Does contemporary premature feather loss among common tern chicks in Lake Ontario reflect persistent pollutants, enigmatic diseases or novel pathogens?

JENNIFER M. ARNOLD[1*], DONALD J. TYERMAN[2] & STEPHEN A. OSWALD[1]

[1]Division of Science, The Pennsylvania State University, Berks Campus, 2080 Tulpehocken Road, Reading, PA 19610, USA.

[2] Presqu'ile Provincial Park, Ontario Parks, 328 Presqu'ile Parkway, R.R. #4 Brighton, Ontario, K0K 1H0, Canada.

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[*]Corresponding author:

Jennifer M. Arnold

Division of Science,

The Pennsylvania State University, Berks Campus,

2080 Tulpehocken Road,

Reading, PA 19610, USA

Tel: +1-610-396-6002

E-mail: jma25@psu.edu

Abstract

We observed premature feather loss (PFL) among common terns *Sterna hirundo* at a small colony in northern Lake Ontario, Canada in July 2014. This condition is characterized by affected chicks losing all their wing, tail, head and body feathers several weeks after hatching. Rarely observed in wild birds, to our knowledge PFL in terns has not been recorded since 1974 (despite the banding of tens of thousands of tern chicks across North America since then).

In July 2014, we observed PFL in chicks at between 2 and 4 weeks of age. The extent of feather loss was more extreme than in previous reports but was not accompanied by other aberrant developmental or physical deformities. Complete feather loss occurred over a period of a few days but all affected chicks quickly began to grow replacement feathers and all but one most likely fledged 10-20 days after normal fledging age. Feather samples, both shed feathers and re-growing live feathers, were collected from both affected chicks and normal individuals. One subsequently dead PFL chick was collected. Samples are awaiting further analysis.

There was striking temporal association between the onset of PFL and persistent strong southwesterly winds that caused extensive mixing of near-shore, surface water with cool, deep lake waters. To our current knowledge it seems most probable that the PFL we observed in 2014 was caused by pathogens (viruses, bacteria, algal toxins) welling up from these deep waters along the shoreline but a direct link has not yet been made. The re-emergence of PFL in common terns may indicate acute health risks for birds and other wildlife in the Lake Ontario region and may also have potential for human health risks.

Introduction

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

Colonial seabirds and waterbirds are recognized as indicators of aquatic environments (Kushlan 1993, Piatt et al. 2007, Durant et al. 2009) in two main capacities: population-level/demographic effects and physiological/biochemical effects (Kushlan 1993). In most cases, physiological and biochemical endpoints are quicker to quantify and more widely used (Kushlan 1993, Furness and Camphuysen 1997, Burger and Gochfeld 2004). Identification of a pollutant, nutritional deficiency or pathogen using biochemical and cellular assays requires *a priori* supposition of causal agents so that the correct suite of analyses can be implemented. Furthermore, correct diagnosis depends on sampling the most suitable tissue type in which to detect a particular pollutant (Gochfeld 1980). Alternatively, gross physiological endpoints, such as cases of aberrant or retarded development (including feather loss, e.g. Hays and Risebrough 1972) or reduced growth rates (e.g. Lyons and Roby 2011) may be more easily quantified, especially when birds are easy to catch (such as waterbird chicks prior to fledging age). While these do not necessarily permit absolute diagnosis, they allow immediate detection (although not clear causality) of environmental stress and can help to narrow down potential causal factors (e.g. Bourne et al. 1977).

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

The re-emergence of PFL in common terns may be of conservation concern and, given their role as indicators of the aquatic environment, may indicate acute health risks for birds and other wildlife in the Lake Ontario region, and even have potential for human health risks (Bourne et al. 1977). Here, we describe the chronology and progression of PFL at Gull Island, Ontario, and review associated evidence to narrow down potential causes of this aberrant development. We aim to generate discussion among ornithologists and the wider scientific community to assess whether this phenomenon has been observed elsewhere in recent years. We are also seeking ideas that will help us to develop a rigorous sampling protocol for future years to identify causal mechanisms behind PFL and assess the potential for associated health risks.

Materials & Methods

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

On discovery of premature feather loss (PFL) in multiple individual chicks at Gull Island, we took a range of photographs (head, tail, wing, body) and also measured wing length (maximum wing chord) and tail length (maximum length of longest outer tail feather) at each subsequent recapture using a 300 mm wing rule. The same was done for a sample of normally developing tern chicks in this same colony during this time period. Samples of secondary coverts were also removed from each chick exhibiting PFL and eight normal chicks during this period.

Local, hourly weather data from the Trenton, ON, weather station (44°7′N, 77°32′W; 21 km to the northwest) were downloaded from Environment Canada (http://climate.weather.gc.ca/). From these we calculated daily (24 h) means from 1 May to 31 July for air temperature, relative humidity, wind speed, wind direction, visibility and standard atmospheric pressure, and also minimum nighttime temperatures and maximum daytime air temperatures. Lake surface temperature was retrieved from Environment Canada (http://weather.gc.ca) for the nearest near-shore, weather buoy (Ajax, ON, Station 45159, 43°46' N 78°59' W, 105 km E of Gull Island).

Repeated mass measurements from eight chicks that exhibited PFL were used to construct a composite growth curve for comparison to larger samples of normally developing chicks. Median wing and tail growth rates (slopes of measurements within individuals) for chicks exhibiting PFL and normal chicks were compared using Mann Whitney U-tests. For these analyses, only chicks with multiple measurements and of similar age (24 d – 33 d) were included in analyses (6 PFL chicks and 3 control chicks). Analyses were conducted in R (R Development Core Team 2009). All means are reported with ±1 SD, all medians with quartiles [upper, lower].

Results

Premature feather loss (PFL) was first discovered in two common tern chicks at Gull Island on 5 July, 2014. Initial symptoms noted at this time were missing feathers on head and body, similar

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

in extent to that sometimes resulting from territorial aggression by neighboring adults or chicks (but without the associated laceration, bruising or hemorrhaging). However, by 8 July these two chicks had lost down, primaries and most feathers from all areas of the head, body, tail and wings, and in one chick pin feathers were already growing back in places (Fig 1). On this same day, two other chicks also exhibited PFL symptoms for the first time. Between 9 July and 11 July a further 3 chicks were found with PFL and we noted a final case in this month on 24 July. However, we also discovered an unbanded, medium-sized chick (estimated as 13-15 d of age) exhibiting PFL on 15 Aug (which is excluded from the analyses that follow).

The mean age of chicks when first exhibiting PFL was 18 (± 3.7) d (range: 15 – 26 d). Comparison between normal plumage development and that of chicks exhibiting PFL is shown in Fig 1. Although growth in mass for chicks exhibiting PFL appeared normal initially, from about 10 d of age until normal fledging age (~25 d) masses were generally lower than the colony average (Fig 2).

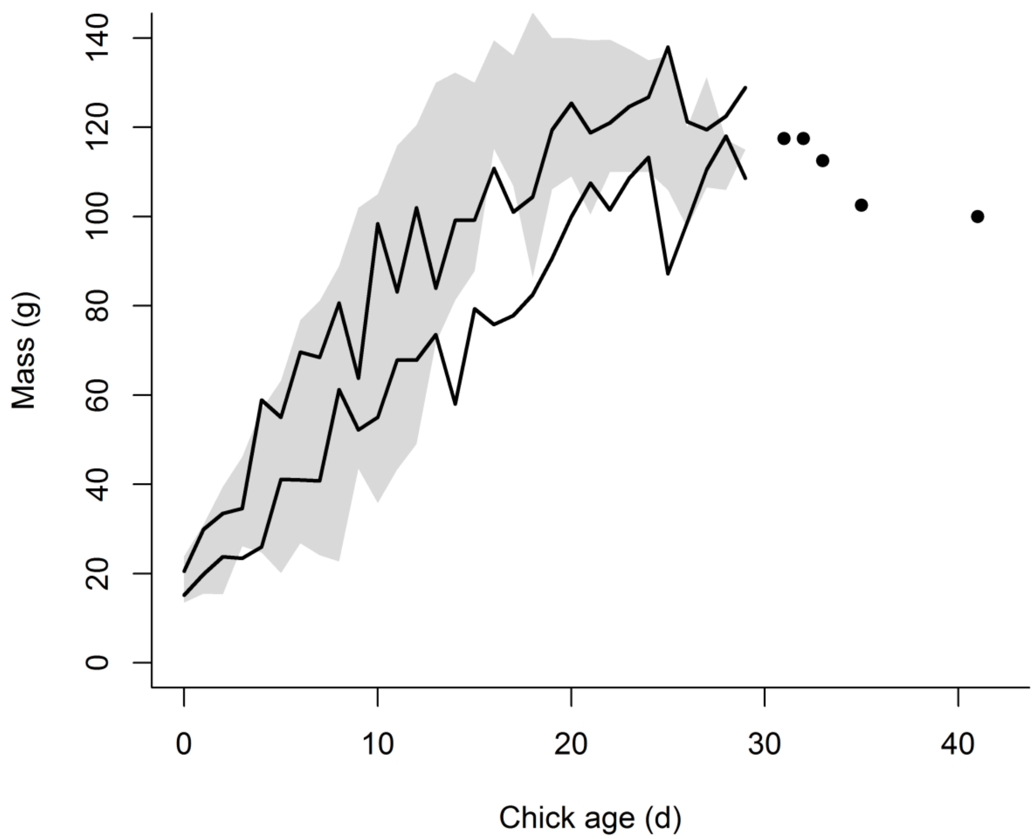

Figure 2. Growth in mass of the eight chicks exhibiting premature feather loss [PFL] (black lines = 95% confidence intervals) superimposed over the range of mass development for normal chicks (n = 159 chicks, grey shading = area between 95% confidence intervals). For PFL chicks measured later in development (> 30 d of age), when fewer measurements were available, individual data points are plotted.

Although median rates of both wing and tail growth were slightly higher for PFL chicks than normal chicks at similar ages, these differences were not statistically significant (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 = 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 = 0.17).

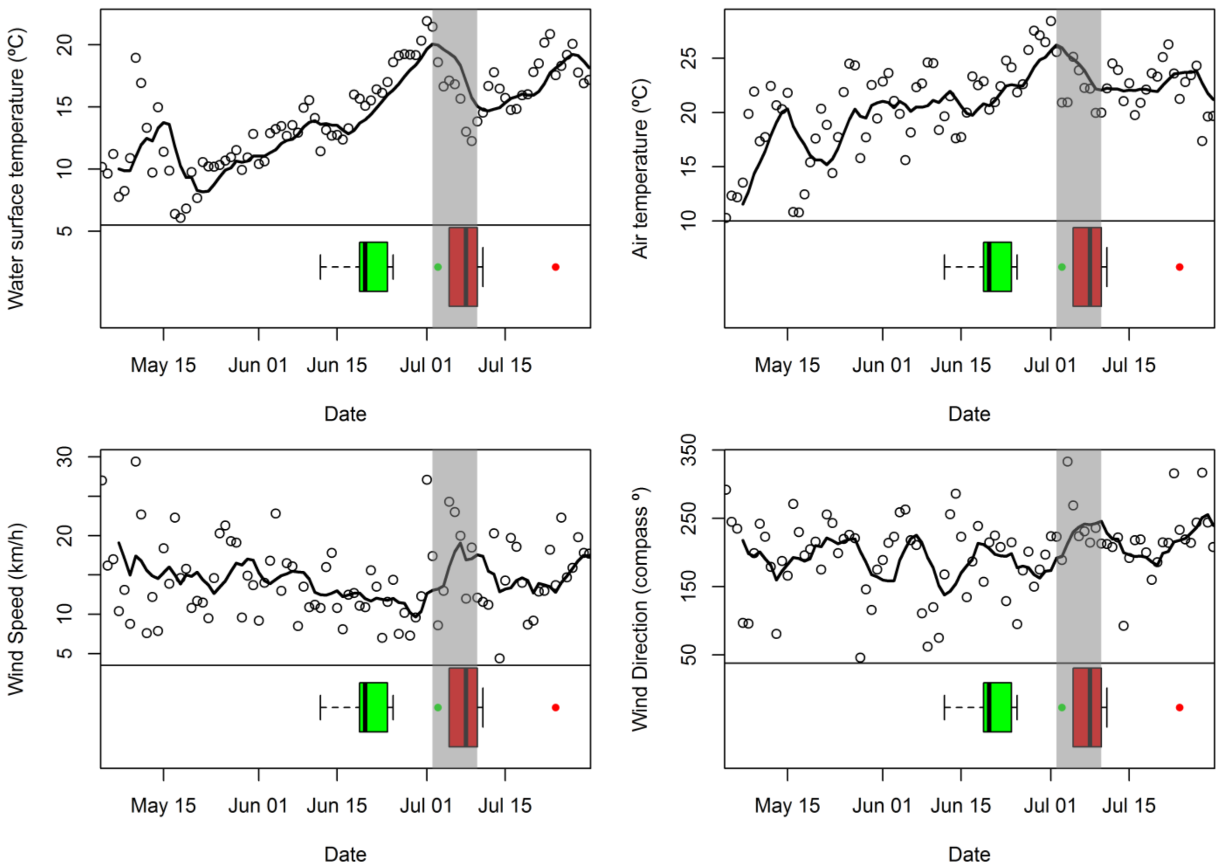

Figure 3. Changes in mean daily weather conditions, (a) near-shore lake surface temperature, (b) air temperature, (c) wind speed, and (d) wind direction (maximum gust), and correspondence with distribution of hatching dates (green boxplots and outlier) and dates of first exhibiting premature feather loss [PFL] (red boxplots and outlier). Trend lines are 7-day running average of the weather variable. Grey shading highlights the period of plummeting near-shore surface water temperatures (2 -10 July).

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

The period in which PFL was first detected in common tern chicks (and three days immediately prior to it; 2 – 10 July) was characterized by plummeting near-shore, lake surface temperatures (Fig 3a) and falling air temperatures (Fig 3b) as well as stronger southwesterly winds (Fig 3c & d) and rising atmospheric pressure (not shown). Minimum nighttime temperatures and maximum daytime temperatures were highly correlated with mean air temperature (r_{89} = 0.82 and r_{90} = 0.99, respectively) and showed the same response (not shown). However, there were no obvious changes in relative humidity or visibility at this time (also not shown).

Discussion

Premature feather loss in common terns: a returning phenomenon?

The premature feather loss (PFL) that we observed in common tern chicks at Gull Island in 2014 is similar in two ways to that described by researchers working on the Atlantic coast of North America in the early 1970s. Firstly, we only observed it in chicks when they were between 2 and 4 weeks of age, the same age as noted by Hays & Risebrough (1972) and similar to Gochfeld (1971) [3-5 weeks]. Secondly, in all our cases, shed feathers were replaced in all areas of the body but chicks appeared otherwise healthy and vigorous (Gochfeld 1971, Hays and Risebrough 1972). In fact, our PFL chicks, although they consequently had shorter wings and tails than normal chicks (Fig 1), showed no noticeable reduction in feather growth rates following feather loss. In fact, median rates of tail and wing growth were slightly higher for PFL chicks (although small sample size precluded statistical significance). This is unsurprising, since feather growth appears highly conserved in spite of nutritional stress (Bize et al. 2006, Lyons and Roby 2011).

There are, however, a few interesting differences between the PFL we observed and that previously documented. Complete feather loss (Fig 1) is the extreme in previous reports, where some birds only lost primaries and/or tail feathers (Gochfeld 1971, 1975, Hays and Risebrough 1972, Feare 1974, Bourne et al. 1977). Similarly, the incidence of PFL at our colony in 2014 was 5% (9/167) of all chicks, higher than that generally reported (0.5 – 1.1%; Hays and Risebrough 1972, Gochfeld 1975), although Feare (1974) reports 4.5% from a likely viral infection among sooty terns *Sterna fuscata*. In addition, unlike all other reports, we did not observe concurrent developmental abnormalities (e.g. crossed-bills , absence of down, aberrant limb development; Feare 1974, Gochfeld 1975, Bourne et al. 1977) in any other common tern chicks at our site. Colony-wide hatching success also did not appear any different from in previous years (Arnold & Oswald unpublished data), suggesting an absence of gross embryonic deformity (such situations were previously linked with PFL; Hays and Risebrough 1972). Interestingly, previous studies in the lower Great Lakes between 1971 and 1974 detected a high prevalence of deformity among common tern chicks (including one chick at Presqu’ile Provincial Park) but no cases of PFL (Gilbertson et al. 1976).

Although high mortality among chicks developing PFL has been previously reported (Hays and Risebrough 1972) or assumed (Gochfeld 1980), we only recovered one dead chick with this condition despite intensive searching. Although, dead chicks can desiccate and decompose quickly (Gochfeld 1971), because we visit each nest on a near-daily basis at this site, we generally recover a large majority of chicks that die at this late stage of development. Although it is possible that the parents relocated their territories > 30 m from the nest site (which has been observed in August in previous years when the colony was largely deserted) and the chicks died outside our search area, in 2014 there was still an active breeding colony on 11 Aug when we estimated that most of our PFL chicks would be capable of flight. Thus, it is unlikely that parents moved their chicks to such an extent or that dead chicks were removed by scavengers. Given this, and the seemly vigorous condition of PFL chicks when last seen (our intensive searches finished on 24 July for logistic reasons), we expect that many of these chicks eventually fledged. This would not be completely unprecedented since successful fledging of tern chicks that exhibit PFL during development has been previously reported (Hays and Risebrough 1972).

While growth rates of chick wings and tails of chicks recovering from PFL were not different from normal, PFL chicks had lower masses than normal chicks between 10 d of age and normal fledging age (~25 d). While some of this may be directly due to the absence of a plumage, previously documented cases have not found any differences in mass accompanying PFL (Gochfeld 1971) and the maximum differences we observed (~30 g on average at 18 d of age; Fig 2) were likely in excess of integument deficiencies. As chicks recovering from PFL appeared vigorous and highly aggressive in some cases, this is unlikely to result from a competitive disadvantage during provisioning events (e.g. Oswald et al. 2012) but instead a preferential channeling of energy to feather regrowth.

Other reports of PFL have been for chicks late in the breeding season (Gochfeld 1971) but at Gull Island in 2014 PFL was first observed in early July (mean hatching date across all chicks in 2014 was 30 June) and an active colony persisted well into mid-August. There was a striking association between the timing of occurrence of onset of PFL at Gull Island in 2014 and plummeting (up to 13 C˚) near-shore, lake surface temperatures, falling air temperatures, and strong southwesterly winds (Fig 3). Sustained strong winds may cause substantial mixing of cold, deep lake waters with warmer surface waters which, after a period of warm lake surface temperatures, can bring anoxic bacteria (such as Type E *Clostridium botulinum*) to the surface, causing botulism outbreaks (Perez-Fuentetaja et al. 2004, Chun et al. 2013). However, we did not see much evidence of botulism among ring-billed gulls or Caspian terns at this time (we have never encountered botulism in common terns at Gull Island), and systematic beach surveys at the Park did not report any unusual mortality events. It is possible, however, that the cooler, deep waters that mixed with near-shore waters contained, or vectored, sediment contaminated with pathogenic organisms or historical pollutants. In the early 1970s, there was evidence that PCBs might be responsible for gross deformities in chicks in Lake Ontario (although not PFL) (Gilbertson et al. 1976), as elsewhere (Ludwig et al. 1996), but research has largely debunked this idea (Kuiken et al. 1999), contaminant levels in common tern eggs have declined following legislative action (Weseloh et al. 1989) and recent monitoring (via long-term monitoring of contaminants in herring gull eggs) has not indicated a return to problematic contaminant levels (D. Crump, pers. comm). Since PFL in 2014 was observed within a matter of days after falling near-shore lake temperatures (Fig 3), this largely precludes bioaccumulation of contaminants (PCBs [Hays and Risebrough 1972] or mercury [Gochfeld 1980]) as causal agents (C Custer, pers. comm.).

Exposure to as yet unknown pathogens between 2 and 10 July 2014 seems the most likely preliminary explanation of PFL in common tern chicks at Gull Island. Most affected chicks were between 1-2 weeks of age during this time period, although affected one chick was hatched at this time and the egg of another chick that developed PFL in August was laid at this time. Thus, it is possible that the causal agent persisted in the environment or was communicated to the developing embryo from the parent. Pathogens such as algal toxins and botulism-causing bacteria (Bourne et al. 1977) or tick-borne (Feare 1974) or other viruses (Leeson and Walsh 2004, Ha et al. 2007) may have caused PFL in 2014. Possible viral infections can cause extensive feather loss, for example “French Molt” in budgerigars *Melopsittacus undulatus* (Katoh et al. 2010), and a similar mechanism been suggested for PFL in seabirds (Gochfeld 1975, Bourne et al. 1977). Feather loss, deformity and onset of molt, although not necessarily complete molt, are well studied in poultry and have also been associated with periods of starvation and nutritional deficiency (e.g. low protein diets, zinc, Vitamin E, and selenium; Leeson and Walsh 2004). Thus, although we currently favor exposure to pathogenic organisms as the causal mechanism we cannot rule out acute nutrient deficiency.

Towards formulating a research consensus

The re-emergence of PFL in common terns at Gull Island in 2014 is currently enigmatic but may indicate acute health risks for birds and other wildlife in the Lake Ontario region or beyond. Additionally, because some causes may have potential for human health risks (Bourne et al. 1977) a robust research plan is needed. We are therefore seeking the following information from the wider scientific community:

- *Reports of similar, unusual physiological phenomenon observed in wildlife within Lake Ontario or elsewhere in recent years*
- *Potential analytical approaches for analyzing current samples: shed feathers, re-growing coverts and one dead PFL chick*
- *Potential sampling protocols for future laboratory analysis if PFL reoccurs*
- *Information about possible events in early July 2014 in Lake Ontario that may explain PFL among common tern chicks*
- *Most appropriate funding sources to support follow-up and new sampling work*

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