Cytochrome P4501A biomarker indication of the timeline of chronic exposure of Barrow•s goldeneyes to residual *Exxon Valdez* oil

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We examined hepatic EROD activity, as an indicator of CYP1A induction, in Barrow•s goldeneyes captured in areas oiled during the 1989 *Exxon Valdez* spill and those from nearby unoiled areas. We found that average EROD activity differed between areas during 2005, although the magnitude of the difference was reduced relative to a previous study from 1996/1997, and we found that areas did not differ by 2009. Similarly, we found that the proportion of individuals captured from oiled areas with elevated EROD activity (P 2 times unoiled average) declined from 41% in winter 1996/1997 to 10% in 2005 and 15% in 2009. This work adds to a body of literature describing the timelines over which vertebrates were exposed to residual *Exxon Valdez* oil and indicates that, for Barrow•s goldeneyes in Prince William Sound, exposure persisted for many years with evidence of substantially reduced exposure by 2 decades after the spill.

1. Introduction

Some of the oil released during the 1989 *Exxon Valdez* oil spill has remained in intertidal sediments of Prince William Sound, Alaska over the subsequent two decades (Boehm et al., 2008; Short et al., 2004, 2006). Estimates of the quantity remaining (Boehm to be a reliable indicator of oil exposure in birds generally and sea ducks speci“cally (Esler, 2008; Miles et al., 2007).

Elevated indicators of CYP1A induction have been documented in a number of vertebrate species sampled from areas of Prince William Sound, Alaska that received oil during the 1989 for the null model would indicate that variables considered in other candidate models did not explain important variation in the response.

The model with the lowest AIC value corrected for small sample size (AIC_c) was considered to have the strongest support from the data among the models considered. Another metric, AIC_c weight (w), was calculated for each model; AIC_c weights sum to 1.0 across the entire model set and provide a measure of relative support for candidate models. The variables included in the models with highest support are considered to explain important variation in the response. Parameter likelihoods, which are the sums of w for all models including a given parameter, indicate the relative support for that variable, taking into account model uncertainty. Parameter likelihoods close to 1 indicate strong support. Finally, we calculated weighted parameter estimates and associated unconditional standard errors, which are estimates of the size, direction, and associated variation of effects of variables calculated across the set of candidate models.

To evaluate trends in EROD activity over time, we applied corrections to account for between-year differences in reported values. Between-year EROD values varied substantially across laboratory runs. In consultation with the laboratories, we con“rmed that, although within-year comparisons between areas were valid, between-year comparisons were not appropriate without correction (Esler, 2008). Therefore, we created an index for CYP1A values, in which we set average EROD activity for Barrow•s goldeneyes that we captured at our unoiled areas (Montague Island and Culross Passage) to 1 for each year, and we adjusted all values accordingly within the same sample year (Esler, 2008). When comparing data across years, this index assumes that oil exposure, and hence EROD activity, at unoiled sites was the same across years, which is reasonable because these are relatively pristine areas with little inter-annual variation in human activity and, hence, little variation in occurrence or concentrations of CYP1A-inducing compounds. Indexed values and their associated variation were graphically contrasted across years and oiling history status. For each year, we also calculated the proportion of individuals captured in oiled areas with elevated EROD activity, which we de“ned as a value P 2 times the average value on unoiled areas for that year. We recognize that this criteria for elevation is arbitrary, but is one that we considered to represent a biologically meaningful difference in CYP1A expression. This metric was designed to evaluate whether the incidence of exposure changed over time.

3. Results

We captured 79 Barrow•s goldeneyes over the course of our study; sample sizes by year, area, sex, and age are described in Table 1. For samples collected in 2005, the model with area and individual attributes as explanatory variables ($w = 0.44$) and the model with area only ($w = 0.41$) had essentially equivalent support (Table 2). The best-supported model had an R^2 of 0.30. The remaining two models had little support (Table 2), with differences in AIC_c values from the best-supported model (ΔAIC_c) of >3.0 and $w < 0.10$. These “ndings indicated that area explained important variation in EROD activity in 2005, with some support for explanatory value of likelihood of 0.96. Age provided little explanatory value, as the SE exceeded the absolute value of the parameter estimate. However, both sex and mass seemed to explain important variation in EROD in 2009. Speci“cally, females had lower average EROD activity than males, and EROD activity was negatively related to body mass (Table 3).

found subtle effects of individual attributes, particularly in 2009. Speci“cally, males had higher average EROD activity and body mass was negatively related to EROD activity. Sex differences had not been found in harlequin ducks (Esler et al., 2010) or Barrow•s goldeneye in previous sampling periods. A subtle negative relationship between body mass and EROD was detected in harlequin ducks from winter 1998 (Esler et al., 2002), but not in harlequin ducks (Esler et al., 2010) or Barrow•s goldeneyes in most periods since 1998. Evidence for a slight relationship between body mass and EROD in Barrow•s goldeneyes in 2009 was surprising, particularly because there was little evidence of elevation in most individuals. We do not know whether our results for 2009 are spurious (i.e., artifacts of this speci“c data set) or whether they re”ect patterns in the population of interest.

Some authors have questioned whether oil spilled during the Exxon Valdez event can be assumed to be the primary source of CYP1A inducing compounds in oiled areas of Prince William Sound (Harwell and Gentile, 2006), recognizing that there may be multiple CYP1A-inducing compounds from multiple sources within a given area (Lee and Anderson, 2005). However, studies indicate that PAHs in the areas where elevated CYP1A was observed in vertebrates are predominately from the Exxon Valdez (Short et al., 2004), supporting the inference that Exxon Valdez oil was the inducing agent. Also, other studies (Trust et al., 2000; Ricca et al., 2010) considered the potential role of PCBs in observed CYP1A indication in harlequin ducks in Prince William Sound and determined that concentrations were very low and generally not related to CYP1A induction. In addition, Short et al. (2006) calculated that, given the distribution of residual Exxon Valdez oil through 2003, benthic foraging vertebrates were likely to encounter lingering oil during routine foraging activities. Finally, our results indicating declines in CYP1A induction in Barrow•s goldeneye over time were consistent with exposure to a source declining in availability over time, as would be expected with Exxon Valdez oil, rather than compounds predicted as constant over time such as atmospheric PCBs or oil from natural seeps. Our results for Barrow•s goldeneyes were encouraging in that they indicated declining exposure to residual Exxon Valdez oil in a previously-exposed species and, hence, progress towards ecosystem recovery.

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