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Seabirds as regional biomonitors of legacy toxicants on an urbanized coastline

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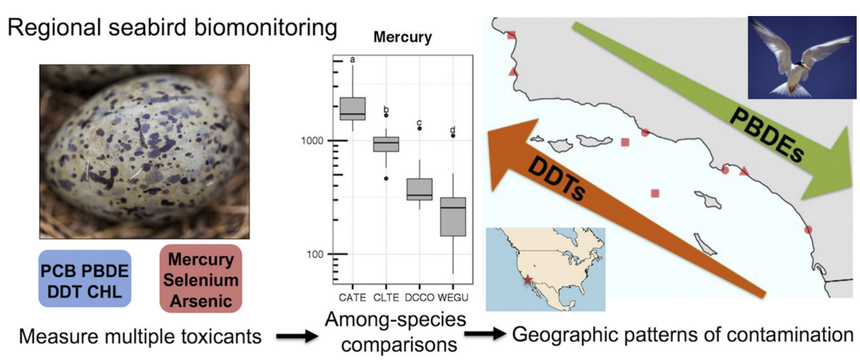
HIGHLIGHTS

- Coastal species are susceptible to mixtures of chemical pollution.
- We compared contaminant concentrations in seabird eggs across a regional water body.
- Legacy contaminants remain dispersed and persistent in seabirds in the SCB.
- Concentrations of contaminant classes and congeners displayed geographic patterns.
- Seabird contaminant monitoring informs remediation & management of coastal regions.

GRAPHICAL ABSTRACT



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ABSTRACT

Seabirds are often cited as sentinels of the marine environment, but are rarely used in traditional ocean and coastal contaminant monitoring. Four classes of persistent organic pollutants (POPs, $n = 68$) and three trace elements (mercury, selenium, and arsenic) were measured in the eggs of California least terns (*Sterna antillarum browni*), caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), and western gulls (*Larus occidentalis*) that nest in the Southern California Bight. Building on a periodic five year regional monitoring program, we measured contaminant exposure and assessed the utility of seabirds as regional contaminant biomonitors. We found that the eggs of larger, more piscivorous species generally had the highest concentrations of POPs and trace elements while California least terns had the lowest concentrations, except for mercury which was higher in least terns. As expected, DDT concentrations were elevated near the Palos Verdes Superfund site. However, we also detected a previously unknown latitudinal pattern in PBDE concentrations in least terns. POP congener profiles also confirmed differences in contamination in urban least tern colonies closest to urban centers. Though toxicants were at detectable levels across species and sites, concentrations were below those known to cause adverse effects in avian taxa and are steady or declining compared to previous studies in this region. Our results suggest that regional seabird monitoring can inform site-specific remediation and support management and protection of regionally-threatened wildlife and coastal systems. Integration of seabird contaminant data with traditional sediment, water, bivalve and fish monitoring is needed to further our understanding of exposure pathways and food web contaminant transfer.

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Abbreviations

Birds

CATE	Caspian tern
CLTE	California least tern
DCCO	Double-crested cormorant
WEGU	Western gull

Toxicants

POPs	persistent organic pollutants
CHLs	chlordanes
DDTs	dichlorodiphenyltrychloroethanes
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
SCB	Southern California Bight

1. Introduction

Human population density continues to increase in coastal areas worldwide, including coastal California (Crossett et al., 2004). Point source pollution, runoff, and atmospheric deposition associated with urban, suburban, agricultural, and industrial development has led to spikes in persistent organic pollutants (POPs) and trace elements in coastal environments (Elliott and Elliott, 2013; Schiff et al., 2001). While production of some toxicants is banned or closely regulated, persistent toxicants remain in coastal waters and sediments for decades and cycle through aquatic food webs. This is especially problematic for long-lived, top predators like seabirds, as many POPs and some trace elements are subject to bioaccumulation and biomagnification (Elliott, 2005; Rowe, 2008). At high concentrations, toxicants can reduce individual survival and reproduction, resulting in population decline (Bustnes et al., 2003; Hellou et al., 2013). Even at sub-lethal levels, these toxicants can impair physiological, immune, and reproductive function (Finkelstein et al., 2007; Tartu et al., 2013; Goutte et al., 2015) and in some species, combinations of toxicants even below effects thresholds have been linked to endocrine disruption (Silva et al., 2002; Bryan et al., 2005). Though effects vary by species, contaminant type, and concentration, the impacts have been observed in multiple taxa and are severe enough to warrant regular screening.

Despite their widespread distribution and ecological effects, multiple contaminant classes are rarely quantified among species or sites for regional analysis (but see Braune et al., 2002, Mallory and Braune, 2012). While single-site, single -species studies can provide data on species' vulnerability in one location, these analyses can overlook regional patterns of contaminant exposure, distant points of contamination, or fail to account for the mobility of marine taxa (Jarvis et al., 2007; Parnell et al., 2008). Given our nascent understanding of the synergistic or additive effects of multiple contaminant types (Finkelstein et al., 2007; Rowe, 2008; Goutte et al., 2015; Noyes and Lema, 2015), a multi-site and species approach can enhance our baseline knowledge of mixtures of toxicants present in impacted ecosystems. This information is particularly relevant along urbanized coastlines, where wildlife have higher exposure to a wide range of anthropogenic toxicants (Phillips et al., 1997; Schiff and Allen, 2000; Jarvis et al., 2007; Millow et al., 2015).

The Southern California Bight (SCB), which extends from Point Conception, CA to Cabo Colnett, Baja California, Mexico, is a seabird biodiversity hotspot that is home to many species of conservation concern, including the California least tern (*Sterna antillarum browni*; Gray, 1997). As high trophic level consumers, seabirds in the SCB are exposed to high concentrations of toxicants and declines in seabird populations in the SCB have been linked to exposure to several compounds, including DDT (dichlorodiphenyltrichloroethane) dispersal from the Palos Verdes Superfund site (Risebrough et al., 1967; Ohlendorf et al., 1985; Fry, 1994). Numerous other toxicants, including mercury (Hotham and Powell, 2000; Komoroske et al., 2012), selenium (Ohlendorf et al., 1985; Hotham and Powell, 2000), arsenic (Komoroske et al., 2011), PCBs (polychlorinated biphenyls, e.g. industrial and electrical byproducts, Fry, 1995, Schiff and Allen, 2000, Brown et al., 2006, Jarvis et al., 2007), PBDEs (polybrominated diphenyl ethers, e.g., flame retardants, Brown et al., 2006) and CHLs (chlordanes, Ohlendorf et al., 1985, Schiff and Allen, 2000), have also been detected in wildlife, sediments, and waters (Zeng et al., 2005; Dodder et al., 2012) in the SCB.

Although seabirds have been recognized as sentinels of marine systems (e.g., Burger and Gochfeld, 2002; Elliott and Elliott, 2013), most contaminant monitoring efforts have yet to include seabirds as part of the typically studied samples, a list that often includes water, sediment, bivalves, and fish (e.g., Zeng et al., 2005; Parnell et al., 2008; Dodder et al., 2012). Here, we assess the loads of the four classes of POPs and three trace elements in four seabird species nesting in the SCB to compare differences in toxicant concentrations within and among species, look for spatial trends in exposure levels within species, and consider the link between contaminant exposure and biological responses. Our research highlights the utility of seabird tissues and ecology in examining spatial, temporal, and biologically-relevant trends in regional contaminant biomonitoring.

2. Methods

2.1. Study species

Salvaged seabird eggs, i.e. eggs left at the end of a breeding season, have been demonstrated to serve as a robust tissue type for toxicant analyses (Hickey and Anderson, 1968; Braune et al., 2002; Burger, 2002; Mallory and Braune, 2012; Millow et al., 2015). Using salvaged eggs, we analyzed the egg contents of four seabird species: California least tern (*Sterna antillarum browni*), Caspian tern (*Hydroprogne caspia*), double-crested cormorant (*Phalacrocorax auritus*), and western gull (*Larus occidentalis*). The selected species differ in foraging strategies and ranges, which are known to influence toxicant load (Mallory and Braune, 2012; Lavoie et al., 2015). For instance, California least terns and Caspian terns are both plunge diving, piscivorous birds, but may consume different prey species (Ohlendorf et al., 1985; Lewison and Deutschman, 2014). Double-crested cormorants are also piscivorous and forage by diving at depth. Western gulls are generalists that forage on the ocean surface as well as on marine, coastal, and terrestrial subsidies. These differences in foraging strategies and prey items may result in varying contamination levels in the eggs of each species.

2.2. Egg collection, processing, and chemical analysis

Salvaged eggs were collected from the nests of the study species from 16 sites in the Southern California Bight (Fig. 1, Table A.1) during spring and summer 2013. Egg collection was executed by permitted individuals at each site in accordance with State, Federal and IACUC guidelines. All collected eggs were determined to be fail-to-hatch eggs due to nest abandonment or were taken as part of a depredation effort. Eggs were placed in cardboard cartons and transported to the US Fish and Wildlife Office in Carlsbad, CA for subsequent morphometric analysis, and other laboratories as described in the Supporting Information for chemical analysis. Eggs were processed using standard protocols for avian egg harvest for chemical analysis, embryo examination, and shell thickness determination. Because a single least tern egg does not contain enough material for all chemical analyses, we combined the contents of multiple least tern eggs into composite samples until sufficient matrix was present for subsequent analyses. Least tern composite samples comprised the egg contents of 2–4 eggs collected from the