Implications of Sublethal Lead Exposure In Avian Scavengers

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IMPLICATIONS OF SUBLETHAL LEAD EXPOSURE IN AVIAN SCAVENGERS

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Abstract.—The high incidence of lead exposure being reported in avian scavengers is not surprising, considering the frequency with which lead ammunition residues occur in the remains of gun-killed animals. Population impacts likely are underestimated because of latency of effect, low probability of carcass discovery, and the difficulty of detecting the health manifestations of sublethal lead burdens. There are good reasons to expect that sublethal lead is harmful, especially in view of the considerable body of human health literature providing evidence of multiple adverse effects associated with very small amounts of lead, together with the implication that lead physiology is broadly similar among vertebrates. A detailed experimental study of growth and behavior involving dosing and controls in developing Herring Gulls (*Larus argentatus*), and reports of morphological and physiological responses in other species, offer insight into the implications of sublethal lead exposure on wild populations. Further studies of lead's sublethal effects on avian scavengers are therefore warranted and may benefit from advancements in bone-lead measurement and feather analysis, particularly where lead burdens can be benignly assessed among live birds in the field.

Key Words: *California Condor*; Gymnogyps californianus; *avian scavengers*; *bullet fragments*; *lead poisoning*; *raptors*; *sublethal lead exposure*.

CONSECUENCIAS DE LA EXPOSICIÓN A DOSIS SUBLETALES DE PLOMO EN AVES CARROÑERAS

Resumen.—La elevada incidencia de exposición al plomo que está siendo reportada en aves carroñeras no es sorprendente, considerando la frecuencia con la que se encuentran residuos de municiones de plomo en animales muertos por bala. Los impactos a nivel poblacional probablemente son subestimados debido a la latencia del efecto, a la baja probabilidad de encontrar un cadáver y a la dificultad de detectar manifestaciones en la salud de cargas subletales de plomo. Existen buenas razones para creer que el plomo subletal es dañino, especialmente considerando la considerable cantidad de bibliografía sobre salud humana que brinda evidencia de los múltiples efectos adversos asociados con pequeñas cantidades de plomo, junto con la implicación de que la fisiología del plomo es, en líneas generales, similar entre los vertebrados. Un detallado estudio experimental del crecimiento y comportamiento que involucró dosificaciones y controles en individuos en desarrollo de *Larus argentatus* e informes sobre respuestas morfológicas y fisiológicas en otras especies, ofrecen pistas sobre las consecuencias de la exposición a dosis subletales de plomo en poblaciones salvajes. Por lo tanto, se necesitan mayores estudios sobre los efectos de dosis subletales de plomo en aves carroñeras. Estos estudios pueden beneficiarse de los avances en la medición de plomo en los huesos y del análisis de las plumas, particularmente donde las cargas de plomo pueden ser determinadas de forma benigna en aves vivas en el campo.

[Traducción del equipo editorial]

Bird mortality is often associated with evidence that can be used to identify the causal agent, consider population impact, and suggest corrective action when the source is human-related. Even poisons can be directly implicated (Otieno et al. 2010), or they can impart discoverable manifestations, as with DDT and its effects on avian reproduction. Some toxins are slow to act, however, with the result that fatalities lie far from exposure sites and, even if discovered after a time, may offer little remaining evidence of source. Such is the case with lead ingestion, which often takes weeks to debilitate and kill, and whose incidence is accordingly obscure in many species. Lead-poisoned California Condors (*Gymnogyps californianus*), for example, frequently develop crop stasis or its equivalent and go to the ground where they starve unseen (Parish et al. 2007).

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Sublethal impacts of lead on population health and individual well-being are even more difficult to assess (see Scheuhammer 1987, Franson 1996 for reviews). Lead in the blood stream is sequestered in soft tissue and ultimately in bone, where it may remain for decades in molecular positions normally occupied by calcium, the bonding properties of which lead mimics (Pokras and Kneeland 2009). The role of calcium in synaptic action means that neural networks where lead has been substituted are subject to malfunction. This generality of distribution and effect, often subtle, obscures lead's full range of manifestations.

Over the last decade, epidemiologists analyzing human-health statistical data have produced dozens of studies associating a variety of neurological and systemic disorders with surprisingly low levels of lead in tissue, and some of these manifestations have the potential to reduce longevity and impair reproduction. Weisskopf et al. (2009) found positive associations between bone lead levels and overall human mortality, and between bone lead and death from cardiovascular disease. Lead has been shown to impair motor function (Cecil et al. 2008), cognitive ability (Lanphear et al. 2005, Jusko et al. 2008), intellectual development (Schnaas et al. 2006), kidney function (Ekong et al. 2006), endocrine function (Doumouchtsis et al. 2009), somatic growth, and reproductive development (Hauser et al. 2008). Lead is associated with spontaneous abortion (Borja-Aburto et al. 1999), decreased brain volume (Cecil et al. 2008), and behavioral abnormalities (Needleman et al. 2002, Braun et al. 2006). The fact that few, if any, basic differences exist between the chemistry of lead in human bodies and that in birds implies that multiple sublethal consequences of lead exposure also should exist in avian populations (Pokras and Kneeland 2009).

The quantitative tools of epidemiology, so productive in revealing lead-related human pathology, are rarely applicable to the kinds of data available for wild birds. Progress in assessing sublethal lead effects in birds has therefore been modest compared to that for humans, and has mainly dealt with developmental impairment. Dosing experiments performed by Burger and Gochfield (2000) on developing Herring Gulls (*Larus argentatus*) demonstrated impacts on growth, motor coordination, behavioral development, thermoregulation, depth perception, and individual recognition in both the laboratory and the wild. Hoffman et al. (1985a, 1985b) showed multiple morphological and physiological responses in dosing experiments of nestling American Kestrels (*Falco sparverius*), including reductions in hematocrit and the hemic pathway enzyme δ-aminolevulinic acid dehydratase, although Pattee (1985) found no effect on survival, egg-laying, or fertility in experimental lead-dosing of adult kestrels, and little if any transfer of lead to embryos. Low doses of lead that increased blood levels to only 1.6 μg/dl caused reduced hematocrit in developing Red-tailed Hawks (*Buteo jamaicensis*; Redig et al. 1991). Lead-exposed Japanese Quail (*Coturnix japonica*) laid fewer eggs (Edens and Garlich 1983), and Ringed Turtle-Doves (*Streptopelia risoria*) showed testicular degeneration and sperm reduction (Kendall et al. 1981, Veit et al. 1983).

Although much more work is needed, the weight of current evidence, together with the inference from human studies, suggests that sublethal lead exposure can influence avian demography (Burger 1995, Scheuhammer and Norris 1996). Nowhere is this possibility more likely than in large, long-lived avian scavengers where the incidence of exposure is often high (Cade 2007, Mateo 2009, Pain et al. 2009). Ingestion of shotgun pellets in waterbird carrion has long been known to poison eagles (Scheuhammer and Norris 1996, Kramer and Redig 1997, Mateo 2009), and such knowledge contributed to restrictions on the use of lead for waterfowl hunting in the United States (Anderson et al. 2000). Eagles are also vulnerable to ingesting the numerous small lead fragments that typically remain in the offal piles and unrecovered carcasses of ungulates and other animals killed with standard lead-based rifle bullets (Iwata et al. 2000, Hunt et al. 2006, Krone et al. 2009); in one study, 90% of discarded offal piles of deer contained bullet fragments and 50% contained more than 100 fragments (Hunt et al. 2006). Other frequent scavengers of rifle-killed animal remains include condors, Old World vultures, buteos, and ravens (Craighead and Bedrosian 2008, Mateo 2009, see Fisher et al. 2006 for review). Green et al. (2008) concluded that the California Condor population introduced to Arizona is inviable without blood-lead monitoring, treatment of lead-poisoned condors, and programs effective in encouraging the use of non-lead bullets by deer and elk hunters (Sieg et al. 2009).

The apparent regularity with which California Condors ingest lead in Arizona and Utah may, by inference, also be expected to expose them to lead's sublethal consequences. Repeated individual exposure might well produce a latency of population impact, in that accumulated lead may predispose organs to decreased function or eventual failure. Particularly bothersome are the implications of multiple exposures over weeks or months (Parish et al. 2007, Green et al. 2008). Birds with high bone lead levels, or possibly confounding contaminant burdens or other environmental stressors, over time may incur greater risk of death or reproductive impairment from additional lead exposure. The slow development of condor nestlings—5–6 mo from hatching to fledging—increases the potential for them to consume lead during the period of greatest vulnerability to its permanent effects. Fortunately, in Arizona, the ungulate hunting seasons (the period of highest lead availability) normally occur just after fledging.

Gangoso et al. (2008) found lead-associated reductions in bone mineralization and, by inference, greater bone fragility in wild Egyptian Vultures (*Neophron percnopterus*), an effect that could influence the outcome of collisions or other limb stresses. Mute Swans (*Cygnus olor*) with moderately elevated blood-lead levels showed a significantly higher incidence of collisions with power lines than those with low or high levels (Kelly and Kelly 2005). The authors interpreted the results as suggesting that moderate lead levels impaired the swans but did not prevent them from flying and colliding with the lines, whereas high lead levels rendered them too weak to fly and therefore not subject to power line collisions.

The lack of basic knowledge of lead exposure rates, fatalities, and body burdens among wild avian populations, and the unknown degree to which sublethal lead stores affect vital rates, impart a degree of uncertainty to demographic predictions (Baas et al. 2009). Blood assay is the most commonly employed method for assessing lead exposure, but the brief half-life of lead in bird blood (Fry and Mauer [2003] estimated 13 d for California Condors) results in a weak and confusing profile of exposure history unless blood is tested frequently. Monitoring exposure in condor populations has been difficult because they are wide-ranging, and testing is accordingly opportunistic (Parish et al. 2007). It is conceivable that studies might benefit from blood assays for standard human markers of systemic abnormality known to be lead-related. Lead analysis of organs such as liver and kidney are useful in the diagnosis of scavenger fatalities, but these tissues are often unavailable because blowflies (Calliphoridae) destroy them prior to carcass acquisition. Measuring lead concentrations sequentially along the length of growing feathers appears a promising method of assessing the chronology of exposure events (Finkelstein et al. 2010) and offers a way to assess exposure in live birds, given that samples can be harmlessly collected. Such studies would benefit from work with captive birds to establish feather growth rates and annual molt sequences where appropriate.

Lead in bone appears to be the best measure of overall body burden. A variety of raptors have been found to contain elevated bone lead levels, some very high, and those showing the highest levels have been species that tend to consume the discarded remains of game animals (Komosa and Kitowski 2008, Komosa et al. 2009). Lead in bone collected from fatalities can be assayed at reasonable prices by a variety of commercial laboratories using inductively coupled plasma mass spectrometry. Quantitative studies of this kind could be used to further examine *ex post facto* the relation of lead levels to collision risk when compared with other forms of diagnosed mortality (Kelly and Kelly 2005). Knowledge of bone lead levels in live birds would be even more valuable in assessing the effects of subclinical lead burdens, because such data could be more directly compared with behavior, reproductive performance, longevity, and other traits. *In vivo* bone lead measurement by means of K-shell x-ray fluorescence, so applicable to human subjects (Ahmed et al. 2005), could be highly valuable in bird studies if technical problems relating to differences in bone density and configuration could be overcome. Such considerations underscore the need to develop noninvasive or otherwise humane techniques, equipment, and methods of calibration specific to lead-exposed species of birds.

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