Quantification of Injury to Benthic Resources from the Chalk Point Oil Spill on the Patuxent River

by

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Introduction

This report presents the quantification of benthic resource injury in the subtidal soft-bottom habitat following the Chalk Point oil spill of 7 April 2000. About 126,000 gallons of No. 2 and No. 6 fuel oil were released into upper Swanson Creek, which then spread into lower Swanson Creek and the Patuxent River. Quantification estimates are made possible by availability of results from (1) quantitative sampling in June 2000 and again in September 2000 in a Versar report by Llanso and Volstad (2001); (2) quantitative sampling in September 2000 in an Academy of Natural Sciences report by Osman (2001); (3) long-term multi-year sampling data from the Maryland Chesapeake Bay Long-term Benthic Monitoring Program (LTB); and (4) a growing body of scientific understanding of the effects of oil on marine benthic invertebrates. This published literature on impacts of petroleum hydrocarbons on benthic invertebrates was used to interpret the empirical field data and develop the conceptual and mechanistic basis for the injury quantification. By evaluating injury on a species-by-species basis and matching empirically demonstrated patterns of change temporally and spatially related to the spill to mechanistic understanding of known sensitivity to contaminants in those species, this quantification procedure yields the most scientifically defensible identification and quantification of injuries (Peterson 2001). Any alternative based on risk assessment modeling is characterized by much higher uncertainty and is biased towards underestimating injury for many reasons (Peterson 2001).

Methods

The approach taken to developing the injury quantification for subtidal benthic resources was to review the data contrasts and statistical analyses conducted in Llanso and Volstad (2001) and Osman (2001). Specifically the evidence for and against spill impacts to the soft-bottom benthos was assembled and organized by geographic area and time frame. The results of these statistical analyses, along with tables of data on average densities, were then used to identify those species or higher taxonomic groups that demonstrated responses, positive or negative, to the spill and the geographic extent and temporal duration of the responses. The biomass contrasts for each of those affected species or taxa were then used to estimate the magnitude of the lost production per unit area (m^{-2}), the area of the geographic region of each impact was then calculated by GIS based on the shoreline in the SCAT report (Entrix 2000), and the product of these latter two factors was computed to estimate the total biomass change induced by the oil spill at that sampling date for each affected taxon. Finally, an estimate of the biomass production lost in 2000 from the spill was made based on inferences from the density and biomass changes over the season and literature knowledge of the life histories of the affected species to integrate the production losses over the entire warm season of 2000. Projections of recovery and duration of injury in subsequent years (2001 and 2002) were made by examining the degree of convergence of oiled and unoiled areas in 2000 and by using the scientific literature on recovery rate of analogous taxonomic groups from past oil spills.

Results of Injury Demonstration

Patuxent River

There is little evidence that benthic impacts from the Chalk Point oil spill extended into the Patuxent River. The most rigorous and probably the statistically most powerful analysis on which this conclusion rests is the failure of a BACI (Before After Control Impact: Stewart-Oaten et al. 1986) analysis on total abundance of benthic organisms to reveal a statistically significant response to the spill or the data even to suggest a possible decline following the spill (Llanso and Volstad 2001: Fig. 8). This BACI analysis utilized an impact station in the Patuxent River near Chalk Point and compared it to an environmentally analogous control river site in the Chester River for which biannual sampling data extended back for 10 years prior to the spill (until 1990). The failure of this analysis to detect a spill response is not a problem of insufficient power but rather reflects a true lack of response in total benthic abundance.

The computations of the Benthic Index of Biotic Integrity (B-IBI) as a measure of the biotic health of the benthos in the Patuxent River also failed to exhibit any evidence of the Chalk Point oil spill extending into the River itself. The LTB monitoring stations sampled in the Patuxent River in September 2000 exhibited a pattern of benthic community degradation only well downstream of Chalk Point, typical of impacts of oxygen stress where waters are deeper and more strongly stratified, not evidence of an oil spill response (Llanso and Volstad 2001: Fig. 3).

The only suggestions of a potential impact of the oil spill on benthos in the Patuxent River come from examination and analysis of the long-term monitoring data in the Patuxent mainstem. A contrast of total abundance and biomass both show significantly lower values in June samples from 2000 after the spill than in the earlier 1990-1993 period (Llanso and Volstad 2001: Fig. 4). The bivalve *Rangia cuneata* appeared to explain most of the difference in biomass between June 2000 and earlier years. Shannon diversity and numbers of species failed to indicate any significant difference between the June 2000 and 1990-1993 years (Llanso and Volstad 2001: Fig. 4). Such differences among years cannot be unambiguously interpreted and cannot be used in isolation to infer impacts of the oil spill, when the BACI test that controls for inter-annual differences failed to reveal even a suggestion of an impact. *Rangia cuneata* populations are known to fluctuate greatly among years in response to its sensitivity to low temperatures and its reliance on higher salinity for successful recruitment (Hopkins 1973).

Sampling of the mainstem of the Patuxent River in September 2000 produced estimates of the Shannon species diversity, number of species, total benthic abundance, and biomass that did not differ significantly from the 1995-1999 summer samples (Llanso and Volstad 2001: Fig. 5). Consequently, this subsequent more intensive sampling of the river does not suggest any oil spill impact that is detectable in September 2000. Given that the impact to *Rangia cuneata* in upper Swanson Creek did appear to persist until at least the September sampling there (see below), this result further supports the interpretation that no oil spill impact appeared in the Patuxent River mainstem, even to *Rangia cuneata*. Nevertheless, it is possible that the oil spill effect on *Rangia cuneata* extended out of Swanson Creek and into the Patuxent River. The failure of the BACI test to exhibit an impact of the oil spill on total abundance of benthic invertebrates does not preclude the possibility of one of the component species showing an effect. Uncertainty exists about the spatial scope of the reduction in *Rangia cuneata* abundance following the Chalk Point oil spill.

Swanson Creek

There is strong evidence that the Chalk Point oil spill induced impacts to the subtidal benthic community and several large changes in several component taxa of the soft-bottom benthic community within Swanson Creek. Most of the responses were apparently limited to the upper Swanson Creek, but the most sensitive species among the dominant members of the community exhibited injury in lower Swanson Creek also. The injuries were evidenced in the June 2000 samples and recovery had only begun to occur by the September 2000 samplings. The empirical sampling evidence of injury is derived by first comparing upper Swanson Creek and lower Swanson Creek to Hunting Creek as a control. Where lower Swanson failed to demonstrate evidence of a response to the oil spill for a given taxon, then for that species or taxon, lower Swanson Creek and Hunting Creek were both used as control sites against which to judge the magnitude of the spill-related difference. The average biomass values were weighted equally in making such contrasts that used two control sites.

The Hunting Creek control is suitably located in geographic proximity about the same distance along the Patuxent and of similar size and area (Llanos and Volstad 2001: Fig. 3). Furthermore, sampling stations were positioned in similar habitat, allowing for justifiable contrasts of benthic populations and communities. Habitat information collected during sampling (Llanso and Volstad 2001: Appendices) shows similar mean station depths (1.0 m for upper Swanson, 1.1 m for lower Swanson, and 1.2 m for Hunting Creeks), silt/clay contents of sediments (84.9 % for upper Swanson, 90.5 % for lower Swanson, and 84.8 % for Hunting Creeks), and salinities (4.3 ppt for upper Swanson, 5.5 ppt for lower Swanson, and 6.0 ppt for Hunting Creeks). These similarities in salinity and sedimentology represent compelling grounds to consider the three geographic areas comparable for the purposes of inferring impacts of the oil spill. Because other factors also contribute to differences in benthic community composition and abundances of component taxa, however, some level of uncertainty persists in even the most rigorous method of inference of impact from spatial contrasts in the absence of information from before the spill. However, evidence of partial to complete convergence over time in the impacted resources at the three sites, as exists for this spill in the benthic data in the Llanso and Volstad (2001) report (see below), provides confirmation that the other unmeasured environmental variables do not seriously confound the ability to use spatial contrasts to infer injury.

The statistical tests conducted by Llanso and Volstad (2001) on various community parameters for the soft-bottom benthos provide the basis for a conclusion that the oil spill exerted an impact on upper Swanson Creek primarily and that the impact was reduced but still detectable in September 2000. In June 2000, upper Swanson Creek had significantly lower Shannon diversity and significantly higher species richness and total benthic abundance than lower Swanson Creek or the Hunting Creek control (Llanso and Volstad 2001: Fig. 9). These differences can be largely explained by the enhanced dominance by the spionid *Streblospio benedicti* in upper Swanson Creek and the enhanced numbers of polychaete species in that site. In September 2000, upper Swanson Creek exhibited significantly lower Shannon diversity and significantly lower total biomass than lower Swanson Creek or Hunting Creek (Llanso and Volstad 2001: Fig. 11). Shifts in relative abundance of taxonomic contribution to the communities were also evident, with upper Swanson Creek possessing relatively more polychaetes and fewer bivalves and crustaceans than lower Swanson or Hunting Creeks (Llanso and Volstad 2001: Figs. 12, 13). This pattern existed in both June 2000 and September 2000, although its intensity had decreased by September. Calculation of the index of community health (B-IBI) for the benthos from the September samples confirmed that upper Swanson Creek was still degraded at the end of the warm season relative to lower Swanson Creek and Hunting Creek. In upper Swanson Creek, only 2 of 10 sampling sites met benthic community restoration goals, while 8 were degraded or severely degraded (Llanso and Volstad 2001: Fig. 14). In contrast, 8 of the 10 sites in lower Swanson Creek met restoration goals and 6 of 9 (with the remaining one marginally degraded) sampling sites in Hunting Creek met restoration goals (Llanso and Volstad 2001: Fig. 14).

The species of high biomass and production in Swanson Creek that exhibited detectable changes in abundance and biomass are two bivalve molluscs, *Macoma balthica* and *Rangia cuneata*, the amphipod *Leptocheirus plumulosus*, and a group of largely spionid polychaetes (Table 1). The oligochaete *Tubificoides* spp. also exhibited differences in abundances among creek sites in June 2000, but this species did not represent one of the biomass dominants in the system (Llanso and Volstad 2001). *Macoma balthica* exhibited a pattern of dramatically lower density in upper Swanson Creek than in the control areas of lower Swanson Creek and Hunting Creek during both the June and September 2000 samplings (Table 1). *Macoma balthica* is a species with known sensitivity to mortality from oil exposure (Shaw et al. 1976), so the experimental support exists in the literature for the conclusion from the Llanso and Vostad (2001) sampling data that the oil spill decreased the abundance of this species in upper Swanson Creek through acute mortality. *Rangia cuneata* exhibited a similar but less strong pattern of lower density in upper Swanson Creek than in lower Swanson Creek or in Hunting Creek during the Llanso and Volstad (2001) June sampling (Table 1). By September, the *Rangia* abundance differences had narrowed considerably but only because of dramatic reductions in abundance in the control creeks, not from any increase or recovery in upper Swanson Creek (Table 1). Both *Macoma balthica* and *Rangia cuneata* are classified as pollution sensitive species in the Chesapeake Bay B-IBI (Weisburg et al. 1997). For both *Macoma balthica* and *Rangia cuneata*, the densities in lower Swanson Creek were actually intermediate between upper Swanson and Hunting Creek (Table 1), raising the possibility that the oil impact also affected these bivalves in lower Swanson also but to a lesser degree than in upper Swanson. One interpretation of the density patterns in *Rangia cuneata* after the oil spill is that effects did indeed extend not only to lower Swanson Creek but also into the Patuxent River, where analogous reductions in density were suggested by the sampling data in Llanso and Volstad (2001). This interpretation cannot be fully discounted, but the typically high variability of *Rangia cuneata* abundance (Hopkins 1973) renders the support for such a conclusion relatively weak.

The burrowing amphipod *Leptocheirus plumulosus* exhibited complete absence from upper Swanson Creek and an almost 98 % lower density in lower Swanson Creek than in the control Hunting Creek in June 2000 (Table 1) using data in Llanso and Volstad (2001). By September 2000, *Leptocheirus* had not returned to upper Swanson Creek, but the densities in lower Swanson Creek and the Hunting Creek control had converged through apparent increases in abundance in lower Swanson Creek and a dramatic decline in abundance in Hunting Creek (Table 1). Sampling in late September 2000 of the heavily oiled site in Swanson Creek and in the control Hunting Creek by Osman (2001) confirmed the absence of *Leptocheirus* in Swanson and its presence in Hunting Creek. Amphipods are typically among the most sensitive taxa to oil pollution, with dramatic, often long-term (typically multi-year) declines documented in experimental studies and in impact assessments (Bonsdorff and Nelson 1981, Elmgren et al. 1983, Dauvin 1987, Kingston et al. 1995, Jewett et al. 1999). Because of their known sensitivity to contaminants, amphipods including *Leptocheirus plumulosus* are commonly used in laboratory tests to assess the toxicity of sediments (Schlekat et al. 1992, U.S. EPA 1994). In addition, field and laboratory studies with *Leptocheirus plumulosus* indicate that it is indeed a good indicator of sediment contamination (McGee et al. 1999). Consequently, there is strong mechanistic support in the literature for the conclusions that the abundant amphipod *Leptocheirus plumulosus* suffered mortality from the Chalk Point oil spill, that this impact extended over both upper and lower Swanson Creek in June 2000, but that only upper Swanson was still affected in September 2000 (Table 1). No field sampling was conducted in Swanson Creek after September 2000, so the duration of injury to amphipods can only be inferred from the literature of past impacts to sensitive amphipods from oil spills. Dauvin (1987) demonstrated impacts of the Amoco Cadiz oil spill to peracarid amphipods that lasted for nearly a decade, while Jewett et al. (1999) showed that isaeid and phoxocephalid amphipods had not fully recovered 6 years after the Exxon Valdez oil spill. Consequently, impacts on *Leptocheirus plumulosus* in upper Swanson Creek probably extended into subsequent years. In the absence of empirical field data beyond September 2000 and given the impossibility of measuring future change before it has happened, a reasonable estimate for duration of impact to this highly sensitive species that had not initiated recovery in upper Swanson Creek by September 2000 extends the impact through both generations in 2001 and the first brood of spring 2002. This expectation represents a balance between assuming immediate recovery in upper Swanson Creek in 2001, for which there is no evidence, and assuming that impacts on amphipod production stretched out for 6 or more years, as evidenced by other oil spills (Dauvin 1987, Jewett et al. 1999).

In contrast to the two bivalve molluscs and the aorid amphipod, polychaetes, driven almost exclusively by a guild of spionids, exhibited much higher densities in the upper Swanson Creek than in lower Swanson Creek or in Hunting Creek (Table 1), using the June 2000 sampling results reported in Llanso and Volstad (2001). The species involved in this contrast were primarily the spionids *Streblospio benedicti* and *Hobsonia florida,* and a capitellid, *Heteromastus filiformis* (Llanso and Volstad 2001). By September 2000, dramatic reductions in abundance of polychaetes had occurred at all three creek areas, creating near or complete convergence between the most heavily oiled upper Swanson Creek and its controls of lower Swanson Creek and Hunting Creek (Table 1). The enhancement of certain sedentary polychaetes like capitellids and spionids that can feed on surface organic particles is consistent with a high incidence of opportunism in that phylum, which typically exhibits positive responses to organic enrichment, even driven by petroleum hydrocarbons (Pearson and Rosenberg 1978, Gray 1982, Conan 1982, Swartz et al. 1986, Warwick and Clarke 1993, Peterson et al. 1996, Jewett et al. 1996, Peterson 2001). Consequently, there is good empirical literature support and mechanistic understanding to reach a conclusion that this difference in polychaete abundance between upper Swanson Creek and the two controls, lower Swanson Creek and Hunting Creek, represents evidence of a density enhancement by the spill. This enhancement was evident in Llanso and Volstad's (2001) June 2000 sampling data but had largely disappeared by their September 2000 sampling (Table 1). The mechanism of enhancement probably involves organic enrichment from the hydrocarbons and oil-degrading microbes, but it may also reflect initiation of succession after removal of the bivalve biomass dominants by the oil toxicity.

Results of Injury Quantification

The only compelling evidence of injury to subtidal benthic resources comes from Swanson Creek. The injury is most appropriately quantified by using biomass rather than numerical density because biomass represents a better standard that can be used to estimate lost production. This creates a standard unit that is comparable across species and taxa, of special importance if restoration of damages cannot be done precisely in kind. In addition, biomass production better reflects the value of a taxon as energy for transfer to higher trophic levels and as a biogeochemical processor of materials within the ecosystem. These are the two ecosystem services of greatest concern in any compensation or restoration.

The average biomass per m^2 of each major taxon can be computed for upper Swanson Creek, lower Swanson Creek, and the Hunting Creek from sample data provided in Llanso and Volstad (2001: Appendices). Table 2 provides these means for the June 2000 and Table 3 for the September 2000 samplings in units of Ash Free Dry Weight (AFDW). Assuming that the bivalve injury was restricted to upper Swanson Creek and that the somewhat lower June 2000 densities of both *Macoma balthica* and *Rangia cuneata* in lower Swanson Creek than in Hunting Creek (Table 1) are not reflective of a significant decline in lower Swanson Creek, then the bivalve biomass lost from the spill is 1.14 g m^{-2} as estimated from June data or 2.73 g m^{-2} as estimated from the September data. There is no evidence in the numerical density data (Table 1) of intense recruitment of any of the injured bivalves during the 2000 summer period, so the increase in the magnitude of the biomass difference largely reflects growth and production foregone during summer. Thus, this higher (September 2000) estimate of biomass injury to bivalves is a more complete one. Because growth slows dramatically as water cools in the fall (Holland et al. 1987), and because *Macoma balthica* is largely an annual species with strong year classes living little more than a year (Holland et al. 1987), the difference in biomass at the end of the warm season in September represents a reasonable estimate of total production lost from the oil spill during 2000. While *Rangia* has the potential to live 5-6 years (Tenore et al. 1968), the *Rangia* abundance in Hunting Creek in September dropped to approximately 10% of the June numbers. Thus for the year 2000, treating *Rangia* as an annual represents a reasonable estimate of the injury. To calculate the injury, the loss of 2.73 g m^{-2} is then multiplied by the area affected (about 708,000 m^2 of upper Swanson Creek) to yield the total bivalve biomass production lost in 2000, 1,932.8 kg (Table 4).

The total biomass production lost by the amphipod *Leptocheirus plumulosus* requires two separate calculations, one for June when injury extended from upper Swanson Creek through lower Swanson Creek, and a second for September, when only upper Swanson Creek remained impacted (Table 1). This species produces multiple broods per year and reproduction is continuous from May to November, with peaks of reproduction and population growth in spring and fall (Spencer and McGee 2001). Hence, an estimation of injury that sums the biomass differences documented in June and September represents the best estimate of *Leptocheirus* biomass production lost in a single year. In June 2000, the lost amphipod production was 0.1067 g m^{-2} in upper Swanson Creek and 0.1024 g m^{-2} in lower Swanson Creek (Table 4). Lower Swanson Creek has an area of about 1,320,000 m^2. Consequently, the total biomass production lost from the spring population peak is the sum of the products of loss per unit area and total area for each of the two segments of the creek, or 75.5 kg for upper Swanson Creek and 135.2 kg for lower Swanson Creek (Table 4). The September 2000 injury, presumably to the second population peak, only appeared in upper Swanson Creek and amounted to 42.6 kg of biomass production lost (Table 4). Thus the total *Leptocheirus* amphipod production lost from the oil spill in 2000 was 253.3 kg (Table 4). Although *Leptocheirus plumulosus* injury may have extended for many years, in the absence of multiple years of sampling, we assume that only three additional broods were affected, those of spring 2001, late summer 2001, and spring 2002. We also assume that only heavily oiled upper Swanson Creek continued to exhibit this injury. Thus we add another

75.5 + 42.6 + 75.5 kg of injury (totaling an additional 193.6 kg) corresponding to loss of the spring 2001, summer 2001, and spring 2002 broods from upper Swanson Creek, followed by complete recovery for all successive generations and years (Table 5). Thus, the total lost production estimated for *Leptocheirus plumulosus* is 446.9 kg. If more than two broods of *Leptocheirus* were affected annually or if impacts continued for longer than spring 2002, then this estimate of production lost is an underestimate.

The enhancement of production of polychaetes, largely spionids but also a capitellid, should be considered as partial mitigation for the loss of bivalve and amphipod production. These small polychaetes, like the injured bivalves *Macoma balthica* and *Rangia cuneata* and the injured amphipod *Leptocheirus plumulosus*, to some degree serve a role as prey for higher trophic level consumers in the system. In specific, hogchokers, mummichogs, and striped killifish are likely consumers of these small polychaetes (Homer and Boynton 1978). The bivalve molluscs of this system are prey for generally larger predators, importantly, blue crabs, white catfish, white perch, yellow perch, and overwintering ducks like canvasbacks (Lovvorn 1987, Hines et al. 1990). The amphipods are likely prey for all of the fishes that consume either polychaetes or bivalves (Hines et al. 1990). Because of their greater longevity and their greater capacity to filter water, the bivalves *Rangia cuneata* (a suspension feeder) and *Macoma balthica* (a facultative suspension/deposit feeder) probably serve a more important biogeochemical function in protecting water quality of the system than the polychaetes, implying that the biomass credit for enhanced polychaete production should not be credited against lost bivalve production on a one-to-one basis. Similarly, substantially more of the amphipods produced are expected to be preyed upon by higher trophic levels than the opportunistic polychaetes because amphipods and other small crustaceans are highly preferred fish foods and these sessile, opportunistic polychaetes typically die from food limitation and decompose in the sediments in large numbers (Marsh and Tenore (1990). Thus, production of opportunistic polychaetes also should not be credited against amphipod production on a one-to-one basis. The biomass enhancement of polychaetes was greatest in June 2000 (Table 1), when it represented 0.349 g m^{-2}. Totaled over the affected area of upper Swanson Creek, the oil spill resulted in 247.1 kg of increased polychaete production (Table 4). The enhancement in abundance was no longer evident in September (Table 1), implying that only one brood was likely affected. The decline in abundance of polychaetes in upper Swanson Creek between the June and September samplings (Table 1) to the point of convergence with abundance in the control Hunting Creek probably represents evidence of the combined effects of starvation because of limited food resources (Holland et al. 1987, Marsh and Tenore 1990) and predation (Holland et al. 1980), implying a partial trophic transfer for this unnaturally high level of polychaete production. Holland et al. (1980) showed that predation during spring and summer on *Streblospio benedicti* and *Macoma balthica* explained much of the sharp seasonal decline of these two species in muddy-sand habitats of Chesapeake Bay. Other studies (Holland et al. 1987, Marsh and Tenore 1990) imply that food limitation is the cause of the summer crash in abundances of opportunistic polychaetes in estuarine systems, including the Chesapeake Bay. A full credit for the enhanced production of polychaetes of 247.1 kg is not warranted because of the high likelihood that a substantial fraction of this production of opportunists suffered food limitation, died, and decomposed. A credit of 50% might account fairly for the existence of two credible and well-supported alternative fates for the opportunistic polychaetes. That would reduce the total AFDW injury of subtidal benthos by 123.6 kg (Table 5).

The net loss of production by subtidal benthic invertebrates from the April 200 Chalk Point oil spill thus involves summing the losses to each taxon by year and then applying partial credit for the enhancement of opportunistic polychaetes (Table 5). In 2000, lost bivalve production was 1,932.8 kg, and lost *Leptocheirus plumulosus* production was 253.3 kg. The additional losses of *Leptocheirus plumulosus* production are projected to be another 118.1 kg in 2001 and 75.5 kg in 2002, totaling an additional 193.6 kg. Thus the total injury to amphipods, not discounted by year of occurrence, was estimated to be 446.9 kg. Giving a 50% credit for enhancement of production by opportunistic polychaetes reduces overall injury by 123.6 kg. Consequently, the undiscounted sum of all injuries and credits to the subtidal benthos is 2,256.1 kg of AFDW. Because these injuries occur in different years, discounting is required to sum them. Assuming that restoration is initiated in 2002, we apply discounting accordingly to express these injuries to subtidal benthic invertebrates in 2002, using the standard discount rate of 3% annually. This requires application of two years of discounting (multiplication by 1.03) for injuries in 2000, one year of discounting for injuries in 2001, and no discounting for injuries expected in 2002. This set of calculations (Table 5) yields a net injury of 2,385.3 kg of AFDW discounted to year 2002. For every year that passes beyond 2002 before restoration is initiated, this number requires further adjustment by multiplication by the annual discount rate of 3%.

The estimation of benthic injury identified in this report is a conservative estimate, for three reasons. First, the calculations assume that the lower densities of both *Macoma balthica* and *Rangia cuneata* in lower Swanson Creek compared to the control Hunting Creek observed in June 2000 (Table 1) do not indicate bivalve injury extending into lower Swanson Creek. If this does indicate a true bivalve injury in lower Swanson Creek, then the bivalve injury from the spill would be enhanced by 324.1 kg of additional production lost. This figure comes from the same method used in Table 4, that produces an estimated difference in biomass density between lower Swanson Creek and Hunting Creek in June 2000 of 0.246 g m^{-2} or 324.1 kg total summing over the whole area of lower Swanson Creek. Furthermore, the lower density of *Rangia cuneata* in the Patuxent River near the convergence with Swanson Creek is also assumed to be the consequence of natural variation and not an impact of the oil spill. If injury to *Rangia cuneata* actually extended into the Patuxent River, then our estimate fails to include it. Second, the calculations of benthic production lost from the oil spill in Table 4 make the assumption that only 2 cohorts in 2000, 2 cohorts in 2001, and 1 cohort in 2002 of *Leptocheirus plumulosus* were affected and one cohort in 2000 of *Macoma balthica*. Because *Leptocheirus plumulosus* achieves multiple broods during the summer May-to-September warm season with a peak in the October/November period (Spencer and McGee 2001), the estimates in Table 4 are conservative. Similarly, *Macoma balthica* produces a new cohort each year in the fall-to-spring time period (Holland et al. 1987), so its next cohort too may have suffered an impact if there was elevated residual contamination. Third, all the calculations of biomass production lost (or gained) as impacts of the Chalk Point oil spill apply to the 2000 year, with effects through spring 2002 limited to amphipods. No fall 2000 or any 2001 sampling data exist to assess empirically whether impacts persisted so as to influence production in subsequent years. The most likely of the impacts to persist beyond spring 2002 would be those to the amphipod *Leptocheirus plumulosus*, arguing from its evident greater sensitivity (it alone unambiguously revealed an impact that extended throughout Swanson Creek: Table 1) and from the multi-year duration of impacts to other amphipods in other oil spills (e.g., Dauvin 1987, Jewett et al. 1999). *Leptocheirus plumulosus* had apparently recovered in lower Swanson Creek by September 2000, but when recovery in the more directly oiled upper Swanson Creek might be predicted to occur is uncertain. Absent sampling in summer 2001, assuming recovery of *Leptocheirus plumulosus* in upper Swanson Creek after the first brood of spring 2002 on the basis of the recovery dynamics from June to September in lower Swanson Creek and on the basis of prediction from multi-year recovery periods for other amphipods following oil spills is accompanied by some uncertainty. As species somewhat less sensitive to contaminants, the two bivalves *Macoma balthica* and *Rangia cuneata* can be predicted to recover quickly enough that injury will not also recur in 2001.

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Table 1. Average density m^{-2} of the species and higher taxa that showed the greatest responses to the Chalk Point oil spill of April 2000.

Species/Taxa	June 2000			Sept 2000		
	Upp Sw	Low Sw	Hu	Upp Sw	Low Sw	Hu
Polychaetes (total) (mostly spionids)	10,633.7	622.4	1232.8	386.4	25.3	315.1
Bivalves (total)	46.0	144.6	294.4	26.8	186.3	193.2
Malcoma balthica	15.3	55.9	108.1	0	133.4	165.6
Macoma mitchelli	7.7	19.7	18.4	29.9	48.3	9.2
Rangia cuneata	23.0	69.0	167.9	6.9	4.6	18.4
Crustaceans (total)	214.7	105.2	1214.4	73.6	250.7	262.2
Cyathura polita	161.0	78.9	110.4	66.7	78.2	64.4
Leptocheirus plumulosus	0	16.4	1044.2	0	172.5	170.2

Upp Sw = Upper Swanson Creek (spill source)
Low Sw = Lower Swanson Creek
Hu = Hunting Creek

Table 2. Average gm AFDW biomass m^{-2} of all higher taxa in June 2000 after the Chalk Point oil spill of April 2000.

Taxon	**Upper Swanson (n = 3)**	**Lower Swanson (n = 7)**	**Hunting (n = 10)**
Polychaetes (mostly spionids)	.6011	.2701	.2337
Bivalve molluscs	.1273	1.1451	1.3906
Crustaceans	.2860	.0872	.2375
Nemerteans	.0828	.0118	.0235
Tubificids	.0069	.0035	.0045
Gastropod molluscs	.0004	.0022	.0078
Insect larvae	.0008	.00003	.0022
Burrowing anemones	.0529	0	.0007

Table 3. Average gm AFDW biomass m^{-2} of all higher taxa in Sept. 2000 after the April 2000 Chalk Point oil spill

Taxon	**Upper Swanson (n = 10)**	**Lower Swanson (n = 10)**	**Hunting (n = 10)**
Polychaetes (mostly spionids)	.4945	.0252	.0515
Bivalve molluscs	.2298	3.5031	2.4187
Crustaceans	.2327	.3227	.2513
Nemerteans	.0745	.0196	.0281
Tubificids	.0030	.0031	.0045
Gastropod molluscs	0	0	0
Insect larvae	.0029	.0283	.0119
Burrowing anemones	.0004	0	0
Others	———	*Low*	———

Table 4. Estimation of subtidal benthos injury during 2000 in units of AFDW biomass production lost for Chalk Point oil spill of April 2000.

Injured or affected resource	**Date**	**Biomass difference (Impact-Control)**	**Affected area**	**Total biomass change over affected area**	**Biomass production lost[a] in 2000[b]**
Bivalve molluscs (mostly *Macoma balthica*, also *Rangia cuneata*)	June Sept	-1.14 g m^{-2} -2.73 g m^{-2}	708,000 m^2 708,000 m^2	-807.1 Kg -1,932.8 Kg	-1,932.8 Kg
Polychaetes (mostly spionids, also capitellids)	June	+0.349 g m^{-2}	708,000 m^2	+247.1 Kg	+247.1 Kg
Crustacean amphipod					
Leptocheirus plumulosus	June	-0.1067 g m^{-2} in Upper Sw	708,000 m^2	-75.5 Kg	
	June	-0.1024 g m^{-2} in Lower Sw	1,320,000 m^2	-135.2 Kg	
	Sept	-0.0602 g m^{-2} in Upper Sw	708,000 m^2	-42.6 Kg	-253.3 Kg

a = negative number means a loss in production
b = assumes 2000 impacts to a single cohort of bivalves, two cohorts of *Leptocheirus*; and only one cohort of polychaetes

Table 5. Summation across years and across taxa of injuries to subtidal benthos in units of biomass production lost (in kg of AFDW), with inclusion of discounting.

Injured or affected resource	**Biomass production lost (-) or gained (+) in Year:**			**Production discounted to 2002 basis**
	2000	**2001**	**2002**	
Bivalve molluscs	-1,932.8	0	0	-2,050.5
Leptocheirus plumulosus amphipod	-253.3	-118.1	-75.5	-465.9
Opportunistic[a] polychaetes	+123.6	0	0	+131.1
Total	-2,062.5	-118.1	-75.5	-2,385.3

a = the credit applied here is 50% of the enhancement in production (see text for explanation)

Comments on Draft Quantification of Injury to Benthic Resources from the Chalk Point Oil Spill on the Patuxent River

Prepared by:

A. Fred Holland,
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&
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I reviewed the document entitled "Draft Quantification of Injury to Benthic Resources from the Chalk Point Oil Spill on the Patuxent River" and the supporting information provided in the associated technical reports (Llanso and Volstad, 2001, Osman 2001). My review of this work is summarized below.

Overall Assessment

The data that were obtained for this study are of a high quality (e.g., few missing data, taxonomically complete, well summarized and presented) and were applied in a reasonable and through manner to develop a synthesis and conclusions about the impacts of the Chalk Point April 2000 Oil Spill on benthic resources in the Patuxent Estuary. The synthesis that was produced and the conclusions reached are reasonable and defensible. The assessment is consistent with the technical data provided. The conclusion that most of the damage from the Chalk Point Oil Spill was limited to Upper Swanson Creek is reasonable and valid. Upper Swanson Creek is probably the area where restoration efforts should be focused. If the benthos of upper Swanson Creek can be demonstrated to have recovered from the damage associated with the Chalk Point Oil Spill then it is reasonable to assume the rest of the system has recovered.

The use of a biomass standard to estimate ecological damage was an ecologically meaningful and prudent choice. As the assessment indicates, biomass has great ecological relevance (e.g., fish eat mass not numbers, energy flow is based on mass not numbers, the nutritional value of benthic biomass of the dominant biota at Chalk Point is relatively similar), lower variability, and can be used to evaluate the degree of restoration in a relatively unambiguous manner. Had the assessment been based on a biodiversity or abundance conclusions would have had greater uncertainty and less ecological relevance. This does not suggest that the biodiversity and abundance data should not be used in the assessment process. These parameters reinforce the validity of the biomass information and address damage to other ecological attributes of the ecosystem.

The assumptions made for the analyses used to quantify the ecological damage resulted in a conservative (i.e., minimal) estimate of the impact on benthic biomass. As the author indicates, less conservative assumptions and interpretations could have been made resulting in greater estimates of damage (e.g., "One interpretation of the density patterns in *Rangia cuneata* after the oil spill is that the effects did indeed extend not only into lower Swanson Creek but also into the Patuxent River") Therefore, both the extent and duration of the impact may have been underestimated. For example, rather than assume proportional damage (e.g., 25% of lower Swanson Creek was damaged), no impact was assumed for this stratum. It appears, however, from the data in Llanso and Volstad (2001) that some damage (*albeit* small) may have occurred in the upper portions of the lower stratum. In addition, impact on *Rangia* biomass was assessed as if this bivalve was an annual species; *Rangia*, however, is a relatively long-live benthic organism (>5 years) with highest production in later years. As a result, the damage to the productivity and filtering capacity of this clam is likely underestimated. Finally, the ecological value of the observed increases in polychaete biomass was treated as if they were equivalent (1:1) with the observed declines in bivalve biomass. The importance of bivalves as ecological filters is generally considered to be greater that of an equivalent mass of spionid polychaete. The assessment recognized this deficiency but did not adjust for it (e.g., weight the biomass data for the spionid polychaetes differently from the data for the bivalves) in any manner.

It is unfortunate that the sediment chemistry data that were collected were not processed and used to quantify the spatial extent of the exposure to spilled oil. The sediment chemistry information would have greatly reduced the uncertainty in the estimates of the spatial extent of the oiled sediments to which benthic organisms were exposed (i.e., the strata used to estimate damage would have been based on exposure data and geographical boundaries defined by less objective techniques). In addition, a single reference site (Hunting Creek) was the basis of most of the comparisons/contrasts used to quantify damage. Addition reference stations were sampled but the data collected for them were not processed. Failure to process the samples from addition reference sites increased the uncertainty associated with estimating the spatial extent of the damage from spilled oil.

Year-to-year, seasonal, and spatial variation in natural environmental conditions such as salinity, temperature, freshwater inflow, depth, sediment characteristics including total carbon, and other environmental parameters are known to affect the abundance and biomass of benthic stocks. The text of the document(s) reviewed, however, suggests that "Habitat information collected during sampling (Llanso and Volstad 2001: Appendices) shows similar mean station depths (1.0 m for upper Swanson, 1.1 m for lower Swanson, and 1.2 m for Hunting Creeks), silt/clay content of sediments (84.9% for upper Swanson, 90.5% for lower Swanson, and 84.8% for Hunting Creeks), and salinities (4.3 ppt for upper Swanson, 5.5 ppt for lower Swanson, and 6.0 ppt for Hunting Creeks)" implying these factors did not greatly influence benthic distributions in space and time. No analyses (e.g., regressions of environmental factors vs benthic biomass or abundance), however, were provided to support this statement, and no adjustments were made to the biomass/abundance data collected to account for differences among years or space due to "natural" environmental parameters. These data are available (e.g., Llanso and Volstad 2001: Appendices) and it is possible that these environmental parameters varied among stations and years in a manner that was associated with the distributions of benthic abundance and biomass. Preliminary correlations of just the Swanson Creek data suggest a relatively strong associations between *Strebliospio benedicti* and *Rangia cuneata* abundances and total carbon, silt/clay and even the small salinity gradient that occurred. Such adjustments (e.g., Analysis of Covariance using silt/clay content of sediments as a covariant) may have increased the sensitivity and power of the statistical contrasts evaluated (especially the contrasts across years). I **recommend** that preliminary analyses be conducted to validate that the environmental gradients among the sample sites were not a significant contributing factor to the observed distributional patterns. This analysis could be done in less than a manday using the data in Llanso and Volstad (2001). Correlations and regressions that account for less that 25% of the variance should probably be considered as unimportant and would not likely alter findings. Correlations that account for more than 25% of the variance may alter findings (either increasing or decreasing the estimated damage).

Assumptions

In order to conduct an assessment of the damage resulting from the Chalk Point April 2000 spill on the natural resources of the Patuxent Estuary it appears that the assessment made the following assumptions. I listed the assumptions to assist me in evaluating the reliability of the data and conclusions. These assumptions are reasonable and are likely result in a conservative estimate of ecological damage.

- Damage to intertidal habitats (mud flats) was assumed to be equivalent to that which occurred in subtidal areas (i.e., the aerial estimates for intertidal plus subtidal habitats were used as the geographical basis for the assessment and the subtidal benthic data were used as the biological basis for the damage assessment).

- Gradients in benthic distributions observed in Swanson were the result of the oil spill incident not due to changes in environmental conditions (e.g., salinity, depth, sediment characteristics, and the amount of emergent marsh vegetation).

- Watershed properties (size, land cover) in the drainage basins of the Swanson and Hunting Creeks were assumed to have similar effects upon benthic distributions.

- *Rangia* was assumed to be an annual species and *Leptocherius* was assumed to have an average of two broods over the summer period. These assumptions may have resulted in an underestimate of damage to *Rangia* and *Letocherius* biomass.

- The ecological value of a unit of benthic biomass is equivalent across the dominant species occurring at Chalk Point. This is probably true for the nutritional value of the dominant benthic biota at Chalk Point, but may not be true for other ecological attributes. For example, the filtering value of bivalves may be superior to that of polychaetes.

- Chronic impacts from the oil spill were minimal and the majority of the damage occurred between April 2000 and September 2000. This may not have been true and would have resulted in an underestimate of damage.

- The threshold values for the B-IBI for the low mesohaline area are appropriate to apply to the Chalk Point region of the Patuxent River and are equally applicable in Swanson and Hunting Creeks. The Chalk Point regions is characterized by strong environmental gradients and given the state-of-science for benthic index development this is the best assumption that could have been made.

Sample Design Concerns

Below several concerns that affect the reliability and uncertainty associated with the assessment of the damage resulting from the Chalk Point Oil Spill are identified. These concerns provide the Trustees a framework for deciding if additional analyses would be beneficial (i.e., reduce the uncertainty or better define the existing assessment). Most importantly, they provide information that may be beneficial to future damage assessments. The approaches that are identified for addressing these concerns are not the only approaches that could be used. These approaches should not be considered recommendations. They are suggestions for use in future assessments.

The sample design of the study required the damage assessment to make assumptions about the spatial extent of exposure to the spilled oil. Sediment chemistry data were not processed and were not available to better define the degree of exposure to spilled oil. Had sediment chemistry data been available then it would have been possible to use these data as covariates and to define the extent and degree of oiled benthic habitat. Under the best of circumstances benthic assessments consist of a triad of: (1) exposure data, (2) sensitive species toxicity data, and (3) benthic community response data. The present sample design is missing the exposure leg of this three-legged stool. The toxicity data are available from the literature (i.e., #2/6 fuel oil exposures kill sensitive biota at ppb levels) and the community data are available in Llanso and Volstad (2001). This deficiency/concern is identified to emphasize the value of following an exposure, toxicity, and response indicator strategy when conducting damage assessments.

The vast majority of the estimates of the impact of the oil spill was based on differences between a single reference location (Hunting Creek) and/or the mainstem Patuxent River. These reference locations may not have been appropriate reference locations because of differences in depth, water quality, sedimentation rates, proximity to emergent vegetation, and exposure to gradients resulting from the Chalk Point power plant. A higher level of confidence could have been obtained had an average/mean value for several reference creeks (upstream and downstream) been used for contrasts. That is it may have been beneficial to sample multiple reference creeks but take fewer samples in each. This concern is identified to emphasize the value of multiple reference sites to the damage assessment process.

The BACI (Before-After-Control-Impact) portion of the study is also based on contrasts to a single control station (Chester River) that is located in a different water body with a different drainage basin and watershed characteristics. A higher level of confidence in conclusions could have been obtained if the BACI analyses were based upon the average value of multiple reference stations representing a range of similar environmental settings (e.g., Chester, Severn, Potomac). This concern is identified to emphasize the value of multiple reference sites to the damage assessment process.

The BACI analyses appeared to be based on a single parameter (abundance). This parameter is a variable one and more interpretable results may have been obtained had a suite of benthic parameters been used (e.g., the metrics used for the B-IBI). No data for less variable parameters (e.g., biomass) were provided for the Chester River. Thus, an evaluation of these parameters and the appropriate BACI hypothesis tests could not be conducted. This concern is identified to emphasize the value of using multiple ecological attributes in damage assessments and analyses like BACI.

Sampling was not conducted following the major recruitment period for most of the biota composing benthic communities at Chalk Point (i.e., spring 2001). It is not know if the differences observed in upper Swanson Creek in Spring 2000 reappeared in Spring 2001 representing a chronic response to the oil spill. Differences between upper and lower Swanson Creek may have reappeared in Spring 2001 suggesting an impact on recruitment processes and sensitive early life stages. This concern is identified because it is considered to be the greatest weakness in the study design. Had samples been obtained in the following spring recruitment period that upper Swanson Creek had benthic communities that were similar in the kinds, abundances, and biomass as occurred in appropriate reference sites then recovery would have been considered to have occurred.

Data were not collected on the size of benthic organisms at each site (e.g., length of *Macoma* and *Rangia*). Size data would have provided for a less ambiguous assessment of damage (i.e., impacts on growth could have been separated from impact on recruitment). This concern is identified to highlight the value of obtaining size/age data in the interpretation of assessment data. Size data need only be collect for "key" species.

A stratification of Hunting Creek was not a part of the design and an evaluation was not conducted to show such stratification was not appropriate. A gradient from the upper to lower Hunting did not appear to exist; however, no analysis was presented to validate this. A demonstration of no gradient in Hunting Creek would have made the conclusions related to the gradient observed in Swanson Creek more creditable.

Response to "Comments on Draft Quantification of Injury to Benthic Resources from the Chalk Point Oil Spill on the Patuxent River".

Prepared by: Charles Peterson (UNC), Roberto Llanso (Versar), and Beth McGee (USFWS).

Comment 1: "The assumptions made for the analyses used to quantify the ecological damage resulted in a conservative (i.e., minimal) estimate of the impact on benthic biomass. As the author indicates, less conservative assumptions and interpretations could have been made resulting in greater estimates of damage (e.g., "One interpretation of the density patterns in *Rangia cuneata* after the oil spill is that the effects did indeed extend not only into lower Swanson Creek but also into the Patuxent River") Therefore, both the extent and duration of the impact may have been underestimated. For example, rather than assume proportional damage (e.g., 25% of lower Swanson Creek was damaged), no impact was assumed for this stratum. It appears, however, from the data in Llanso and Volstad (2001) that some damage (*albeit* small) may have occurred in the upper portions of the lower stratum."

Response: Our conclusions were based on an analysis that we thought was scientifically rigorous and defensible, one that we believe could withstand scrutiny in a court of law. Whether or not these estimates are conservative, is arguable. We acknowledge in the injury quantification report that there is a suggestion in the survey data of Llanso and Volstad (2001) that the injury to Rangia may extend beyond upper Swanson Creek into lower Swanson in June 2000. However, no augmentation of the spatial scope of injury is added for this possibility because the biomass and numerical data for Rangia are not fully consistent in their indication of Rangia injury in lower Swanson Creek. In addition, there is no rigorous information available on which to base a quantified estimate for how far into lower Swanson Creek the injury to Rangia may have extended. The reviewer's comment on this point illustrates the difficulty in quantifying injury in its arbitrary suggestion of 25% as a possibility for the proportion of lower Swanson Creek that was injured, without a compelling rationale for that choice.

Comment 2: "In addition, impact on *Rangia* biomass was assessed as if this bivalve was an annual species; *Rangia*, however, is a relatively long-live benthic organism (>5 years) with highest production in later years. As a result, the damage to the productivity and filtering capacity of this clam is likely underestimated."

Response: While the injury report acknowledges that Rangia cuneata can live for several years, perhaps up to a decade, the injury calculations for this spill are based on the assumption that the Rangia that died in Swanson Creek during spring 2000 because of the oil spill would not have survived past September 2000 in the absence of the spill. This assumption is based upon the disappearance of Rangia from the reference site, Hunting Creek, between June and September 2000 as documented in the Llanso and Volstad (2001) report. Consequently, the addition of a term for production foregone in later years is not supported by the data. The reason for the disappearance of Rangia at the control site may be mortality due to increased salinity from June to September. That is, Rangia, which prefers low oligohaline conditions, can recruit into low salinity areas during the spring, but cannot tolerate the salinity increase during the summer (Llanso, Versar Inc, personal communication).

Comment 3: "Finally, the ecological value of the observed increases in polychaete biomass was treated as if they were equivalent (1:1) with the observed declines in bivalve biomass. The importance of bivalves as ecological filters is generally considered to be greater that of an equivalent mass of spionid polychaete. The assessment recognized this deficiency but did not adjust for it (e.g., weight the biomass data for the spionid polychaetes differently from the data for the bivalves) in any manner."

Response: The calculations of injury in the report are done separately by taxon so that the various taxa can later be weighted differently in scaling restoration to compensate for the losses. In that scaling process, the reviewer's point that polychaete biomass gain should be weighted less heavily than bivalve loss is, in fact, adopted. Changes in bivalve biomass are given double the weighting given to changes in polychaete biomass. The injury document has been revised to reflect this change.

Comment 4: "It is unfortunate that the sediment chemistry data that were collected were not processed and used to quantify the spatial extent of the exposure to spilled oil. The sediment chemistry information would have greatly reduced the uncertainty in the estimates of the spatial extent of the oiled sediments to which benthic organisms were exposed (i.e., the strata used to estimate damage would have been based on exposure data and geographical boundaries defined by less objective techniques)."

Response: Under the Oil Pollution Act of 1990, injury to natural resources must be "observable" and "measurable". While we agree that analysis of sediment chemistry may have provided information regarding exposure of benthic organisms to petroleum compounds, it is also true that exposure does not equal effects due to the variety of factors that influence biovailability of sediment-associated contaminants. Hence, we are not convinced that the chemical data would have improved our ability to delineate the impacted area. In addition, one of our concerns was that toxicity in the water column during the time of the spill may have affected recruitment of benthic larvae to subtidal areas. This effect would not be detected through the analysis of sediment contaminants, but rather by looking directly at the benthic macroinvertebrate community. Nonetheless, we will take this recommendation under advisement in the event we are involved with future oil spill NRDAs.

Comment 5: "In addition, a single reference site (Hunting Creek) was the basis of most of the comparisons/contrasts used to quantify damage. Addition reference stations were sampled but the data collected for them were not processed. Failure to process the samples from addition reference sites increased the uncertainty associated with estimating the spatial extent of the damage from spilled oil."

Response: There must be some confusion, as we did not collect samples at additional reference sites in the Patuxent River. We did collect benthic samples in Indian Creek and Trent Hall Creek in September; however, these sites were potentially impacted by the spill. These samples were not analyzed because the evidence suggested that it would be highly unlikely to detect measurable effects in these samples. This assessment was based on the degree of oiling of these tributaries relative to Swanson Creek, and results of analysis of intertidal benthic samples *collected in these areas that did not suggest evidence of injury.*

Comment 6: "Year-to-year, seasonal, and spatial variation in natural environmental conditions such as salinity, temperature, freshwater inflow, depth, sediment characteristics including total carbon, and other environmental parameters are known to affect the abundance and biomass of benthic stocks. The text of the document(s) reviewed, however, suggests that "Habitat information collected during sampling (Llanso and Volstad 2001: Appendices) shows similar mean station depths (1.0 m for upper Swanson, 1.1 m for lower Swanson, and 1.2 m for Hunting Creeks), silt/clay content of sediments (84.9% for upper Swanson, 90.5% for lower Swanson, and 84.8% for Hunting Creeks), and salinities (4.3 ppt for upper Swanson, 5.5 ppt for lower Swanson, and 6.0 ppt for Hunting Creeks)" implying these factors did not greatly influence benthic distributions in space and time. No analyses (e.g., regressions of environmental factors vs benthic biomass or abundance), however, were provided to support this statement, and no adjustments were made to the biomass/abundance data collected to account for differences among years or space due to "natural" environmental parameters. These data are available (e.g., Llanso and Volstad 2001: Appendices) and it is possible that these environmental parameters varied among stations and years in a manner that was associated with the distributions of benthic abundance and biomass. Preliminary correlations of just the Swanson Creek data suggest a relatively strong associations between *Streblospio benedicti* and *Rangia cuneata* abundances and total carbon, silt/clay and even the small salinity gradient that occurred. Such adjustments (e.g., Analysis of Covariance using silt/clay content of sediments as a covariant) may have increased the sensitivity and power of the statistical contrasts evaluated (especially the contrasts across years). I **recommend** that preliminary analyses be conducted to validate that the environmental gradients among the sample sites were not a significant contributing factor to the observed distributional patterns. This analysis could be done in less than a manday using the data in Llanso and Volstad (2001). Correlations and regressions that account for less that 25% of the variance should probably be considered as unimportant and would not likely alter findings. Correlations that account for more than 25% of the variance may alter findings (either increasing or decreasing the estimated damage)."

Response: As recommended, additional data analyses were conducted to validate the assumption that environmental gradients among sampling sites in Swanson Creek and Hunting Creek were not a significant contributing factor to the observed distribution patterns of species abundance and biomass, and hence, to differences between strata that may confound impacts from the oil spill (see attached document by Llanso and Volstad, 2002). The objective was to determine if the amount of variation due to spatial differences in salinity and silt-clay in Swanson and Hunting Creeks was significant and sufficiently large to justify incorporation of these variables as covariates to improve sensitivity of the impact study. In brief, data were analyzed by ANOVA using the General Linear Model (GLM) procedure in SAS, which is applicable to unbalanced designs (unequal number of observations per cell). Dependent variables in the analysis were total abundance, total biomass, total species richness, Shannon Diversity, the abundance of the top five numerically dominant species (Leptocheirus plumulosus, Streblospio benedicti, Tubificoides spp., Macoma balthica, and Rangia cuneata) and the biomass of Macoma balthica, Macoma mitchelli and Rangia cuneata. Results indicated some significant relationships among grain size and/or salinity and a few of the dependent variables; however, in all cases, the effects of salinity and percent silt-clay could be explained in terms of differences among seasons, sites, *the putative effects of the oil spill or visual examination of the data indicated the significant relationship was likely driven by outliers. Hence, the conclusion was that bottom salinity and grain size were not considered to be major contributing factors to the observed distribution patterns of species abundance and biomass.*

<u>Assumptions</u>

Comment 7: "In order to conduct an assessment of the damage resulting from the Chalk Point April 2000 spill on the natural resources of the Patuxent Estuary it appears that the assessment made the following assumptions. I listed the assumptions to assist me in evaluating the reliability of the data and conclusions. These assumptions are reasonable and [are] likely result in a conservative estimate of ecological damage."

Response: We disagree with the premise that all the stated assumptions likely resulted in a conservative estimate of benthic injury. In particular, we note the following: First, the assumption of injury to benthic communities to intertidal mudflats being equivalent to subtidal injury. The Academy of Natural Sciences conducted a survey in the intertidal areas in Hunting, Swanson and Trent Hall Creeks. These limited data did not indicate differences in benthic community structure that could be related to the oil spill. However, rather than assume no injury to intertidal habitat based on these data, we instead chose to combine it with the subtidal injury assessment. Second, the assumption that benthic distributions in Swanson Creek were the result of the oil spill and not due to changes in environmental conditions. Had we attributed some or all of the changes in benthic community composition in upper Swanson Creek to factors other than oil, then our injury estimate would have been substantially lower. Third, the assumption that watershed properties were similar in Hunting and Swanson Creeks. The effect of differences in the drainage basins may have increased or decreased our estimate of injury.

Comment 8: "*Rangia* was assumed to be an annual species and *Leptocherius* was assumed to have an average of two broods over the summer period. These assumptions may have resulted in an underestimate of damage to *Rangia* and *Leptocherius* biomass."

Response: As indicated above in our response to Comment 2, Rangia was assumed to be an annual species based on a comparison with the reference site, Hunting Creek, and the fact that they had all but disappeared from this area by the September sampling. We agree that Leptocheirus may have multiple broods from spring through fall; however, they also suffer very high natural mortality rates during the summer due to food limitation and predation. Typically, the result is extremely low population densities throughout the summer. Leptocheirus populations generally experience two seasonal peaks, in the fall and spring, and so we felt it was reasonable to estimate injury based on the loss of production of two generations per year.

Comment 9: "The ecological value of a unit of benthic biomass is equivalent across the dominant species occurring at Chalk Point. This is probably true for the nutritional value of the dominant benthic biota at Chalk Point, but may not be true for other ecological attributes. For example, the filtering value of bivalves may be superior to that of polychaetes."

Response: See response to Comment 3.

Comment 10: "Chronic impacts from the oil spill were minimal and the majority of the damage occurred between April 2000 and September 2000. This may not have been true and would have resulted in an underestimate of damage."

Response: We agree that the assessment was not focused on measuring chronic effects and, unfortunately, that reflects the state of the science. Natural variability of benthic populations will likely mask the ability for one to detect chronic, sublethal effects on benthic populations, if they exist. Presently, the injury quantification does assume that recovery of the benthic community in Swanson Creek had occurred by spring 2001. The possibility that the duration of injury was underestimated is acknowledged in the injury quantification report. Absent additional field sampling, there is insufficient information with which to test the assumptions about duration of injury. The assumption of rapid recovery is based upon the field evidence of Llanso and Volstad (2001) of successful recovery of Leptocheirus, in lower Swanson Creek by September 2000. This amphipod is likely the most sensitive of all the major taxa to contaminants, so its rapid recovery in a portion of the affected area provided support for assuming that recovery in upper Swanson Creek would occur by 2001. Nonetheless, we recognize the uncertainty associated with this assumption. Consequently, we have changed our estimate of biomass loss to reflect this uncertainty. As stated in the revised injury quantification report, the most likely injury to persist would be to Leptocheirus, due to its sensitivity to contaminants and from the multi-year duration of impacts to other amphipods in other oil spills. Therefore, we have extended the recovery of Leptocheirus populations until September 2002. Assuming a similar lost production for this time period years as occurred in 2000 (75.5kg for June 2001+ 42.6 for September 2001 + 75.5 kg for June 2002), we estimate the additional loss of biomass as 193.6 kg. Bivalves are typically less sensitive to contaminants; hence, we have not altered the recovery estimates for Macoma and Rangia.

<u>Sample Design Concerns</u>

Comment 11: "The approaches that are identified for addressing these concerns are not the only approaches that could be used. These approaches should not be considered recommendations. They are suggestions for use in future assessments.

The sample design of the study required the damage assessment to make assumptions about the spatial extent of exposure to the spilled oil. Sediment chemistry data were not processed and were not available to better define the degree of exposure to spilled oil. Had sediment chemistry data been available then it would have been possible to use these data as covariates and to define the extent and degree of oiled benthic habitat. Under the best of circumstances benthic assessments consist of a triad of: (1) exposure data, (2) sensitive species toxicity data, and (3) benthic community response data. The present sample design is missing the exposure leg of this three-legged stool. The toxicity data are available from the literature (i.e., #2/6 fuel oil exposures kill sensitive biota at ppb levels) and the community data are available in Llanso and Volstad (2001). This deficiency/concern is identified to emphasize the value of following an exposure, toxicity, and response indicator strategy when conducting damage assessments."

Response: See response to Comment 4.

Comment 12: "The vast majority of the estimates of the impact of the oil spill was based on differences between a single reference location (Hunting Creek) and/or the mainstem Patuxent River. These reference locations may not have been appropriate reference locations because of differences in depth, water quality, sedimentation rates, proximity to emergent vegetation, and exposure to gradients resulting from the Chalk Point power plant. A higher level of confidence could have been obtained had an average/mean value for several reference creeks (upstream and downstream) been used for contrasts. That is it may have been beneficial to sample multiple reference creeks but take fewer samples in each. This concern is identified to emphasize the value of multiple reference sites to the damage assessment process."

Response: We do not believe there were other appropriate reference sites within the Patuxent River. Salinity regimes in Patuxent River tributaries that were not impacted by the spill (either upstream or toward the mouth of the Patuxent River) are much different than the area around Swanson Creek. Tributaries within the same salinity regime (with the exception of Hunting Creek) were thought to be impacted by the spill. In hindsight, reference areas with similar physico-chemical characteristics could have been sampled in tributaries outside the Patuxent River, but given the circumstances, we believe our approach was rationale and defensible.

Comment 13: "The BACI (Before-After-Control-Impact) portion of the study is also based on contrasts to a single control station (Chester River) that is located in a different water body with a different drainage basin and watershed characteristics. A higher level of confidence in conclusions could have been obtained if the BACI analyses were based upon the average value of multiple reference stations representing a range of similar environmental settings (e.g., Chester, Severn, Potomac). This concern is identified to emphasize the value of multiple reference sites to the damage assessment process."

Response: We agree that properly replicated control areas constitute an important element of BACI design, as is finding control sites with similar environmental characteristics. In the BACI assessment, Station 68 in the Chester River was chosen as the control site because characteristics of the station, the salinity regime and the location in a small tidal basin, were most similar to those of Station 74 in the Patuxent River. In addition, Station 68 exhibited good benthic condition, indicative of good water quality, an important criterion in the selection of a control site. Ideally, control sites should be located in proximity to the impact site, should be independent of one another and should be randomly chosen. This is not always possible. Long-term fixed monitoring sites in Chesapeake Bay, for example, were specifically selected to measure trends in sensitive areas targeted for pollution abatement. Therefore, selection of control sites for this study was problematic. Another limitation of applying the BACI design to the Chalk Point data is there is inadequate temporal replication. Ideally, sites before and after the perturbation should be sampled at small time intervals. Times between successive sampling events should be random. None of this was possible because this study used data from a monitoring program with a fundamentally different monitoring objective and sampling regime. Because of the limited data, natural temporal variability in abundances make short-term impacts difficult to detect. Adding more control sites or using a different suite of benthic parameters would not have alleviated this problem. In fact, biomass data from low mesohaline sites *throughout the Chesapeake Bay are extremely variable because of the influence of bivalves, which are sampled with varying efficiencies. Finally we note that, theoretically, it is possible that the use of multiple control sites might have reduced our ability to detect differences between impact and control sites. Control sites representing different systems will be influenced by varying levels of perturbation, variation among the controls will not be consistent, and there will be temporal interactions among controls that could result in a reduction in the sensitivity of the test.*

Comment 14: "The BACI analyses appeared to be based on a single parameter (abundance). This parameter is a variable one and more interpretable results may have been obtained had a suite of benthic parameters been used (e.g., the metrics used for the B-IBI). No data for less variable parameters (e.g., biomass) were provided for the Chester River. Thus, an evaluation of these parameters and the appropriate BACI hypothesis tests could not be conducted. This concern is identified to emphasize the value of using multiple ecological attributes in damage assessments and analyses like BACI."

Response: See response to Comment 13.

Comment 15: "Sampling was not conducted following the major recruitment period for most of the biota composing benthic communities at Chalk Point (i.e., spring 2001). It is not known if the differences observed in upper Swanson Creek in Spring 2000 reappeared in Spring 2001 representing a chronic response to the oil spill. Differences between upper and lower Swanson Creek may have reappeared in Spring 2001 suggesting an impact on recruitment processes and sensitive early life stages. This concern is identified because it is considered to be the greatest weakness in the study design. Had samples been obtained in the following spring recruitment period that upper Swanson Creek had benthic communities that were similar in the kinds, abundances, and biomass as occurred in appropriate reference sites then recovery would have been considered to have occurred."

Response: We recognize this as an area of uncertainty (see response to Comment 10) and have increased our estimate of injury in an attempt to account for some of the uncertainty associated with recovery estimates.

Comment 16: "Data were not collected on the size of benthic organisms at each site (e.g., length of *Macoma* and *Rangia*). Size data would have provided for a less ambiguous assessment of damage (i.e., impacts on growth could have been separated from impact on recruitment). This concern is identified to highlight the value of obtaining size/age data in the interpretation of assessment data. Size data need only be collect for "key" species."

Response: We will take this recommendation under advisement in the event we are involved with future oil spill NRDAs.

Comment 17: "A stratification of Hunting Creek was not a part of the design and an evaluation was not conducted to show such stratification was not appropriate. A gradient from the upper to lower Hunting did not appear to exist; however, no analysis was presented to validate this. A demonstration of no gradient in Hunting Creek would have made the conclusions related to the gradient observed in Swanson Creek more [credible].”

Response: Stratification of Swanson Creek was conducted as part of a “near field-far field” design to evaluate pollution induced impact. Variability due to gradients in environmental factors (e.g., salinity) were believed to be negligible. However, as noted in the response to Comment 6, additional statistical analyses were conducted to address the concern about effects of potential gradients in salinity and grain size on species’ distributions in Swanson and Hunting Creeks. The conclusion was that bottom salinity and grain size were not considered to be major contributing factors to the observed distribution patterns of species abundance and biomass; hence, there was no evidence for a gradient effect in Hunting Creek.