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# Community-wide patterns of plastic ingestion in seabirds breeding at French Frigate Shoals, Northwestern Hawaiian Islands☆

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ABSTRACT

Between 2006 and 2013, we salvaged and necropsied 362 seabird specimens from Tern Island, French Frigate Shoals, Northwestern Hawaiian Islands. Plastic ingestion occurred in 11 of the 16 species sampled (68.75%), representing four orders, seven families, and five foraging guilds: four plunge-divers, two albatrosses, two nocturnal-foraging petrels, two tuna-birds, and one frigatebird. Moreover, we documented the first instance of ingestion in a previously unstudied species: the Brown Booby. Plastic prevalence (percent occurrence) ranged from 0% to 100%, with no significant differences across foraging guilds. However, occurrence was significantly higher in chicks versus adult conspecifics in the Black-footed Albatross, one of the three species where multiple age classes were sampled. While seabirds ingested a variety of plastic (foam, line, sheets), fragments were the most common and numerous type. In albatrosses and storm-petrels, the plastic occurrence in the two stomach chambers (the proventriculus and the ventriculus) was not significantly different.

## 1. Introduction

Seabirds are valuable biological indicators of changing marine ecosystems over short and long time scales, including the spatial distributions and temporal trends in pollutants (Burger and Gochfeld, 2004; Finkelstein et al., 2006; Gaston et al., 2009; Wilcox et al., 2015). In particular, due to the broad range of trophic levels, feeding guilds, and foraging habitats, different seabird species sample distinct oceanographic domains and food web components (Day et al., 1985; Sileo et al., 1989; Hyrenbach et al., 2009; Titmus and Hyrenbach, 2011). Furthermore, because seabirds breed on land, often in large colonies, they are readily accessible for study. In particular, oceanic islands with large numbers of concurrently breeding species are ideal sites for comparative studies of trophic ecology and pollutant loads across foraging guilds (Sileo et al., 1989; Robards et al., 1995; Keller et al., 2009; Winship et al., 2016). While previous studies have documented the widespread prevalence of plastic debris and other associated pollutants in seabirds (Tanaka et al., 2013; Lavers et al., 2014; Wilcox et al., 2015; Provencher et al., 2017), quantifying the occurrence and loads of plastic ingestion by seabird populations remains a research priority, and an important step for understanding the impacts of these pollutants on marine food webs (Lewison et al., 2012; Vegter et al., 2014).

Seabirds are increasingly being used as biological sensors of the levels and trends in marine plastic pollution (Ryan et al., 2009; Galgani et al., 2013; Wilcox et al., 2015; Provencher et al., 2017). For instance, the OSPAR commission (Oslo and Paris Conventions), comprising 15 European governments and the European Union (EU), established Ecological Quality Objectives (EcoQOs) for monitoring ecosystem health in the North Sea (ICES-WGSE, 2001). These EcoQOs establish an acceptable marine plastic debris target, defined as < 10% of Northern Fulmars (*Fulmarus glacialis*) having > 0.1 g of plastic in their stomach contents, which is quantified using 50–100 beached birds sampled over a five-year period. While this objective has not been met in all the monitored areas of the North Sea, it has provided a metric for quantifying plastic pollution trends over time (van Franeker et al., 2011). More recently, the European Commission identified trends in the amount and composition of litter ingested by marine animals as one of the four focus areas for marine debris monitoring, under the auspices of the European Marine Strategy Framework Directive (MSFD, 2008/56/EC) (Galgani et al., 2014). This decision (2010/477/EU) sets a precedent that could be adopted in other ocean regions afflicted by plastic pollution (e.g., Lavers and Bond, 2016).

Tons of floating marine plastic debris wash ashore on the Hawaiian archipelago every year, driven by large-scale oceanographic processes (Morishige et al., 2007; Barnes et al., 2009; Ribic et al., 2011). Located

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within the North Pacific subtropical gyre, roughly equidistant between America and Asia, the waters surrounding the Hawaiian archipelago are influenced by large-scale (1000s km) and small-scale (10s km) oceanographic features, which transport and accumulate marine debris (Howell et al., 2012; van Sebille et al., 2012; Cózar et al., 2014). Recent modeling efforts estimated that the North Pacific contains the greatest number and weight of floating plastic of the world's oceans ($199 \times 10^{10}$ pieces; $964 \times 10^{2}$ tons). In fact, the magnitude of plastic deposition in the Northwest Hawaiian Islands (NWHI) is so great that the Center for Biological Diversity has nominated the region as a superfund cleanup site (Rochman et al., 2013; Eriksen et al., 2014).

The rocky islets and coral atolls in the NWHI comprise some of the most important seabird colonies in the world, providing nesting habitat for roughly 5.5 million seabirds encompassing 22 species, and supporting over 99% and 95% of the global Laysan Albatross (LAAL, *Phoebastria immutabilis*) and Black-footed Albatross (BFAL, *Phoebastria nigripes*) breeding populations, respectively (Keller et al., 2009). A previous survey of plastic ingestion by Hawaiian seabirds breeding in the NWHI completed in 1986–1987, involving 1757 samples from 16 species sampled over five sites (Midway Island, Laysan Island, Tern Island, Nihoa Island, Pearl and Hermes Reef), documented widespread exposure, with 13 species ingesting plastic (Sileo et al., 1989). Yet, despite mounting evidence of increasing marine debris in the North Pacific, there has been no systematic survey of plastic ingestion by Hawaiian seabird populations in the last three decades.

This study aimed to characterize the occurrence and loads of ingested plastic by opportunistically necropsying naturally-deceased seabirds of multiple age classes (chicks, juveniles, adults) for the species nesting in the NWHI. More specifically, the goals of this study were to: (1) document current (2006–2013) community-wide patterns of plastic ingestion in the seabird species breeding on French Frigate Shoals (FFS); (2) establish a baseline for future standardized monitoring of plastic ingestion by NWHI seabirds; and (3) whenever sample sizes and methodologies allowed, compare current ingestion levels with historical records (1980s). Additionally, to inform future monitoring, we addressed three potential biases influencing the quantification of plastic ingestion rates, relating to: (1) differences in age classes within species; (2) ingestion of different plastic types (fragment, foam, line, sheet); and (3) disparities in plastic prevalence within the two stomach chambers (proventriculus and ventriculus) of tubenose species (belonging to the order Procellariiformes).

## 2. Methods

### 2.1. Study site

FFS, located at 23.870°N 166.284°W, is the largest atoll in the NWHI, lying roughly at the midpoint of the 2575 km long Hawaiian archipelago. Thirteen small named islands exist within FFS, most of which are shifting sandy spits. Tern Island (TI) is the largest island, with an area of 105,276 $m^2$ (26.014 acres), and a vegetation dominated by salt-tolerant and drought-resistant plants, characteristic of beach strand and coastal scrub habitats. FFS hosts populations of 19 of the 22 seabird species that breed in the NWHI, making it an ideal location for community-wide assessments. In particular, 17 of these species breed on TI, the site with of a U.S. Fish and Wildlife Service (USFWS) field station (Keller et al., 2009).

### 2.2. Specimen collections and necropsy

This opportunistic study targeted all age classes (chick/immature/adult) of all locally-breeding seabird species (Table 1). Age classes were defined following the criteria previously used by Sileo et al. (1989): C = chick (pre-fledging), J = juveniles (immature birds capable of sustained flight), A = adult (mature), and B = immature or adult (unclear if I or A). Age classes were assigned using three criteria (plumage, morphometrics, development of sexual organs), on the basis of species-specific breeding phenology and life history (Pyle, 1997; Pyle, 2008; Howell, 2010). Whenever possible, USFWS banding records were used to validate the age class assignments. To facilitate broader ecological comparisons, the species were also classified into six foraging guilds, following previous categorizations (Harrison et al., 1983; Dearborn et al., 2001). For the sake of consistency, we refer to the species using the American Ornithological Union species four-letter codes throughout the text, and in all tables and figures (Table 1, Chesser et al., 2016).

A total of 362 naturally-deceased seabirds of 16 species were collected opportunistically from TI starting in 2006, with specimens from 2010 to 2012 representing the bulk (98%) of the collections. While large samples sizes (≥ 20 specimens; NRC, 2009) were sought for all age classes of the 17 locally-breeding species, the sample sizes varied greatly across different species * age groups, due to ecological and logistical limitations. Namely, because the species vary in overall abundance and breeding phenology, in relation to the field work season (November–July) (Keller et al., 2009). Moreover, chicks were much more readily available than adults, due to their higher mortality rates. Thus, while some species * age groups surpassed our target (20 specimens), others yielded smaller sample sizes (Table 1).

All specimens were coded for freshness and completeness, upon collection (van Franeker, 2004). While specimens of different freshness levels were sampled, ranging from recently dead "very fresh" (FFF code) to "very old" (OOO code), only complete specimens were included in this study. Incomplete birds with signs of scavenging by crabs or missing parts, were discarded. Complete specimens with ruptured abdomens (i.e. albatross chicks) or stomachs (i.e., Tristram's Storm-petrel, TRSP, *Oceanodroma tristrami*) were collected, as long as the ingested plastics could be recovered from the bird's esophagus or by rinsing the body cavity. Specimens were necropsied in the field or frozen and returned to the lab in Oahu. All necropsies followed standardized protocols and were completed by trained personnel, with one of the authors in the lead (Work, 2000; van Franeker, 2004).

### 2.3. Stomach dissection and content processing

For each specimen, the stomach was removed and dissected using standardized protocols, and the gastrointestinal tracts were stored frozen prior to sorting and quantification in the lab (van Franeker, 2004; Barrett et al., 2007). To investigate plastic retention in Procellariiform species (albatrosses, petrels, shearwaters, storm-petrels) with two distinct stomach chambers, the contents of the proventriculus and ventriculus (or gizzard) were kept separate, whenever possible, for quantification (Ryan and Jackson, 1987; Youngren et al., submitted). For all other species with non-distinct stomach chambers (frigatebirds, boobies, terns, noddies), all stomach contents were analyzed together.

Stomach contents were sieved through a series of stacked 8-in. brass sieves (ASTM E-11) with 8-in. O-ring gaskets to seal between adjacent sieves and an 8-in. plastic bucket for drain. The topmost 0.5 mm sieve served as an aerator to prevent splashing/loss of contents. Contents were placed on the second 0.5 mm sieve, and the drain bucket caught water from the stacked sieves, and directed it to a 1 mm mesh catch used to ensure that plastic contents were not being lost in the stacked sieves. A hose attached to a sink faucet provided a high-pressure water source. This protocol was modified to deal with the small fragments ingested by TRSP, whereby the stomach samples were filtered using paper filters, rinsed and sorted by SMY (Youngren et al., submitted). All other samples were cleaned and sorted by DCR.

The sieved stomach contents were placed in water for further cleaning and sorting using light magnification (2 ×, 5 ×) and high power magnification under a binocular dissecting microscope (10–40 ×) (Motic Digital). All plastics were separated from the other stomach contents, and any remaining fouling was gently wiped away from the plastics. When needed, a small jewelry cleaner (35 W; 42,000