Chemosphere 84 (2011) 544–552

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Pollutants and the health of green sea turtles resident to an urbanized estuary in San Diego, CA

Lisa M. Komoroske [a,b,*], Rebecca L. Lewison [a], Jeffrey A. Seminoff [c], Dimitri D. Deheyn [d], Peter H. Dutton [c]

[a] Department of Biology and Coastal & Marine Institute, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182-4614, United States
[b] Department of Wildlife, Fish & Conservation Biology, University of California at Davis, Davis, CA 95616, United States
[c] Southwest Fisheries Science Center, NOAA–National Marine Fisheries Service, 8604 La Jolla Shores Drive, La Jolla, CA 92093, United States
[d] Marine Biology Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA 92093-0202, United States

ARTICLE INFO

Article history:
Received 22 November 2010
Received in revised form 30 March 2011
Accepted 7 April 2011
Available online 6 May 2011

Keywords:
Coastal urbanization
Contaminant
Chelonia mydas
Habitat quality
Sea turtle
San Diego Bay

ABSTRACT

Rapid expansion of coastal anthropogenic development means that critical foraging and developmental habitats often occur near highly polluted and urbanized environments. Although coastal contamination is widespread, the impact this has on long-lived vertebrates like the green turtle (*Chelonia mydas*) is unclear because traditional experimental methods cannot be applied. We coupled minimally invasive sampling techniques with health assessments to quantify contaminant patterns in a population of green turtles resident to San Diego Bay, CA, a highly urbanized and contaminated estuary. Several chemicals were correlated with turtle size, suggesting possible differences in physiological processes or habitat utilization between life stages. With the exception of mercury, higher concentrations of carapace metals as well as 4,4′-dichlorodiphenyldichloroethylene (DDE) and γ chlordane in blood plasma relative to other sea turtle studies raises important questions about the chemical risks to turtles resident to San Diego Bay. Mercury concentrations exceeded immune function *no-effects* thresholds and increased carapace metal loads were correlated with higher levels of multiple health markers. These results indicate immunological and physiological effects studies are needed in this population. Our results give insight into the potential conservation risk contaminants pose to sea turtles inhabiting this contaminated coastal habitat, and highlight the need to better manage and mitigate contaminant exposure in San Diego Bay.

1. Introduction

Nearshore ecosystems support high levels of biodiversity across a wide range of taxa (Gray, 1997). However, many coastal areas are also subject to intense human activities that can severely degrade habitat quality. Resulting effects on coastal species are difficult to quantify because reduced habitat quality rarely leads to immediate mortality and may take years to manifest in long-lived species. Though coastal urbanization is widely cited as a threat to marine megafauna, currently few studies exist on the effects of pollutants and other stressors related to habitat alteration.

Marine turtles rely on nearshore areas as critical foraging and developmental habitats (Morreale and Standora, 2005), and may be particularly sensitive to the alteration of these ecosystems due to their delayed maturation and longevity (NMFS, 1998). Populations have declined in many regions (Chaloupka et al., 2004), making marine turtle conservation a high priority (NMFS, 1998). Traditional conservation actions have focused on direct threats to populations (e.g. harvest and incidental catch) with little consideration given to sublethal risks from coastal contamination (but see Keller and McClellan-Green, 2004; Keller et al., 2004a; Day et al., 2007; van de Merwe et al., 2010a). Recent attention to the importance of marine spatial planning highlights the need for accurate data on cumulative impacts across threats (Crowder and Norse, 2008). Consequently, evaluating effects of anthropogenic factors is now a top global research priority for marine turtle conservation, with the specific impacts of pollution on marine turtles identified as an area needing study (Hamann et al., 2010).

Chemical contaminants such as metals and persistent organic pollutants (POPs), e.g. pesticides, flame retardants and polychlorinated biphenyls (PCBs), make their way into coastal environments from a range of industrial, agricultural and urban sources (Sindermann, 2006). These chemicals can exert lethal and sublethal effects in wildlife, including alteration of neurological and immune function, growth, and reproduction (Beyer et al., 1996). For species like marine turtles, the required experimental toxicology research to determine these relationships is not feasible because the manipulation of long-lived endangered species is rarely permitted. A

* Corresponding author at: Department of Wildlife, Fish, and Conservation Biology, University of California at Davis, One Shields Avenue, 1088 Academic Surge, Davis, CA 95616, United States. Tel./fax: +1 530 752 2505.
E-mail address: lmkomoroske@ucdavis.edu (L.M. Komoroske).

0045-6535/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2011.04.023

substantial number of studies have quantified chemical pollutants in sea turtle tissues, however, the majority are post-mortem analyses of stranded turtles or fisheries bycatch (for reviews see Pugh and Becker, 2001; Storelli and Marcotrigiano, 2003). Although these data are valuable, such specimens may not be representative of the overall population, and cannot provide information on physiological effects.

Recent studies have demonstrated the advantages of non-lethal methods for monitoring contaminants and health in protected species (Keller et al., 2004b; Day et al., 2007; van de Merwe et al., 2010b). Blood concentrations of many pollutants can be a proxy for recent exposure, while keratinous scutes reflect a longer-term signature because they incorporate elements over time. With the advent of precise instruments capable of detecting pollutants at very low levels, pollutants in blood and shell can now be accurately determined to monitor levels in wild populations. When paired with quantitative health assessments, these methods have the potential to identify relationships between contaminants and physiological condition (Keller et al., 2004a; Day et al., 2007), providing information on the conservation risk that contamination poses to sea turtles.

San Diego Bay (CA, USA) is the natural northern range limit for the east Pacific green turtle (*Chelonia mydas*) along the Pacific coast of North America, and harbors a resident population of post-pelagic juveniles and adults (Dutton and McDonald, 1990). Though the bay has been identified as critical habitat and foraging area for the green turtle, it is also highly urbanized and listed as an impaired water body (Fairey et al., 1998). Development activities such as dredging reintroduce chemicals from historical sources (e.g. PCBs) back into coastal food webs, while present-day pollution in San Diego Bay stems from a large variety of commercial and residential activities (Fairey et al., 1998). Of particular concern are polybrominated diphenylethers (PBDEs), used predominantly as flame-retardants. Many PBDEs have recently been banned due to a growing body of evidence that they have toxic and bioaccumulative effects (Hites, 2004), but previously manufactured products containing PBDEs are still in widespread use and contribute to the growing environmental reservoirs of these chemicals (Ross et al., 2009). The bay provides protection from other threats green turtles face throughout their range, but chronic pollutant exposure in this estuary may pose a threat to sea turtles inhabiting this and other contaminated coastal regions. Utilizing a combination of non-lethal techniques, we quantify levels of contaminants in the San Diego Bay green turtle population and consider possible sublethal effects to this long-lived endangered species residing in a highly urbanized nearshore environment.

2. Methods

2.1. Study site and sample collection

This study was conducted in San Diego Bay, CA (N32°40.0′ W117°13.7′), a semi-enclosed estuarine system encompassing over 57 km^2 (Fig. 1). The bay is bordered by San Diego, a densely populated metropolis with 2.9 million people, and is the terminus of three watersheds encompassing over 660 km^2. Connected to the Pacific Ocean by a narrow northwest channel, water residence time is largely driven by tidal pumping. Depths range between 5–15 m, and temperatures vary seasonally from approximately 13–25 °C (Delgadillo-Hinojosa et al., 2008).

Live green turtles were captured between November 2007 and March 2009 using large mesh gillnets deployed from a National Marine Fisheries Service vessel across three areas in the South Bay channel of San Diego Bay (Fig. 1). Thirty-one unique individuals were captured, with seven turtles being captured two of more

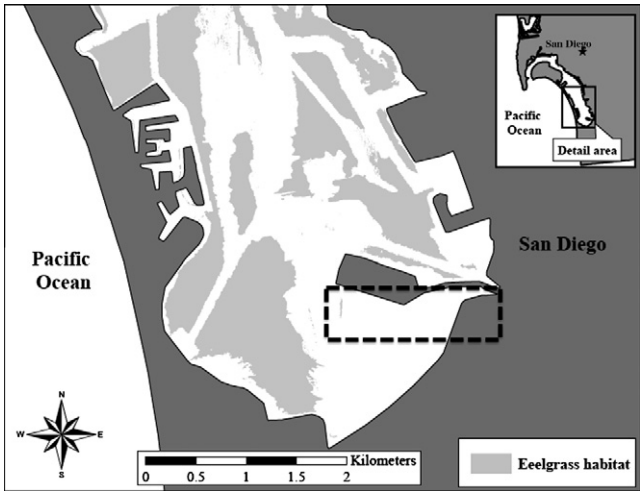

Fig. 1. Map of study area in south San Diego Bay, CA, USA (N32°40.0′ W117°13.7′). Dark gray shading denotes land surrounding the bay. Water area is shown in white, with submerged eelgrass habitat depicted by light gray shading. Green turtles utilize all regions of the Bay, particularly the southern portion (inset) and eelgrass habitats. Dashed black box denotes South Bay channel where turtles were captured.

times (total = 41). We classified turtle life stages according to Seminoff et al. (2003), including juveniles (sex undetermined) and adults (male and female). As part of a broader ecological study examining the demography and foraging ecology of green turtles, individuals were brought ashore for morphological measurements and tagging. At this time, blood and carapace tissue were sampled according to modified protocols of Owens and Ruiz (1980) and Day et al. (2005), respectively (see Appendix).

2.2. Contaminant analyses and health assessments

We conducted trace metal analyses for whole blood, red blood cells, and carapace at Scripps Institution of Oceanography (University of California, San Diego) and the Institute for Integrated Research in Materials Environments and Society (California State University, Long Beach). We used inductively coupled plasma mass spectrometry (ICP-MS) and cold vapor atomic fluorescence spectrometry for trace metals and mercury, respectively, according to modified methods of Deheyn and Latz (2006). Percent recovery of standard reference materials ranged from 59.9% to 155% (Tables A1 and A2). Blood plasma was analyzed for a panel of persistent organic pollutants (POPs) at Mississippi Chemical Laboratory (Mississippi State, MS) according to modifications of EPA Methods 3545, 3620B, and 8081A. Spiked sample recoveries ranged from 57.3% to 110.0% (Table A3). Clinical health panels were conducted by a reptilian specialist at IDEXX (Irvine, CA) within 24 h.

2.3. Statistical analysis

We conducted all statistical analyses using SYSTAT 12 (Chicago, IL). We determined contaminant level differences among juveniles, adult male and adult females with one-way analyses of variance (ANOVA) for each element or chemical. For metals, we used paired *t-tests* for each element to determine differences between sample matrices. We used Pearson and Spearman correlation coefficients to identify relationships (1) within and across sample types (i.e. red blood cells, whole blood, carapace), and (2) among curved carapace length (CCL, an indicator of age), health markers, and chemicals. Recaptures were only sampled if caught after a minimum of 1 month to limit non-independence. Because we used blood