2015). Pathogens such as algal
270 toxins and bacteria (Bourne et al. 1977) or tick-borne (Feare 1974) or other viruses (Leeson and
271 Walsh 2004, Ha et al. 2007) have been suggested as causes of PFL but we found no evidence of
272 known viral (e.g. Psittacine Beak and Feather Disease [Circovirus]; Katoh et al. 2010, Varsani et
273 al. 2014) or bacterial agents or tick infection. Feather loss, deformity and onset of molt, although
274 not necessarily complete molt, are well studied in poultry and have also been associated with
275 periods of starvation and nutritional deficiency (e.g. low protein diets, zinc, Vitamin E, and
276 selenium; Leeson and Walsh 2004), but there was no strong evidence of acute nutritional

277 deficiency in the PFL chicks in our study. Thus, we currently favor exposure to unknown toxins
278 or pathogenic organisms as the causal mechanism.

279 Comparison with sporadic records of PFL in other birds (Table 1) suggests that PFL may be a
280 rare, but non-specific response to a range of potential stressors, including environmental
281 contaminants, viral and bacterial infections, tick-borne disease or nutritional deficiency. Given
282 that PFL is very obvious in affected chicks (Fig 1) but is seldom reported despite the great
283 number of studies that should detect it, suggests that the low incidence of reporting represents a
284 rare condition rather than simply underreporting (Gochfeld 1971, Roy et al. 1986, Barbosa et al.
285 2015, Grimaldi et al. 2015). In 2015, we found no evidence of PFL in common terns despite
286 similar nesting numbers and research protocols, but we did observe a single herring gull (*L.*
287 *argentatus*) chick exhibiting premature feather loss (Arnold & Oswald unpubl. obs.). Thus, the
288 reemergence of PFL in penguins (including adults; Grimaldi et al. 2015), and now gull and tern
289 chicks, may perhaps indicate widespread environmental changes that could lead to health risks
290 for birds and other wildlife, especially if pathogenic organisms are responsible (Bourne et al.
291 1977).

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Table 1. Reports of premature feather loss (PFL) in waterbirds. In all reports, feather-loss in some individuals studied was extensive.

Species	Location	Years	Explanation	Source
Common tern (<i>Sterna hirundo</i>)	Long Island, NY	1970-1974	Proposed link to contaminants (e.g. PCBs, mercury)	Gochfeld 1971, 1975; Hays & Risebrough 1972
Sooty tern (<i>Sterna fuscata</i>)	Seychelles	1973	Tick-borne soldado-virus	Feare 1974
Greater Black-backed gull (<i>Larus marinus</i>)	Witless Bay, Newfoundland	1984	Unknown cause	Roy et al. 1986
Herring gull (<i>Larus argentatus</i>)	Witless Bay, Newfoundland	1984	Unknown cause	Roy et al. 1986
African penguin (<i>Spheniscus demersus</i>)	South Africa	1989	Malnutrition	van Heezik and Seddon 1992
Emperor penguin (<i>Aptenodytes forsteri</i>)	Cape Washington, Antarctica	mid-1990s	Unknown cause	reported in Varsani et al. 2014
Magellanic penguin (<i>Spheniscus magellanicus</i>)	Argentina	2007	Unknown cause	Kane <i>et al.</i> 2010
African penguin (<i>Spheniscus demersus</i>)	South Africa	2009	Unknown cause	Kane <i>et al.</i> 2010
Adelie penguin (<i>Pygoscelis adeliae</i>)	Cape Crozier, Antarctica	2011	Unknown cause	reported in Varsani et al. 2014
Common tern (<i>Sterna hirundo</i>)	Gull Island, Lake Ontario	2014	Unknown cause, possible link to environmental conditions	This study
Adelie penguin (<i>Pygoscelis adeliae</i>)	Ross Is. & Antarctic Peninsula	2011-2015	Proposed avian virus (polyomavirus, novel astrovirus)	Barbosa <i>et al.</i> 2015; Grimaldi <i>et al.</i> 2015
Herring gull (<i>Larus marinus</i>)	Gull Island, Lake Ontario	2015	Unknown cause	Arnold & Oswald unpubl. obs.

400 **Figure 1.** Plumage characteristics resulting from premature feather loss (PFL) in common tern chicks at
401 Gull Island in 2014 (left hand panel) versus normal development (right hand panel; photo with white
402 background taken from Common Tern Aging Guide: Wails et al. 2014). In each case, whole body (a,b),
403 wing (c,d) and tail (e,f) are shown (pictures taken between 9 and 18 July). Chicks shown are between 21
404 and 27 d of age (fledging usually occurs between 21-29 days; Nisbet 2002).

405 **Figure 2.** Mean (\pm SE) corticosterone concentrations (pc/mm) in secondary covert feathers collected from
406 common tern chicks exhibiting normal feather growth (control; n=8) and premature feather loss (PFL;
407 n=7) at Gull Island in 2014. Differences among groups are not statistically-significant ($t_{13} = 0.96$, $P =$
408 0.36). The method limit of detection was 0.5 pg/mm.

409 **Figure 3.** Changes in mass throughout development of the eight chicks exhibiting premature feather loss
410 [PFL] (black lines = 95% confidence intervals) superimposed over the range of weights for normal chicks
411 (n = 159 chicks, grey shading = area between 95% confidence intervals). For PFL chicks measured later
412 in development (> 30 d of age), when fewer measurements were available, individual data points are
413 plotted.

414 **Figure 4.** Changes in mean daily weather conditions, (a) near-shore lake surface temperature, (b) air
415 temperature, (c) wind speed, and (d) wind direction (maximum gust), and correspondence with
416 distribution of hatching dates (blue boxplots and outlier) and dates of first exhibiting premature feather
417 loss [PFL] (green boxplots and outlier). Trend lines are 7-day running average of the weather variable.
418 Grey shading highlights the period of plummeting near-shore surface water temperatures (2 -10 July).







