AQUATIC EXPOSURE AND INJURY REPORT
BOUCHARD B-120 OIL SPILL

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EXECUTIVE SUMMARY

On 27 April 2003, the *Bouchard B-120* struck submerged rocks near Buoy G1 at the mouth of Buzzards Bay (Bay), and subsequently released an estimated volume of up to 98,000 gallons[1] of No. 6 fuel oil in this location and as it was towed up the Bay in the shipping channel. Immediately after the spill, oil was present as sheen and slicks on the open water. Within 24 hours, the spilled oil broke up into discontinuous sheen, slicks, tarballs, and patties. Oil first washed ashore in Dartmouth and Mattapoisett, but in the days following the spill, winds and currents drove the bulk of the oil to shorelines in the northwest, north, and to a lesser extent, the northeast portions of the Bay. Oil was unevenly distributed along shorelines and was generally concentrated at exposed points on peninsulas in the western portion of the Bay.

The spill impacted a variety of natural resources, including marshes, rocky and sandy shorelines, recreational beaches, wildlife, and certain aquatic biota. As part of Natural Resource Damage Assessment activities associated with the spill, the Aquatic Technical Working Group (TWG) collected and analyzed data to determine the nature and extent of the aquatic injuries caused by the spill. The Natural Resource Trustees (Commonwealth of Massachusetts, Massachusetts Department of Environmental Protection and Coastal Zone Management Program - Executive Office of Energy and Environmental Affairs[2], Rhode Island Department of Environmental Management, U.S. Fish and Wildlife Service, and the National Oceanic and Atmospheric Administration) designated representatives to the Aquatic TWG, which also included the Responsible Party (Bouchard Transportation Company) through it's technical representative, ENTRIX, Inc. This report presents the results of the cooperative assessment to identify and quantify actual and potential exposure and injury to aquatic resources and habitats that occurred as a result of the Bouchard B-120 spill.

Based upon incident-specific information on the spill and the habitats and resources of Buzzards Bay, the Aquatic TWG determined that several aquatic habitats and resources were potentially impacted from the spill and conducted detailed evaluations on three habitats and two resources of concern. These evaluations were designed to assess the aquatic habitats at risk of injury from the spill, including the water column, subtidal sediments, intertidal sediments[3], and the living resources and services associated with these environments. Resources potentially impacted included finfish, shellfish (e.g., lobster and bivalves), other invertebrates, larval and juvenile planktonic stages of aquatic organisms, and benthos.

The potential exposure and acute injury to the open Bay water column habitat was evaluated using modeling and water column field data to produce estimates of water column concentrations of dissolved monocyclic and polycyclic aromatic hydrocarbons (PAH) resulting from the spill. These concentration estimates were used to evaluate the potential for acute toxicity to aquatic biota in the subtidal waters greater than 3 ft below mean low water (MLW) affected by the spill. The modeling concluded that the concentrations from the spill were not high enough for a long enough duration to cause acute injury to aquatic organisms. The modeling was not applied to intertidal and shallow subtidal areas (less than 3 ft below MLW). Moderately and heavily oiled

1 *Spill estimates range from 22,000 gallons to 98,000 gallons (Independent Maritime Consulting, LTD 2003; USCG 2004).*

2 *Formerly the Massachusetts Executive Office of Environmental Affairs (MAEOEA)*

3 *Intertidal shoreline injury in the visible "footprint" of the oil (the band of stranded oil) was assessed by the Shoreline Assessment Team. To avoid double counting in the intertidal zone, the Aquatic TWG only assessed intertidal injury in areas outside the footprint.*

areas at depths less than 3 ft below MLW, while not modeled, were included in the Aquatic TWG's nearshore injury analysis because these areas could have been exposed to higher water column hydrocarbon concentrations, and because of potential physical contact with oil in these areas.

The potential for the presence of significant areas of submerged oil formed as a result of the release was evaluated though several submerged oil surveys. These surveys did not find evidence of oil on the bottom of the Bay that would be considered substantial or indicate a submerged oil problem. However, at several locations offshore of Barneys Joy, partial oiling of some of the snare on chain drags and on deployed lobster pots indicated that there were relatively small amounts of oil on the bottom. This subtidal oil is believed to have been derived from oil that washed ashore, mixed with sand (and became heavier than seawater), then washed back into Buzzards Bay. The acreage of this area (called the "extended Barneys Joy area"), was estimated and injury to the area was calculated using the Habitat Equivalency Analysis (HEA) methodology to determine service losses and recovery over time. The total debit calculated for this area was 33.9 Discounted-Service-Acre-Years (DSAYs).

The potential exposure and injury to nearshore habitats from fouling with oil or from exposure to dissolved PAH fractions was estimated using the HEA methodology to determine service losses and recovery over time. Nearshore habitats were defined as intertidal areas outside the footprint of the stranded oil and shallow subtidal areas (0-3 ft) adjacent to those shorelines. Injury was only estimated on and adjacent to shorelines classified by the Shoreline Assessment Team as having heavy or moderate oiling. The total intertidal aquatic debit calculated for this area was 42.6 DSAYs, (if the debits for marsh, rocky shoreline, sandy shoreline, and tidal flats are equally weighted and summed). The total nearshore subtidal debit (not including the 33.9 DSAYs for the extended Barneys Joy area) was calculated at 43.0 DSAYs. The addition of the debit for the subtidal area offshore of Barneys Joy to the nearshore subtidal debit, results in a total subtidal debit of 76.9 DSAYs. The total intertidal and subtidal injury was thus calculated at 110.8 DSAYS.

Total PAH concentrations in most sampled bivalves adjacent to oiled shorelines were elevated relative to background levels at the time of the first sample collection, which occurred one to two weeks after the spill. This indicates that bivalves were exposed to and ingested/absorbed PAHs from spill-impacted areas. The potential injury to bivalves from these body burdens was evaluated by comparing the PAH concentrations in the tissues of bivalves to USEPA tissue concentration benchmarks for acute and chronic effects. This analysis suggested that PAH body burdens in bivalves were not high enough for a long enough duration to cause lethal or sublethal effects. However, the effect of those body burdens on predators, reflected as a potential loss of services due to reduced food quality, was factored into the HEA analysis.

The potential exposure of American lobster to oil through physical contact or dissolved concentrations and any subsequent injury was carefully evaluated through an analysis of the life history of the lobster and the known or possible presence/absence of oil based on field evaluations. The Aquatic TWG concluded that due to the time of year and water temperatures, it is unlikely that more than a few lobster larvae were exposed to the oil and therefore this lifestage was not significantly exposed or injured. Adult (including egg-bearing females), early benthic phase, and adolescent lobsters are expected to have been present at the time of the spill and in subsequent weeks during cleanup activities, and these lobsters were potentially exposed to and injured by the oil, primarily through physical fouling from submerged tarballs that were believed to be present in some deeper waters, particularly in the extended Barneys Joy area. The actual proportion of these lobster lifestages in the Bay that may have been exposed to and injured by the oil is unknown but is expected to be small based on an estimation of the amount of habitat in the Bay that was exposed to oil. This conclusion is consistent with the lack of conspicuous visual evidence of lobster mortality, continued commercial harvesting of lobsters in 2003 through 2004 at levels typical for the Bay in recent years (relative to harvesting in non-impacted areas of the Massachusetts portion of the Southern New England stock), and lack of oil on harvested lobsters in 2003. Potential injury to this species was captured in the injury assessment for the nearshore subtidal areas and extended Barneys Joy area, in which the lobster was considered part of the benthic community.

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COSIM	Chemical/Oil Spill Impact Module
DSAY	Discounted-Service-Acre-Year
EBP	Early Benthic Phase
ENC	Electronic Navigation Chart
EPH	Extractable Petroleum Hydrocarbons
ERL	Effects Range - Low
ESI	Environmental Sensitivity Index
FAV	Final Acute Value
FCV	Final Chronic Value
GIS	Geographic Information System
HEA	Habitat Equivalency Analysis
LOEL	Lowest Observable Effects Level
MAEOEA	Massachusetts Executive Office of Environmental Affairs[4]
MADMF	Massachusetts Division of Marine Fisheries
MADEP	Massachusetts Department of Environmental Protection
MCP	Massachusetts Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resource Damage Assessment
PAH	Polycyclic Aromatic Hydrocarbon
RP	Responsible Party
SAT	Shoreline Assessment Team
SCAT	Shoreline Cleanup Assessment Team
SIMAP	Spill Impact Model Analysis Package
TWG	Technical Working Group
USEPA	United States Environmental Protection Agency

[4] *Currently known as the Massachusetts Executive Office of Energy and Environmental Affairs (MAEOEEA)*

1.0 INTRODUCTION

The following sections provide relevant information on the spill incident, spill cleanup efforts, and the aquatic resources that were potentially at risk from the Bouchard B-120 spill.

1.1 Spill Incident

Soon after entering the western approach of Buzzards Bay on April 27, 2003, the B-120 struck submerged rocks near Buoy G1 at the mouth of the Bay, and subsequently released an estimated volume of up to 98,000[5] gallons of No. 6 fuel oil as it was towed up the Bay in the shipping channel. After the spill was detected, the B-120 was towed to Buoy BB in central Buzzards Bay, and then was ordered to Buoy 10 (Anchorage Lima) by the U.S. Coast Guard where it anchored and had the remaining contents of the ruptured cargo tanks transferred to Bouchard barge B-10 (Figure 1).

Immediately after the spill, oil was present as sheen and slicks from the allision[6] location to Buoy 10. Within 24 hours, the remaining oil on the water broke up and was present as discontinuous sheen, slick, tarballs, and patties. Oil first washed ashore in Dartmouth and Mattapoisett, but in the days following the spill, winds and currents drove the bulk of the remaining oil to the northwest, north, and to a lesser extent, the northeast shorelines. Oil was unevenly distributed along shorelines and was generally concentrated at exposed points on peninsulas in the western portion of the Bay. There were additional sporadic occurrences of predominately light and very light oiling on the east side of the Bay and in Rhode Island (e.g., Block Island and Little Compton). Greater than 85% of the shorelines within the spill area were un-oiled or experienced only very light or light oiling. Based upon observations and data collected during the initial response and subsequent studies, it is believed that the majority of the oil remained neutrally or positively buoyant and did not sink and settle on the bottom in large mats or pools.

Emergency response activities were initiated on the evening of April 27, 2003, and by the next day cleanup contractors had arrived on scene. Recovery and cleanup operations included the use of skimming boats, deployment of boom and sorbent material, power washing along the shorelines, and the use of other manual removal techniques. Skimming was conducted for a week after the spill, and then discontinued since there was little oil remaining on the surface of the water. The majority of oil and oiled wrack was removed from the shorelines within three months after the spill, although cleanup activities continued until September 3, 2003, when the Unified Command Post was deactivated and responsibility for cleanup was transferred to the Massachusetts Department of the Environmental Protection (MADEP) under the state Massachusetts Contingency Plan (MCP) regulations. Under the MCP, targeted, small-scale cleanups were conducted in the upper intertidal zone along a few shoreline segments during 2004, 2005, and 2006.

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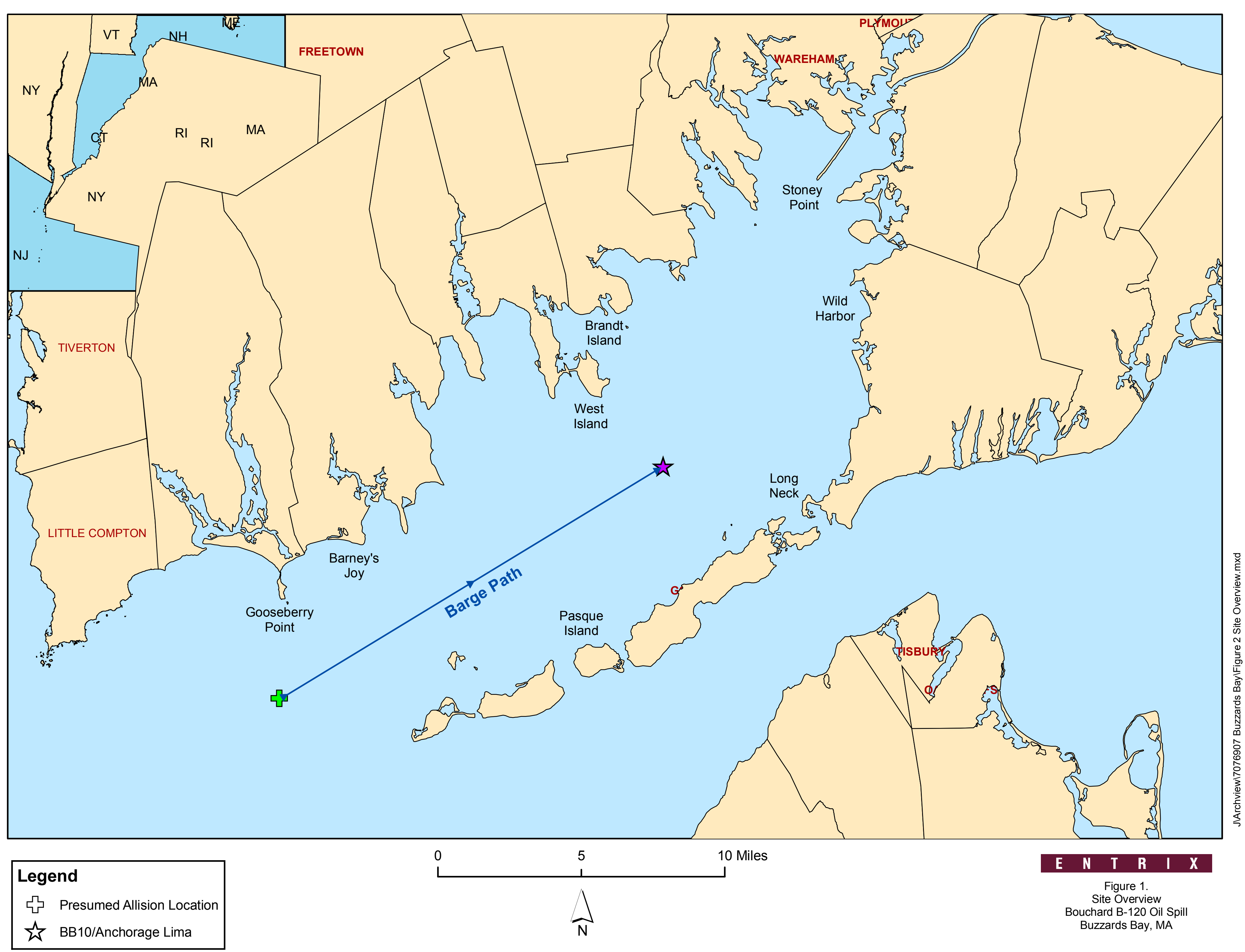
5 Spill estimates range from 22,000 gallons to 98,000 gallons (Independent Maritime Consulting, LTD 2003; USCG 2004).

6 The term "allision" refers to the running of one vessel into or against another, as distinguished from a collision, i.e., the running of two vessels against each other. It is also used to refer to a vessel striking a fixed structure or object (e.g.,. rocks, bridge, pier, moored vessel).



ENTRIX

Figure 1.
Site Overview
Bouchard B-120 Oil Spill
Buzzards Bay, MA

The spill affected a variety of natural resources, including marshes, rocky and sandy shorelines, recreational beaches, wildlife, and fisheries. As part of the Natural Resource Damage Assessment (NRDA), representatives of the Natural Resource Trustees (Trustees) (the Commonwealth of Massachusetts, the State of Rhode Island, the U.S. Fish and Wildlife Service on behalf of the Department of the Interior, and the National Oceanic and Atmospheric Administration [NOAA]) and the Responsible Party (RP) (Bouchard Transportation Company) were given the task of quantifying the impacts of the oil on the natural resources of Buzzards Bay. The Joint Assessment Team, comprised of representatives of the Trustees and the RP, coordinates and approves the activities of subgroups (e.g., Aquatic Technical Working Group [TWG]) that were formed to address impacts to different resource categories. This report describes the data that were collected and analyzed to evaluate the actual and potential exposure and injury to aquatic resources and habitats, and documents the final findings of the Aquatic TWG.

1.2 Aquatic Resources at Risk

Injury is defined by NOAA (1996) as "an observable or measurable adverse change in a natural resource or impairment of a natural resource service. Injury may occur directly or indirectly to a natural resource and/or service." In general, there are three requirements in order for injury to occur to a habitat or resource:

1) the resource/habitat must be exposed to the stressor (pollutant);
2) the stressor (pollutant) must be present at a high enough concentration to cause adverse effects; and
3) the resource/habitat must be exposed to the stressor (pollutant) for a long enough duration to cause an adverse effect.

Oil in the environment can affect organisms by physical fouling of fur, feathers, mouthparts, or other appendages or can kill organisms through toxic effects associated with dissolved oil. In addition, the presence of cleanup workers and equipment can interfere with normal resting, feeding or mating activities of many species. In general, lighter oils have greater acute toxicity and heavy oils are more apt to cause physical fouling and chronic toxicity from exposure to persistent oil residues. The No. 6 fuel oil spilled in this incident is considered to be a heavier oil so physical effects would be expected to predominate, but potential water column toxicity and chronic toxicity was also a concern.

In the days and weeks following the spill, the Trustees and RP determined that based upon:

- observations of bird mortality and dead bivalves at Barneys Joy;
- source oil characteristics;
- degree of oiling on shorelines;
- measured and estimated initial water column concentrations, and surface sheen;
- species expected to be present and vulnerable;
- concentrations of polycyclic aromatic hydrocarbons (PAHs) in shellfish; and
- toxicity threshold values for aquatic life;

The aquatic habitats at risk of injury from the spill included the water column, subtidal sediments, intertidal sediments[7], and the living resources and services associated with these environments. Resources potentially at risk included finfish, shellfish (e.g., lobster and bivalves), other invertebrates, larval and juvenile planktonic stages of aquatic organisms, and benthos. The Bird and Wildlife TWG assessed injury to other animals that may use the aquatic habitat occasionally or frequently, such as birds and terrestrial insects.

The Aquatic TWG evaluated spill data and information as well as existing data and information associated with the habitats and resources to determine if the aquatic habitats and resources at risk from the spill were impacted, and if so, to what extent. In some cases additional data collection was initiated. Evaluations of three habitats and two resources of concern were conducted. These were:

1) potential for, or actual, acute injury to the water column habitat including all life stages of fish and shellfish, in the open Bay due to dissolved fractions of PAHs;
2) potential for, or actual, acute injury to subtidal benthic habitat due to the presence of large amounts of submerged, pooled oil on the bottom of the Bay;
3) potential for, or actual, acute injury to nearshore habitats (intertidal areas outside the footprint of the stranded oil and shallow subtidal areas of the Bay) due to dissolved fractions and/or physical fouling;
4) potential for, or actual, sublethal effects on bivalves due to accumulated PAHs in their tissues; and
5) potential for, or actual, acute injury to the American lobster (*Homarus americanus*) due to physical fouling or toxicity.

This report documents the findings of the Aquatic TWG for these five areas of potential exposure and injury, and includes or references data that were collected and analyzed to support those findings. In some cases, the Aquatic TWG determined that there was exposure to the habitat or resource and estimated the potential injury. In other cases, the Aquatic TWG found that there was no exposure or the exposure was not at a high enough concentration for a long enough time, and therefore, injury quantification was not deemed possible or necessary.

[7] *Intertidal shoreline injury in the visible "footprint" of the oil (the band of stranded oil) was assessed by the Shoreline Assessment Team. To avoid double counting in the intertidal zone, the Aquatic TWG assessed injury only to the intertidal areas outside the footprint.*

2.0 SUMMARY OF RELEVANT DATA SETS USED IN THE AQUATIC INJURY ASSESSMENT

In order to document and evaluate the degree of exposure to habitats and resources in Buzzards Bay and facilitate cleanup efforts, multiple data collection efforts were conducted following the spill. These efforts included shoreline oiling documentation; beached bird surveys; water, sediment and bivalve sampling; and surveys for submerged oil. Some of these data collection efforts were short term; others continued for longer time periods to document recovery. The relevant data sets for the aquatic injury are summarized and discussed in this section. The use of the data and the conclusions drawn from the data are discussed in the following sections. In an effort to reduce report volume and redundancy we have not reproduced the complete data sets and methods in this report. Additional detailed information on the sampling methods, locations, and data can be found in the other reports generated for this project including the *Pre-Assessment Data Report* (Massachusetts Executive Office of Environmental Affairs [MA EOEA] et al. 2005)[8], *Updated Conceptual Site Model* (GeoInsight, Inc. 2005a)[9], and the *Shoreline Injury Assessment Part I: Exposure Characterization - Bouchard 120 Oil Spill, Buzzards Bay, Massachusetts and Rhode Island* (Shoreline Assessment Team 2006).[10]

2.1 Shoreline Cleanup Assessment Team Data

Immediately after the spill, Shoreline Cleanup Assessment Teams (SCAT) were dispatched to document the location and degree of shoreline oiling and develop cleanup recommendations. These response teams completed over 500 SCAT reports detailing the location, thickness, and percent cover of oil on intertidal habitats throughout Buzzards Bay. This information was primarily collected to assist cleanup crews but was also used to map the location of oil for use in injury assessment. The NRDA Shoreline Assessment Team (SAT) compiled and analyzed the data to create maps showing the visible footprint of oiling and based their injury assessment on this footprint. The SCAT data and surveys conducted during the emergency and cleanup phases of the response were used to calculate that approximately 105 miles of shoreline were exposed to greater than trace amounts of oil. The Aquatic TWG used the results of the shoreline exposure assessment to define injury categories in areas near the visible footprint of oiling. This is described in more detail in Section 3.4.1 of this document.

2.2 Submerged Oil Evaluation

Periodic re-oiling of a few shoreline segments in the vicinity of Barneys Joy and West Island during the first month after the release prompted field investigations to evaluate whether or not a residual source of submerged oil was present offshore of these segments and if so, whether or not it could be removed. Four separate survey methods were used in the field investigations: lobster pots with snare, chain drags with snare, absorbent pad swipe, and dive surveys. Submerged oiling data and maps associated with this topic are provided in the *Pre-Assessment Data Report* (MA EOEA et al. 2005).

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8 *This report can be found in the Administrative Record at: http://www.darrp.noaa.gov/northeast/buzzard/index.html*

9 *This report can be found at: http://www.buzzardsbay.org/oilspill-status.htm*

10 *This report can be found in the Administrative Record at: http://www.darrp.noaa.gov/northeast/buzzard/index.html*

2.2.1 Lobster Pot Surveys

The Massachusetts Division of Marine Fisheries (MADMF) conducted initial lobster pot surveys on 2 and 14 May 2003. Four lobster traps loaded with snare were deployed for twelve days on the seabed just offshore of Barneys Joy Point, north of West Island (between West Island and Ram Island) and Southwest of West Island (between Wilbur Point and West Island - east of Long Island). Lobster pot surveys were generally conducted at a distance of 1,100 to 7,500 feet (ft) offshore. Upon retrieval, none of the snare in the four pots was oiled. The traps were then re-deployed northeast of West Island for seven days. Upon retrieval, one snare had small spots of oil on it. NOAA, MADMF, and the RP agreed to conduct additional investigations for potential submerged oil.

Additional lobster pot surveys were conducted between May 30 and June 13, 2003 to further assess the potential occurrence of mobile oil in the subtidal habitat, especially offshore of heavily oiled segments experiencing periodic occurrence of tarballs. Sampling was conducted at a total of six locations in the vicinity of Hen and Chickens Rock, Barneys Joy, and West Island at depths of 11.5 to 59 ft. No oiling of snare within lobster pots was observed at five of the six locations, with the exception being the Barneys Joy location.

Approximately 40 percent of the lobster pots with snare deployed in the vicinity of Barneys Joy (11 out of 27) had light oiling (staining) indicating there was some movement of tarballs along the seafloor in this area, which is consistent with the intertidal shoreline observations that the greatest magnitude of tarball occurrence was at Barneys Joy. Heavy oiling that would be indicative of a pool of submerged oil or large numbers of tarballs was not observed on any of the recovered snare.

2.2.2 Chain Drag Surveys

Chain drag surveys were conducted to evaluate the potential for deep subtidal oil on the substrate surface. During each survey, a 10-foot section of heavy chain with three to four snares attached was deployed from a boat and dragged along the seafloor bottom in a straight line; the chain was then raised and the chain and snare inspected for oil. In May and June 2003, 30 chain drag surveys were conducted in the general vicinity of Black Rock, Barneys Joy, and West Island, which were the most heavily oiled areas. These surveys were conducted from approximately 1,100 to 2,600 ft offshore at depths of 11.5 to 21 ft. The drag length ranged from 0.1 to 0.7 miles. No oiling was observed at four of the five locations with the exception being Barneys Joy. At Barneys Joy, 29 percent of the chain drag surveys (5 out of 17) exhibited light oiling on the snare.

In April 2004, the Aquatic TWG conducted additional chain drag surveys in the vicinity of the presumed allision site. The surveys were intended to document whether or not oil had sunk upon release on April 27, 2003. Eight chain drag surveys were conducted within 0.5 miles of Buoy 1 near Gooseberry Point. Drag lengths ranged from 0.4 to 1.1 miles. No oiling was observed on the chain or snare.

2.2.3 Absorbent Pad Swipe Surveys

Absorbent pad swipe surveys were conducted between May 5 and 21, 2003 at the shellfish sampling stations during low tide to determine if oil was present. Shellfish sampling locations were selected by MADMF in consultation with various Town Shellfish Constables. At each intertidal station, absorbent pads were swabbed along the exposed surface within an approximate 20-ft diameter area in the intertidal zone. The presence or absence of oiling on the pads was noted. For subtidal bed sampling, absorbent pads were individually wrapped around the heads of clam rakes and secured with adhesive tape. The pads were then submerged and swabbed along the bottom in a 20-ft diameter area. The pads were brought to the surface and observations of oiling were recorded. The used absorbent pads were placed in labeled plastic bags for future reference. Minor oil spotting was observed on two absorbent pads collected at the Fairhaven Hacker Street and Sconticut Neck shellfish sample locations. No oil was observed on any of the other absorbent pads.

2.2.4 Dive Surveys

Dive surveys were conducted between July 31 and August 4, 2003. Ocean Technology Foundation and Aquas, LLC conducted six dive surveys at depths ranging from 17 to 64 ft. Surveys included visual assessment of the sediment surface and collection of sediment samples. The surveys were conducted at two locations along the path of the barge and four locations where submerged oil would most likely be present, based on proximity to heavily oiled shorelines, currents, and bathymetry (i.e., offshore of Barneys Joy Point and West Island). At each location, the divers traversed approximately 250 ft in each direction (North, East, South, and West) from the center location. There were no tarballs, oil pancakes, or other observations of oil at any of the dive sites. In addition, there was no staining observed on any sampling gear, including gloves and air hoses (which were dragged along the seafloor). A total of 29 sediment samples were collected from several locations. A summary of this sampling event is provided in Section 2.4.

2.2.5 Submerged Oil Summary

In summary, multiple types of subtidal surveys, conducted in a variety of locations in areas most likely to have submerged oil, did not find evidence of oil on the bottom of the Bay in quantities that would be considered substantial or portend a submerged oil problem. However, small amounts of oil (e.g., a few spots, staining of the snare) consistent with the presence of tarballs on the bottom was found at locations approximately 980 to 2,100 ft offshore of Barneys Joy, in water up to approximately 22 ft deep. This subtidal oil is believed to be oil that washed ashore, mixed with sand to become negatively buoyant, and then washed back into deeper water.

2.2.6 Water Column Sampling

Water column sampling was initiated within 48 hours of the spill. A total of 51 water column samples were collected on five occasions from April 29 through May 12, 2003. Samples were collected at nine stations in the spill area and two reference stations.[11] Sample locations were established offshore of oiled shorelines, and under and near surface oil slicks or tar mats in open water. GPS coordinates were recorded for each sample location and subsequent samples were collected at the same approximate sampling locations for consistency. Total PAH detected in the water samples were below 1 ppb with one exception, which was one of the samples collected within 48 hours of the spill near Barneys Joy (where the PAH concentration was 2.7 ppb).[12]

[11] *Reference locations were east of the Elizabeth Islands and were established based on observations of no oiling and prevailing wind direction since the time of the spill.*

[12] *Based on the relative PAH concentrations in this sample, it is likely that the sample contained tiny oil droplets rather than only dissolved PAHs.*

Total PAH and individual analytes for all samples were below screening benchmarks for the protection of aquatic life in marine water (LOELs).[13] The water column data were used to calibrate the aquatic toxicity models and are presented in the *Pre-Assessment Data Report* (MAEOEA et al. 2005).

Additional sampling events were conducted in June and August of 2004 as part of the requirements for the MCP. In June 2004, three samples were collected offshore of Long Island during cleanup of oil "pavement" on the shoreline. PAHs in all samples were below screening benchmarks for the protection of aquatic life in marine water (Buchman 1999) with the exception of phenanthrene in one sample. In August 2004, five surface water samples were collected in intertidal areas that were considered to be representative of worst case oiling – heavily oiled marshes. Extractable petroleum hydrocarbons (EPH) and PAH fractions were all below detection limits. Additional data and information on data collected to fulfill requirements of the MCP can be found in the *Updated Conceptual Site Model* (GeoInsight 2005a) and the *Phase II Comprehensive Site Assessment Scope of Work and Conceptual Site Model* (GeoInsight 2005b).[14]

2.3 Intertidal Sediment Data

Between May 7 and May 9, 2003, 20 intertidal sediment samples were collected from 10 locations in the spill area; one upper and one lower intertidal sediment sample from each location. Samples were also obtained from one unaffected reference location. All samples were analyzed for PAH, saturated hydrocarbons, total petroleum hydrocarbons, and total organic carbon. Only two samples resulted in total PAH concentrations above screening benchmarks for marine sediments (ERLs[15]), both of which reportedly either contained or were suspected to contain bulk oil (sheen and/or tarballs) during the time of collection. These two samples were taken from the lower intertidal zone at Pope's Beach and the upper intertidal zone of Barneys Joy.

Three additional sediment sampling events were conducted in early, mid and late 2004 to fulfill requirements of the MCP. In 2004, 187 samples were collected from shorelines within Buzzards Bay. These included shorelines classified as very light (17 samples), light (46 samples), moderate (56 samples), and heavily (68 samples) oiled. Samples were collected in marsh substrate and upper, mid, and low intertidal zones of sandy shorelines. Sample locations were free of any visible remaining oil. Results indicated that only two samples (which were collected from very light and light shorelines) had detectable concentrations of EPH fractions and these concentrations were below MCP Method 1 Standards. All samples were below ERL benchmarks for total PAH except one sample collected from a moderately oiled shoreline. Only two samples exceeded ERL benchmarks for individual PAHs. However, further analyses on the two samples indicated they were not dominated by B-120 oil; oil from other sources was present in these samples. Additional data and information on data collected to fulfill requirements of the MCP can be found in the *Updated Conceptual Site Model* (GeoInsight 2005a) and the *Phase II Comprehensive Site Assessment Scope of Work and Conceptual Site Model* (GeoInsight 2005b).

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[13] *EPA Ambient Water Quality Criteria Maximum Concentrations (CMCs) for marine water. For PAHs these are Lowest Observed Effect Level (Buchman 1999).*

[14] *This report can be found at: http://www.buzzardsbay.org/oilspill-status.htm*

[15] *Effects Range - Low (ERL) screening benchmarks for marine sediments (Buchman 1999).*

2.4 Subtidal Sediment Data

Initial subtidal sediment sampling was conducted along both the western and eastern shores of the Bay in May 2003. Five samples, including one reference sample, were collected 190 to 2,600 ft offshore in 2 to 16 ft of water with a Petite Ponar Grab sampler. Total PAHs for the five samples ranged from 15 to 346 ppb.[16] The total and individual PAH concentrations in all five samples were at least an order of magnitude below ERL benchmarks. These subtidal sediment data are provided in the *Pre-Assessment Data Report* (MAEOEA et al. 2005).

During the underwater dive surveys in July and August 2003, 29 sediment samples were collected. Four of the 29 samples were not analyzed because they consisted largely of rock. Total PAH concentrations in the samples analyzed ranged from less than 0.1 ppm to 2 ppm and were below ERL benchmarks. In addition, all samples were below ERL benchmarks for individual PAHs except one analyte in one sample (acenaphthene in sample 2N). Geochemical evaluation of this sample and comparison to B-120 source oil indicates that the B-120 is not the potential PAH source based on the overall PAH fingerprint and relative weathering behavior of individual PAHs.

In July and August 2004, additional subtidal sediment sampling was conducted as part of the initial Phase II characterization for the MCP, to assess the potential for natural shoreline erosion processes to result in redeposition of oiled sediments in the shallow subtidal zone adjacent to heavily oiled shorelines. A total of 61 sediment samples were collected in subtidal habitat adjacent to shorelines categorized as heavily oiled (Long Island South, Sconticut Neck West, and Barneys Joy East), moderately oiled (Pope's Beach), and very lightly oiled (Long Island South, Demarest Lloyd State Park Beach, and Demarest Lloyd marsh). PAH concentrations were detected in 16 of the 61 samples collected and ranged from less than 1 ppb to 2 ppb. All 61 samples were below the ERL benchmark for total PAH. In addition, 59 of the 61 samples were below ERL benchmarks for individual PAHs. Additional data and information on data collected to fulfill requirements of the MCP can be found in the reports prepared for the MCP (GeoInsight 2005a and GeoInsight 2005b).

2.5 Bivalve Tissue Data

Shellfish are sessile, benthic organisms that typically filter large volumes of water and associated entrained sediment during feeding. Shellfish do not efficiently metabolize PAHs, so PAHs that are present in water and sediment tend to bioaccumulate in shellfish tissues. This puts the shellfish at risk for injury due to oil spills and creates the potential for human health risk from consumption of shellfish.

To avoid human exposure to PAHs from consumption of shellfish exposed to oil from the B-120 spill, the MADMF announced the closure of state shellfish areas BB-1 through BB-58 (within Buzzards Bay) and E-1 through E-4 and E-8 through E-10 (adjacent to the Elizabeth Islands) immediately following the release. Most acreage (approximately 151,000 acres) was closed on April 28, 2003, with additional acreage (approximately 26,000 acres) closed on April 30, 2003.[17] Approximately 7,500 of the 177,000 acres were closed prior to or around the time of the incident due to conditional (e.g., seasonal, poor water quality) or permanent closures.

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[16] *Typically some portions of PAHs in sediments are from non-spill related sources (i.e., pyrogenic origins or other historic contamination).*

[17] *Acreage is approximate and representative of entire shellfish areas as defined in MADMF announcements.*

In order to assess human health risks to potentially contaminated shellfish and determine tissue concentrations to allow reopening of the shellfish beds closed as a result of the spill, an extensive sampling effort was conducted. Using SCAT maps, MADMF and Town Shellfish Constables selected sampling locations (shellfish beds) located in the vicinity of oiled beaches where recreational shellfishing commonly occurred.

Between May 2003 and May 2004, seven shellfish surveys were conducted at 33 locations in the shallow subtidal zone around Buzzards Bay to collect tissues for analysis of PAH concentrations. Specifically, two surveys were conducted in May 2003, and one survey in each of June, July, August, and October 2003, and May 2004. Blue mussels (*Mytilus edulis*), oysters (*Crassostrea virginica*), quahogs (*Mercenaria mercenaria*), scallops (*Argopecten irradians,*) and softshell clams (*Mya arenaria*) were the bivalve species targeted for sampling, based on their recreational and commercial importance and abundance. During the May 5 through October 24, 2003 surveys, 151 composite shellfish tissue samples were collected from areas identified within the intertidal and subtidal zones along shorelines classified with all degrees of oiling severity (un-oiled, very lightly oiled, lightly oiled, moderately oiled and heavily oiled). On May 13, 2004, a follow-up sampling survey was conducted and 9 composite shellfish tissue samples were collected.

Composite samples of target species were collected at each location, as available. Three random locations within a shellfish bed were sampled using a clam rake. A composite sample of 12 to 15 specimens of each available species was collected at each station. The shells of each specimen were cleared of debris, sediment, or visible oil using bay water.

Samples were shipped to B&B Laboratories under chain of custody, where the animals were removed from their shells, homogenized, and analyzed for PAH. Refer to the *Pre-Assessment Data Report* (MA EOEA et al. 2005) for a complete list of PAH analytes, as well as analytical parameters and methods.

Total PAH results for samples collected in 2003 ranged from 114,529 ppb in surf clams collected on May 6 off of Barneys Joy (classified as heavily oiled) to 28.7 ppb in oysters collected on August 27 off of the east side of Sconticut Neck (classified as very light). One to two weeks after the spill when they were first sampled, most shellfish adjacent to oiled shorelines had total PAH concentrations above the observed background level (200 ppb).[18] Within four months after the release (August 2003), only four locations had concentrations above background levels. These four locations included one location in Sconticut Neck (mouth of Nakata Creek), two locations in Fairhaven (Hacker Street and West Island-Bass Creek), and one location in Dartmouth (Cow Yard). Within six months after the release (October 2003), only one location was above background concentration (Long Island South). Samples collected on May 13, 2004, approximately one year after the initial spill, ranged in total PAH from 26 ppb in quahogs off the southeast side of Sconticut Neck (classified as heavy) to 169 ppb in quahogs off of Long Island South (classified as heavy).

In addition to evaluating human health risk and determining the timing of re-opening of shellfish beds, these data were also used to assess the potential ecological injury to the shellfish themselves. Section 3.2 discusses the potential for acute and sub-acute injury to shellfish from the measured PAH body burdens.

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[18] *The approximate maximum concentrations in tissue samples from areas documented as having received little to no oiling from the spill were also below approximately 200 ppb.*

3.0 EXPOSURE AND INJURY ASSESSMENT

3.1 Open Bay Water Column Habitat and Resources

As discussed in Section 1.1, the spill occurred at the entrance to Buzzards Bay in or near the ship channel and oil was released as the barge moved into the Bay, first to Buoy BB, then to Anchorage Lima. Anchorage Lima is located in the center of the Bay between West Island and Gosnald. Winds and currents then moved the spilled oil across the Bay and stranded it on the eastern and western shorelines. The Trustees and RP evaluated the potential for injury to the water column and sediment/benthic habitat and their aquatic resources through two different pathways. One pathway was acute toxicity from dissolved fractions of oil (primarily the most toxic fraction, the PAHs) in the water column. The second pathway was acute injury due to physical fouling of organisms on the bottom. Physical fouling is defined as whole oil coating all or parts of benthic organisms. These separate evaluations are discussed below.

3.1.1 Injury due to Dissolved Oil in the Water Column

Injury to the water column habitat and its resources in the open Bay was evaluated by performing aquatic toxicity modeling to produce estimates of water column concentrations of dissolved monocyclic and polycyclic aromatic hydrocarbons resulting from the spill. These concentration estimates were used to evaluate the potential for acute toxicity to aquatic biota in the subtidal waters affected by the spill.

In a cooperative process, the Trustees and the RP representatives agreed upon a set of input parameters and conditions to be used in the modeling. The Trustees and RP used separate model types to convert these inputs into estimates of dissolved PAH concentrations through space and time. The Trustees used the Spill Impact Model Analysis Package (SIMAP) and the RP used the Chemical/Oil Spill Impact Module (COSIM).

Working in parallel, modelers collaborated to determine how varying specific parameters affected results. After conducting sensitivity evaluations using the separate models, the teams discussed and agreed upon key input parameters and data sets. Consensus data sets included the models' spatial domain and grid, bathymetry, water and air temperatures, tidal and other currents, total suspended solids, neat oil chemistry, and winds. The modelers also agreed to either point estimates or ranges for the horizontal dispersion coefficient and wind drift angle. Finally, the modeling group agreed to investigate a range of potential release scenarios, including volumes up to and including 98,000 gallons, the upper range estimated by the U.S. Coast Guard and others. Within each potential release scenario the volume released, location of release, trajectory of the leaking barge, and release rate were varied. After reaching agreement with respect to the use of these conditions, the models were run separately to generate water column concentrations of dissolved aromatics over three-dimensional space and time. The oil mass was also partitioned into several phases including surface water slick, air (evaporation), shoreline, dissolved aromatics, and submerged oil droplets.

The models provided a broad picture of hydrocarbon levels and oil distribution throughout the Bay and after calibration; model results were generally consistent with field observations.

Using the results from both models, the modelers concluded that for all release scenarios tested, the concentrations of dissolved aromatics were too low and the durations of exposure were too short to cause significant injury to biota in the open water subtidal areas of Buzzards Bay and Rhode Island Sound.

Due to the complexity of the shoreline and the oil/shoreline interface, the models did not attempt to predict toxicity to biota present in the very shallow areas of the Bay directly adjacent to the shorelines. The potential for injury due to dissolved oil in these areas is addressed separately in the nearshore injury assessment in Section 3.4.

3.1.2 Injury to Benthic Organisms due to Physical Fouling

As discussed in Section 2.2, the Trustees were concerned that oil from the barge may have sunk to the bottom and injured benthic organisms. To evaluate this potential injury pathway, multiple submerged oil surveys were conducted. Although several areas which were determined to be likely locations for submerged oil were investigated, submerged oil was only observed offshore of Barneys Joy. In this area, 29 percent (chain drags) to 40 percent (lobster pots) of the snare recovered had light oiling.

These observations from the submerged oil surveys, in conjunction with conditions at Barneys Joy (a high energy site with a sandy substrate and very heavy oiling), and the observation of repeated re-oiling of the shoreline at Barneys Joy by tarballs, suggested that the oil found on the bottom offshore of Barneys Joy was tarballs that originated from this shoreline (due to oil mixing with sand and becoming negatively buoyant), rather than a pool of submerged oil that sank before hitting the shoreline.

Based upon the submerged oil surveys, the Aquatic TWG concluded that it was unlikely that there were significant areas of oil on the bottom in the open area of the Bay. In addition, the Aquatic TWG concluded that with the exception of an area offshore of Barneys Joy, there was no evidence to suggest smaller amounts of oil (e.g., tarballs) were present on the bottom of the open Bay. Last, the Aquatic TWG concluded that the exposure pathway and general level of potential injury in the area offshore of Barneys Joy was similar to the exposure pathway and general level of potential injury believed to have occurred in shallow nearshore areas adjacent to other heavily oiled and moderately oiled shorelines. Therefore, injury to biota in the offshore subtidal area adjacent to Barneys Joy due to the presence of tarballs on the bottom was addressed as part of the nearshore injury discussed in Section 3.4.

Based upon the submerged oil surveys, the area beyond the 3-ft depth exposed to tarballs was calculated. Chain drag and lobster pot samples with lightly oiled snare were found as far as 2,100 ft from shore at Barneys Joy. To be conservative, the Aquatic TWG assumed that the tarball exposure extended beyond the 3-ft depth contour line out to 2,500 ft from heavily oiled shoreline (0-ft contour) at Barneys Joy. This area beyond the 3-ft depth contour line totals 458.7 acres (Figure 2). The area between the 0-ft and 3-ft contour lines is not included in this estimate as it is already included as part of the nearshore subtidal habitat exposure discussed in Section 3.4.

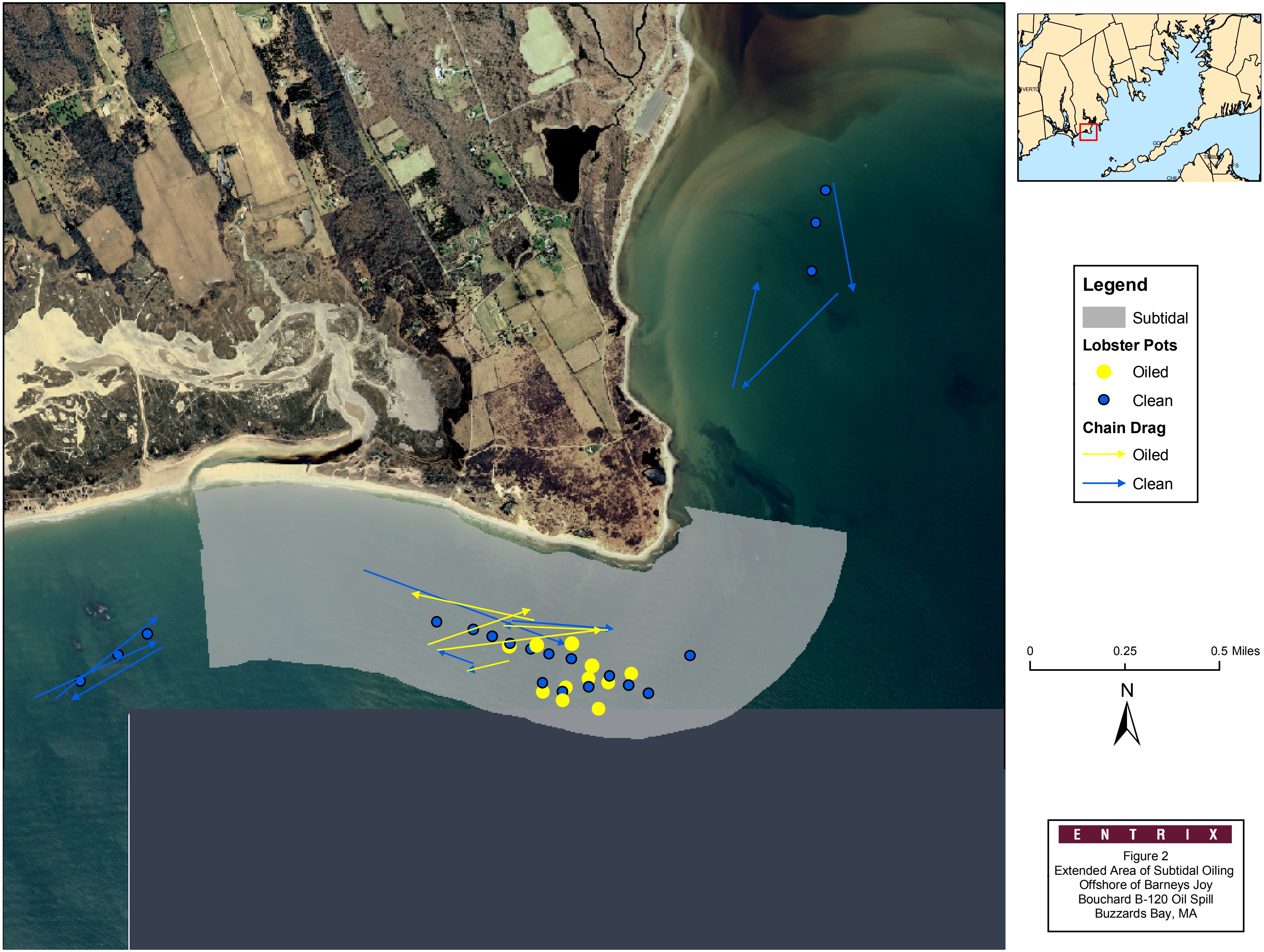

Figure 2
Extended Area of Subtidal Oiling
Offshore of Barneys Joy
Bouchard B-120 Oil Spill
Buzzards Bay, MA

Map Document: (J:\Arcview\7079607 - BuzzardsBaySpill\Aquatic\Barney's Joy Inter-sub_esi.mxd)

3.2 Bivalves

As discussed in Section 2.6, bivalve tissue was collected and analyzed from multiple locations along oiled and reference shorelines several times in 2003 and once in 2004. The primary use of these data was to evaluate human health risk and monitor PAH depuration, and to identify when shellfish beds could be re-opened for shellfish harvesting. The Aquatic TWG used this comprehensive dataset to evaluate ecological injury to the shellfish themselves due to body burdens of PAHs and recovery of potential service losses due to PAH accumulation in shellfish and other organisms. The principal purpose of the analysis was to evaluate the potential for sublethal effects since only a few dead bivalves were found washed up on shorelines during the spill response and dead bivalves were not found during the collection of the shellfish for the tissue analysis surveys.[19] Note that this evaluation does not address potential injury to the shellfish from physical fouling by tarballs or whole oil.

Tissue body burdens of PAHs were compared to United States Environmental Protection Agency (USEPA) benchmarks of 9.31 µmol/g lipid for acute effects[20] and 2.24 µmol/g lipid for chronic effects[21] (USEPA 2003). These benchmarks were calculated to be protective of 95 percent of the aquatic organisms. Although these values are reasonable benchmarks, and the best available for tissue concentrations, they should be considered conservative (protective) when compared to the bivalve data for this spill because there are several assumptions implicit in the derivation of the benchmarks that do not apply to the bivalve data. First, the approach used to derive the toxicity thresholds assumes that the PAHs in the environment and the organisms are in equilibrium. This assumption may not be correct even with exposure to sediment-bound PAHs, and clearly is not true in this case where there was a single, rapid release, a primary pathway of PAHs to the bivalves through the water column, and rapid uptake and depuration. Second, a chronic threshold assumes there is a long-term exposure, which again in this case, is not supported by data collected after the spill. Third, the benchmark values assume that the PAHs are incorporated in the fatty component of tissues (lipids) after passing through the digestive and metabolic organs, and therefore were acting as a true "body burden" interacting with the physiological systems of the shellfish. However, the whole body of the bivalve was included in the chemical analyses and therefore, in reality, it is likely that at least some of the PAHs reported as "tissue PAH" were in fact in the gut bound to sediment and/or organic matter or as tiny droplets of emulsified oil. However, in lieu of other benchmarks, these benchmarks provide a conservative (protective) benchmark to compare against the spill tissue data and assess the relative level of potential PAH effects and injury to bivalves.

Of the 153 samples collected and included in this analysis (the analysis excludes the two Barneys Joy samples collected in May 2003[22]), none of the samples exceeded the acute effects benchmark (9.31 µmol/g lipid) and only nine samples exceeded the even more conservative chronic effects benchmark (2.24 µmol/g lipid). All nine samples were collected in May 2003 in the vicinity of Fairhaven:

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19 Massachusetts Audubon saw and collected 10 small, live and dead oiled surf clams in the oiled wrack at in the vicinity of Barneys Joy in May 2003. In addition, the surf clam samples collected at Barneys Joy by MDMF in May 2003 and provided to ENTRIX for inclusion in the tissue sample analysis, had oil inside and outside of the shell and some were dead. These observations were the exception not the rule.

20 EPA calls this benchmark the "Final Acute Value" or FAV.

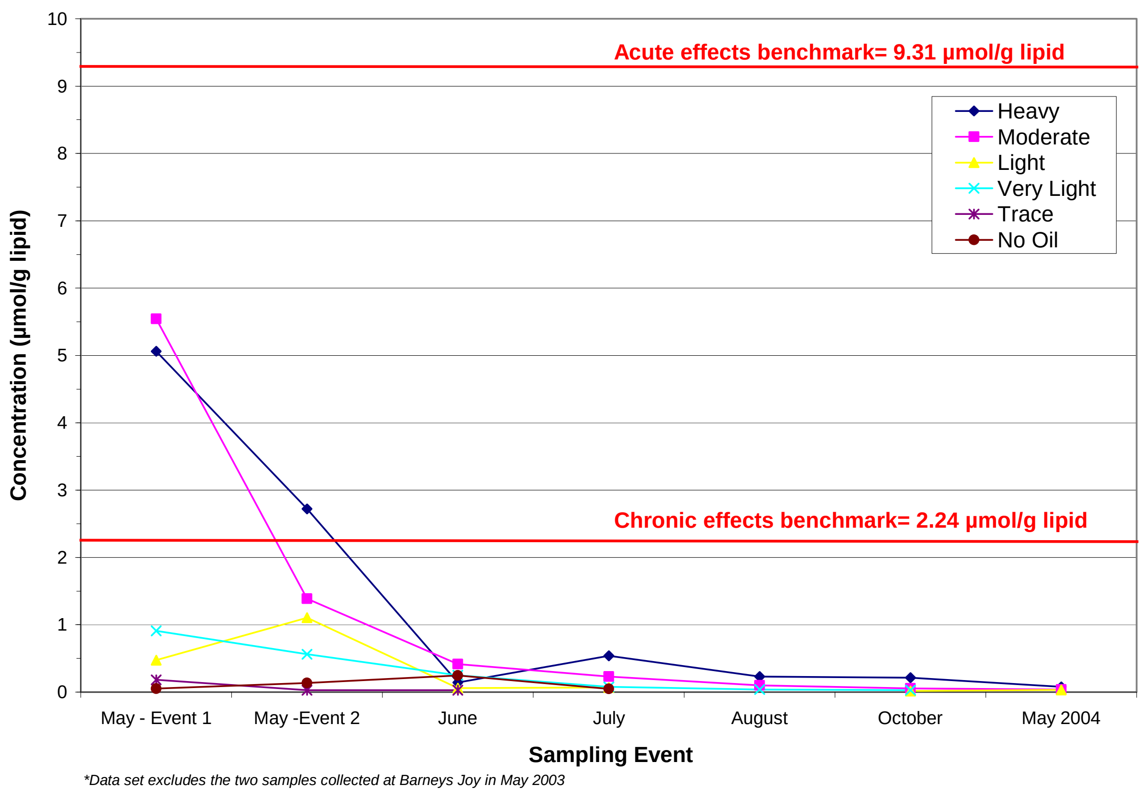
21 EPA calls this benchmark the "Final Chronic Value" or FCV.

22 These samples were not collected according to protocol, and gross oil contamination is suspected (i.e., the data are not representative of tissue concentrations).

- West central side of Sconticut Neck – one sample
- Mouth of Nakata Creek, Southeast side of Sconticut Neck – two samples
- Fairhaven Hacker Street – three samples
- The southwest side of Long Island – one sample
- Northwest side of Sconticut Neck near Hacker Street – one sample
- Bass Creek, East side of West Island of Nasketucket Bay – one sample

Average total PAH concentrations by shoreline oiling and sampling event are shown in Figure 3. On average (excluding the surf clams collected at Barneys Joy in May 2003), shellfish collected along or adjacent to heavily or moderately oiled shorelines had total PAH concentrations somewhat higher than the chronic benchmark in early May 2003, but did not exceed the acute benchmark. On average, shellfish tissue samples collected from less heavily oiled shorelines did not exceed the chronic benchmark. PAH concentrations in tissues declined rapidly in the following weeks. By mid-June, average total PAH concentrations were well below the chronic benchmark for all shoreline oiling types.

FIGURE 3. Average Total PAH Concentration over Time



This data set and benchmarks indicate that some portion of the bivalves adjacent to many moderately and heavily oiled shorelines slightly exceeded the calculated threshold associated with assumed chronic, sublethal effects in the most sensitive (95^{th} percentile) of species in laboratory test environments. It is unlikely however, that these exceedences translate to sublethal injury to the Buzzards Bay bivalves because:

1) Based on a short term pulse exposure, a significant proportion of the PAHs measured in the bivalves were likely to have been present in the gut rather than the tissue, therefore not incorporated into the organism in a way that would potentially exert a toxicological effect; and
2) The chronic benchmark was derived based on an extrapolation from acute exposures in experimental systems at equilibrium and assumes long term constant exposure in the environment under equilibrium conditions. In contrast, the data indicate that for this spill, the bivalves rapidly accumulated and began depurating the oil within weeks of the spill and that even in areas where concentrations exceeded the chronic benchmark, they did so for a short period of time.

Additional detail on this analysis is provided in Appendix A.

3.3 Lobsters

Based on knowledge of the life history of the American lobster, information regarding the behavior of the spilled oil, and data collected immediately and during the months following the spill, there was little basis to conclude that lobsters suffered significant amounts of exposure and/or injury. However, these same data indicated that there might have been some potential for minimal exposure and injury to certain life stages. In order to fully understand the exposure potential and likelihood of significant injury to all lobster life stages and populations in and around Buzzards Bay as a result of the spill, a detailed evaluation was conducted.

Based upon the life history and habitat preferences of the lobster, and the spill characteristics, there was little exposure and injury to lobster eggs, larvae, adolescents, and adults. The potential for exposure and subsequent injury of early benthic phase (EBP) lobsters as well as the uncertainty surrounding the analysis, was higher than the other lifestages; however, the estimated degree of potential exposure and injury to EBP lobsters was also determined to be low. Due to the estimated low levels of potential injury to all lobster lifestages due to the oil and the difficulty in increasing the precision of the estimate of exposure and the degree of injury to exposed lobsters, the Aquatic TWG determined that a resource-specific injury assessment was not warranted for lobsters. Potential injury to this species was captured in the injury assessment for the nearshore subtidal areas and extended subtidal areas offshore of Barneys Joy (Section 3.4), in which the lobster was considered part of the benthic community. The full report, *Evaluation of the Potential for Exposure of the American Lobster (Homarus americanus) to Oil from the Bouchard B-120 Spill* (Aquatic TWG 2008), is provided in Appendix B.

3.4 Nearshore Habitat

As described in Section 1.1, spilled oil moved across the water and was stranded on shorelines around the Bay. Injury due to dissolved concentrations in the water column was assessed through modeling in areas of the bay greater than 3 ft below MLW (see Section 3.1.1). Injury to the area within the intertidal zone where the oil stranded (the "footprint" of the oil), was assessed by the SAT. However, other areas of the intertidal and subtidal zones not addressed by these assessments were likely also exposed to oil. Intertidal areas outside the footprint of the oil and shallow subtidal areas directly adjacent to the shoreline may have had greater exposure to concentrations of dissolved PAHs and entrained oil than the open bay due to the action of the surf. In addition, these areas, while not affected by stranded oil, may have had mobile oil from the nearby footprint moving across the substrate. Therefore, the Aquatic TWG separately evaluated exposure and injury to these other two areas (intertidal areas outside the footprint and shallow subtidal areas adjacent to shorelines) and together named them the "nearshore" habitat to distinguish from the open water areas previously described in this document.

The SAT evaluated the amount of oil present on shorelines, and classified the oiling levels as heavy, moderate, light, very light and trace oiling. The Aquatic TWG included in its injury assessment only heavy or moderate oiled shorelines and the subtidal areas adjacent to those shorelines. Based upon the definitions of light and very light oiling, the Aquatic TWG judged that in areas of very light and light oiling the amount of oil in areas outside the visible footprint of oil (assessed by the SAT) would have been insufficient to produce measurable impacts to the habitats or biota in those habitats.[23] In subtidal areas, the Aquatic TWG narrowed the exposure area to those areas between 0 and 3 ft below MLW. It was assumed, based on available information, that with the exception of the area offshore of Barneys Joy, areas deeper than this were more similar to the open water areas discussed in Section 3.1 and exposure in these areas would be insufficient to produce measurable impacts.

In addition to the two nearshore areas described above, this section also addresses injury to the deeper water area offshore of Barneys Joy that was identified from submerged oil surveys as having potential injury due to physical fouling from small benthic tarballs (Section 3.1.2). Although not strictly a nearshore area, it is discussed in this section because the injury pathway is similar to nearshore areas and injury can be estimated using the same methodology.

Therefore, this section describes the exposure calculations and injury quantification for:

a) intertidal areas outside the area of the footprint along heavily and moderately oiled shorelines;

b) subtidal areas up to 3 ft below MLW adjacent to heavily and moderately oiled shorelines; and

c) an additional subtidal area offshore of the heavily oiled portion of Barneys Joy from the 3-foot depth contour line to a distance of 2,500 ft from the MLW line (also referred to as the "extended Barneys Joy area").

The Aquatic TWG was careful to keep the procedures used for its assessment consistent with those used by the SAT and avoided double counting.

This section is broadly divided into exposure assessment (Section 3.4.1) and injury assessment (Section 3.4.2). The exposure section discusses the mapping process that led to a calculation of acres of exposed nearshore habitat considered by the Aquatic TWG. The injury assessment section discusses the model used to quantify the estimated injury and the rationale for the model inputs, and provides the model input values and results.

[23] *Shorelines with less than 10% cover in narrow bands or less than 1% cover in wider bands were classified as either lightly or very lightly oiled. Trace oiling was characterized as areas where oiling was limited to a few tarballs or pieces of debris. The SAT did not assess injury to this oiling category.*

3.4.1 Exposure Assessment/Calculations

3.4.1.1 Introduction

The exposure assessment quantifies the amount of area (i.e., acres) that is included within the defined nearshore area described above. (The amount of area included in the extended Barneys Joy area was estimated in Section 3.1.2 and is also provided in the final table of this section.) This section describes the data sources and mapping that was done to produce the areas of exposure by habitat type and oiling level, as well as the final values for each unique combination of habitat and oiling level (e.g., heavily oiled marsh). Consistent with the SAT, the areas addressed by the Aquatic TWG are also divided by state (Massachusetts and Rhode Island).

The mapping for the nearshore areas built upon the oiling level and habitat mapping already completed by the SAT. In order to maintain consistency in terminology, the Aquatic TWG adopted the oiling levels used by the SAT to classify the nearshore habitats. Specifically, the Aquatic TWG used heavy and moderate to describe the oiling in intertidal and subtidal areas adjacent to, but outside, the areas assessed by the SAT as heavy or moderately oiled. This designation does not mean that the amount of oil was the same in the areas within the footprint assessed by the SAT and those areas outside the footprint assessed by the Aquatic TWG. Rather it allows shorelines to be described with one oiling designation for all impacts and the oiling maps to be consistent between the two groups. It must be recognized that the amount of oil and the amount of injury within the footprint of the oil, adjacent intertidal areas, and adjacent subtidal areas is different within any one section of shoreline with a single oiling level designation.

The assessment of habitat exposure to oil began by creating a Geographic Information System (GIS) database to analyze shoreline and nearshore oiling. Oiling level, habitat type, aerial photographs, and tidal and bathymetric information were derived from the following sources and entered as layers in the GIS database:

- Shoreline oiling levels previously mapped by the SAT;
- Habitat types developed from NOAA's Environmental Sensitivity Index (ESI) data;
- Aerial photographs from Massachusetts GIS November 2002 aerial photographs; and
- Bathymetry data and tidal ranges adapted from NOAA's Electronic Navigation Chart (ENC) data.

Missing data needed for the analysis were obtained through field efforts, extrapolation from existing data, and the best professional judgment of the Aquatic TWG.

Because the basis for the nearshore mapping was the mapping completed by the SAT, the shoreline mapping is summarized first in Section 3.4.1.2. The mapping process for the intertidal nearshore areas and subtidal nearshore areas are explained in Sections 3.4.1.3 and 3.4.1.4, respectively.

3.4.1.2 Shoreline Mapping

Mapping potentially impacted areas for the aquatic injury assessment began with a consideration of the oiling exposure and habitat maps produced by the SAT. The SAT produced maps showing the visible oiling on shorelines impacted by the spill. The production of these maps used a variety of data sources including the SCAT reports, oiling maps produced by cleanup contractors during the first few days of the spill, reports of oil by wildlife observers, and field observations by the shoreline team. These maps reported the highest level of oiling reported along each section of the shoreline. Shoreline oiling was classified as clean, trace, very light, light, moderate, or heavy. The approach used to assign oiling categories is consistent with standard practice for SCAT data[24] and is shown in Table 1.

Shoreline habitat type data from the ESI database for Massachusetts and Rhode Island was also incorporated and used to develop shoreline habitat maps, and categorize oiling levels by habitat types. For simplicity, multiple similar ESI habitat types that would be expected to have similar types and magnitudes of injury (e.g., fine sand beach and medium sand beach) were grouped into three general habitat types: coarse substrate, sand beach, or marsh. In some cases the ESI habitat characterizations were modified based on field observations by the SAT or during subsequent assessments.

The mapping analysis resulted in all of Buzzards Bay and some areas in Rhode Island outside Buzzards Bay being characterized by an oiling level (clean, very light, light, moderate or heavy) and a habitat code (wetlands, sand beach, or coarse substrate). Average oiling widths for each oiling level were calculated from SCAT data sheets and applied to the oiling length data. Acreage estimates for each unique combination of oiling level and habitat type were then calculated. Details of the procedure and results of shoreline mapping can be found in the document *Shoreline Injury Assessment Part I: Exposure Characterization - Bouchard 120 Oil Spill, Buzzards Bay, Massachusetts and Rhode Island* (Shoreline Assessment Team 2006).

TABLE 1. Shoreline Oiling Categories Based on the Oil Band Width and Percent Oil Cover in the Oil Band

Coverage	**Width of Oiled Band**			
	< 3 ft	**3-6 ft**	**>6-9 ft**	**> 9 ft**
< 1% cover	Very Light	Very Light	Very Light	Light
1-10% cover	Light	Light	Moderate	Moderate
10-50% cover	Moderate	Moderate	Moderate	Heavy
51-90% cover	Moderate	Heavy	Heavy	Heavy
> 90% cover	Heavy	Heavy	Heavy	Heavy

3.4.1.3 Aquatic Intertidal Zone

In order to calculate the amount of area in the intertidal zone that is outside the footprint of the oil (and therefore evaluated by the Aquatic TWG), the Aquatic TWG needed to first calculate the area of the entire intertidal zone, and then subtract the area of the oiled footprint calculated by the SAT. Because the intertidal zone varies substantially in width throughout the spill zone, the Aquatic TWG needed to map the intertidal zone to accurately calculate the intertidal area

24 *Trace oiling is not a standard SCAT category. For completeness, the SAT characterized trace oiling as areas where oiling was limited to a few tarballs or pieces of debris. The SAT did not assess injury to this oiling category.*

included in the nearshore aquatic injury. This intertidal mapping was done by habitat type for all areas of the shoreline identified by the SAT as heavily or moderately oiled.

Intertidal Zone Mapping

The Aquatic TWG evaluated three existing data sources for use in mapping the intertidal zone along heavily and moderately oiled shorelines: NOAA bathymetry data, Massachusetts Wetland GIS coverage, and aerial photography of the Bay. Of the three data sources, NOAA bathymetry data (ENC data) were the most complete set, but were still missing intertidal information in some areas, particularly where the intertidal zone is narrow. In addition, the high tide line is placed at the seaward edge of the marsh rather than the landward edge. After careful consideration by the Aquatic TWG, it was determined that, despite these shortcomings, the NOAA bathymetry data were the best source and were therefore used as the basis for mapping. The ENC data represent depth zones as polygons with the highest elevation polygon being the intertidal zone between mean high water and mean low water. The use of this data set required field studies and data extrapolation to provide information to fill in the missing polygons.

Depending upon the characteristics of the missing intertidal polygons (e.g., location, length, adjacent data), one of three different approaches was used to estimate the missing polygons. On five longer shoreline sections (6.16 miles total) where intertidal polygons were missing from the ENC files, low and high tide data were collected in the field using a Trimble Geoexplore 3 set on point mode. The surveyed data were mapped onto Massachusetts GIS aerial photographs, dated November 2002. Field data for shorelines with ENC data were also collected and mapped for comparison and calibration with existing ENC data. The missing polygons (equaling 79.89 acres) in the five longer shoreline sections were digitized based on this field mapping. On seven shorter sections (2.41 miles total and 27.33 acres total) of shoreline with missing polygons, the high and low tide lines were digitized directly from aerial photographs and connected to the high and low tide lines of adjacent sections. In three sections (1.22 miles total and 12.36 acres total), the intertidal area was determined by using an average width of mapped intertidal polygons and digitizing the average width information into the GIS database.

In addition to the missing polygons, the intertidal polygons were incomplete in marsh areas because the ENC data places the high tide line at the seaward edge of the marsh when in reality the intertidal area can include much of the coastal marsh. The Aquatic TWG examined aerial photographs and the Massachusetts Wetland GIS coverage to identify the full intertidal area on the marsh habitats.

The calculation of aquatic intertidal areas also accounted for un-mapped shoreline oiling. Un-mapped shoreline oiling refers to documented shoreline oiling from SCAT data sheets that could not be entered into the GIS database because there was not enough location information provided on the data sheet to identify the specific location. In most cases, this consisted of short lengths of heavy or moderate oiling within a shoreline segment mapped as light or very light oiling. Therefore, the un-mapped shoreline oiling adjustment primarily increases the proportion of moderate and heavy oiling in order to capture maximum oiling levels. The SAT accounted for impacts to 7,848 ft of moderately and heavily oiled un-mapped shoreline. In order to account for exposure at these sites in nearshore intertidal calculations, the Aquatic TWG estimated the additional area of impacts by applying an average intertidal width to all of the un-mapped lengths. This added acres to the heavily and moderately oiled intertidal areas and reduced the acres of light and very lightly oiled shoreline.

The mapped, un-mapped, and total area of intertidal zone on heavily and moderately oiled shorelines, are shown in Table 2.

TABLE 2. Mapped, Un-mapped, and Total Intertidal Acres on Heavily and Moderately Oiled Shorelines

Degree of Oiling	Acres Exposed		
	Mapped	Un-mapped	Total Intertidal
Massachusetts			
Moderate	179.9	16.1	196.0
Heavy	110.9	1.4	112.3
MA Subtotal	*290.8*	*17.5*	*308.3*
Rhode Island			
Moderate	8.5	0.7	9.2
Heavy	0.0	0.0	0.0
RI Subtotal	*8.5*	*0.7*	*9.2*
Grand Total	299.3	18.2	317.5

Calculation of Area outside the Oiled Footprint

The intertidal area addressed in this document by the Aquatic TWG was calculated by subtracting the area of the oiled footprint that was assessed by the SAT from the total intertidal area shown above in Table 2. These three values are shown below in Table 3.

3.4.1.4 Subtidal Zone Mapping

The NOAA ENC subtidal polygons were used for subtidal mapping. The ENC subtidal polygons were classified as heavily or moderately oiled by drawing lines perpendicular to the shoreline from the juncture of two intertidal oiling polygons. The Aquatic TWG agreed that in all areas except for Barneys Joy, injury to subtidal habitats was restricted to water depths of 3 ft or less and does not include shallow areas separated from the shore by water greater than 6 ft deep. The source of oil for subtidal areas is the shoreline and these non-contiguous shallow areas are not expected to have the same impacts as shallow areas near the shoreline. Also, subtidal areas mapped as 0 to 6 ft deep that are not contiguous are likely in the 3 to 6 ft zone and therefore, not part of the analysis. An exception was made for the rocks off of Mishaum Point where seals were sighted during the spill response. In this area, where the bathymetry is delineated as 0 to 6 ft, but was not connected to the shoreline, the Aquatic TWG agreed to assign 10 percent of the area (0.27 acres) to the intertidal zone to account for the known presence of rocky outcrops.

TABLE 3. Calculation of the Intertidal Area Outside the Oiled Footprint

Degree of Oiling	Acres Exposed		
	Total Intertidal	**Oiled Footprint***	**Outside the Footprint****
Massachusetts			
Moderate	196.0	14.3	181.7
Heavy	112.3	26.6	85.7
MA Subtotal	*308.3*	*40.9*	*267.4*
Rhode Island			
Moderate	9.2	0.5	8.7
Heavy	0.0	0.0	0.0
RI Subtotal	*9.2*	*0.5*	*8.7*
Grand Total	317.5	41.4	276.1

**Assessed by the SAT*

***Assessed in this report by the Aquatic TWG*

The NOAA ENC data depicts 0 to 1.8 m deep (0 to 6 ft) as one polygon. To calculate the subtidal area in the 0 to 3 ft zone, the Aquatic TWG used half the area in the 0 to 6 ft subtidal polygons. This assumption was supported by an analysis of an independent dataset of point depth data available in some of the same areas as the ENC data.

Un-mapped oiling, described above in Section 3.4.1.3, was accounted for in the subtidal zone in a similar manner. In the subtidal zone, the Aquatic TWG estimated the additional area of impacts by applying an average subtidal width to all of the un-mapped lengths. This added 49.8 acres to the moderately oiled subtidal area and 3.7 acres to the heavily oiled subtidal area.

The mapped, un-mapped, and total subtidal acreage addressed by the Aquatic TWG are shown below on Table 4. As discussed previously, subtidal areas quantified in Sections 3.1.2 (extended Barneys Joy area) are included in Table 4.

Intertidal Habitats

The shorelines of Buzzards Bay include a variety of habitats including sand beaches, gravel beaches, tidal flats, marshes, and man-made structures. The SAT used ESI maps to assign habitat types to the shorelines. To maintain consistency with the SAT, the Aquatic TWG followed a procedure similar to the one used by the SAT to assign habitat types.

TABLE 4. Mapped, Un-mapped, and Total Subtidal Acres on Heavily and Moderately Oiled Shorelines

Degree of Oiling on Adjacent Shorelines	Acres Exposed		
	Mapped	**Un-mapped**	**Total Subtidal**
Massachusetts			
Moderate	556.4	49.8	606.2
Heavy	749.2	3.7	752.9
MA Subtotal	*1305.6*	*53.5*	*1359.1*
Rhode Island			
Moderate	26.4	2.1	28.5
Heavy	0.0	0.0	0.0
RI Subtotal	*26.4*	*2.1*	*28.5*
Grand Total	**1331.9**	**55.6**	**1387.6**

3.4.1.5 Assignment of Habitat Types

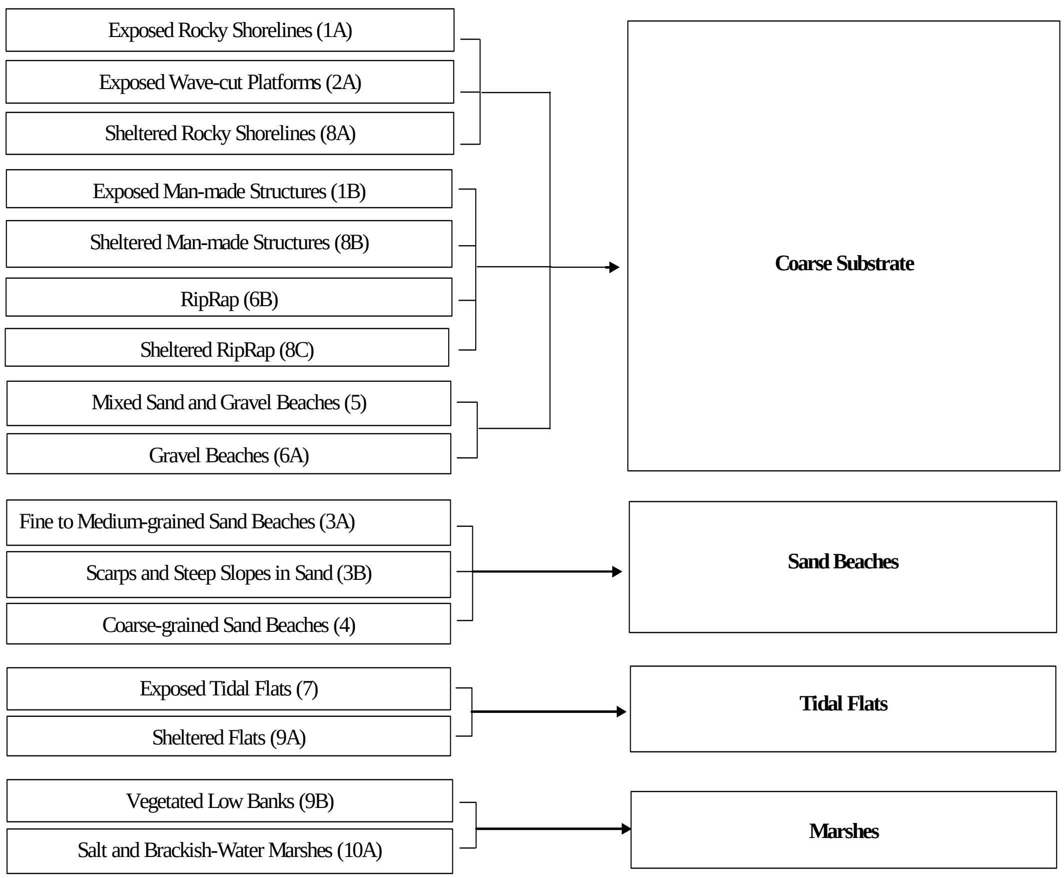
The ESI includes codes for 16 habitat types present in the spill area. If multiple habitat types occur on the same beach profile, shorelines are classified in the ESI database with more than one ESI code. For example, if a tidal flat occurs in front of a sand beach or marsh, codes for both habitat types would be included in the ESI classification. The SAT combined the 16 identified habitat codes into three broader categories (wetlands, sand beach, and coarse substrate) such that each combined group included habitats that would have experienced similar effects from oiling. If a shoreline still had more than one ESI code after combining the codes to the three broad categories, then the area of that shoreline was divided equally among the types.

The Aquatic TWG combined the original 16 ESI codes into four habitat types: marsh, sand beach, coarse substrate and tidal flats (Figure 4). The first three categories are identical to the SAT categories; tidal flats did not contain visible oil, so the SAT did not use this category. Like the SAT, in general, if a shoreline was classified by more than one shoreline type (the four boxes in the right column of Figure 4), then the area of that shoreline was divided equally among the types. However, in areas with wide tidal flats, the area of tidal flat habitat was delineated from an aerial photograph in GIS rather than assuming it was the same width as other habitat types.

Subtidal Habitats

Information on substrate type and communities in the nearshore subtidal zone was not readily available and impacts were assumed to be similar regardless of substrate type. Therefore, the nearshore subtidal zone was considered a single habitat.

FIGURE 4. Grouping of ESI Codes into Shoreline Types for the Aquatic Intertidal Injury Assessment



3.4.1.6 Calculations and Results

The exposure assessment for the intertidal areas outside the area of the footprint results in eight unique combinations of intertidal oiling and habitat type (injury categories). Four injury categories were identified for subtidal oiling. Two of these address subtidal areas 0-3 ft deep adjacent to moderately oiled shorelines and most heavily oiled shorelines. Two additional injury categories address subtidal areas adjacent to heavily oiled shoreline on Barneys Joy. In this area, acreage for the 0-3 ft zone is reported separately from the extended Barneys Joy area. The extended Barneys Joy area is the deeper water offshore of Barneys Joy that was identified during the submerged oil surveys. Tables 5 and 6 summarize the area exposed in each of the 12 total injury categories. These two tables separate the acreage by state; however, the injury categories are independent of the location of the exposed area. For example, the injury category "moderately oiled coarse habitat" is found in both Massachusetts and Rhode Island but is a single injury category. Oiling and habitat maps of the nearshore habitat and extended Barneys Joy area are provided in Appendix C.

TABLE 5. Acres of Aquatic Nearshore Habitat in Massachusetts Including the Extended Barneys Joy Area

Habitat	Acres of Nearshore Habitat Exposed		
	Heavy Oil	**Moderate Oil**	**Total**
Coarse	43.4	115.3	158.7
Sand	20.3	36.4	56.7
Marsh	9.5	13.8	23.3
Tidal Flat	12.5	16.2	28.7
Intertidal Total	**85.7**	**181.7**	**267.4**
Subtidal 0-3 ft excluding Barneys Joy	258.9	606.2	865.0
Subtidal 0-3 ft at Barneys Joy	35.3	0	35.3
Subtidal Extended Barneys Joy Area	458.73	0	458.73
Subtidal Total	**752.9**	**606.2**	**1359.1**
Grand Total	**838.6**	**787.8**	**1626.5**

TABLE 6. Acres of Aquatic Nearshore Habitat in Rhode Island

Habitat	Acres of Nearshore Habitat Exposed		
	Heavy Oil	**Moderate Oil**	**Total**
Coarse	0.0	4.8	4.8
Sand	0.0	3.9	3.9
Marsh	0.0	0.0	0.0
Tidal Flat	0.0	0.0	0.0
Intertidal Total	0.0	8.7	8.7
Subtidal 0-3 ft excluding Barneys Joy	0.0	28.5	28.5
Subtidal 0-3 ft at Barneys Joy	NA	NA	NA
Subtidal Extended Barneys Joy Area	NA	NA	NA
Subtidal Total	0.0	28.5	28.5
Grand Total	0.0	37.2	37.2

NA= not applicable

3.4.2 Injury Assessment

This section describes the methodology used to quantify injury, general concepts used to frame the injury assessment for these habitats (e.g., injury pathways, habitat services, etc.), and the specific rationale and values determined for each of the twelve injury categories.

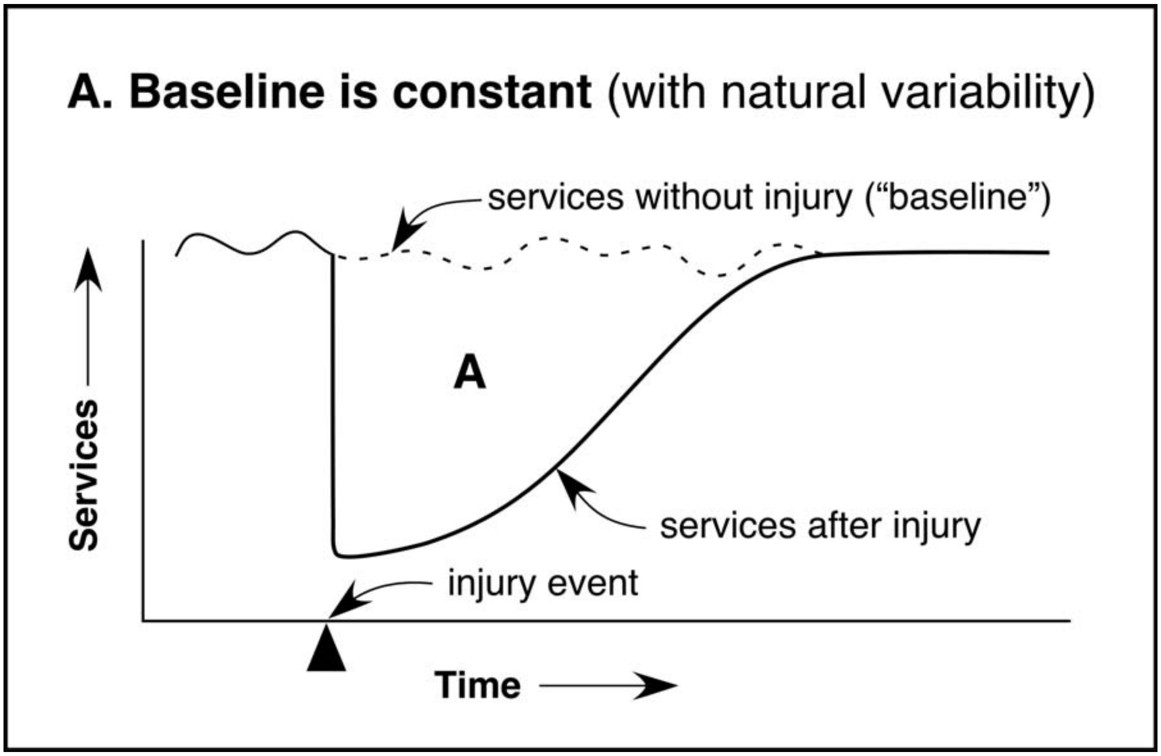
3.4.2.1 Description of Habitat Equivalency Analysis

Natural resource trustees are authorized to act on behalf of the public to protect the resources of the nation's environment. Under the Oil Pollution Act of 1990, trustee agencies determine the damage claims to be filed against parties responsible for injuries to natural resources resulting from discharges of oil; *injury* is defined as "an observable or measurable adverse change in a natural resource or impairment of a natural resource service" (NOAA 1996). Claims can be made for *primary* restoration (actions taken to directly restore the injured resources) and *compensatory* restoration (actions taken to replace the interim loss of resources from the time of injury until the resources recover to baseline conditions). For injuries resulting from oil spills, shoreline cleanup is a key part of the primary restoration actions that are taken. Often, there are few additional actions that can be taken to restore the injured resources, thus the injury assessment is based on the loss of services during the natural recovery period. Habitat Equivalency Analysis (HEA) is a methodology used to determine compensation for such resource injuries. The principal concept underlying the HEA method is that lost habitat resources/services can be compensated for through habitat replacement projects providing additional resources/services of the same or similar type (NOAA 2000).

Under the HEA method, trustees determine the injury using metrics that can be used to scale appropriate compensatory restoration options. The size of a restoration action is scaled to ensure that the present discounted value of project gains equals the present discounted value of interim losses. That is, the proposed restoration action should provide services of the same type and quality, and of comparable value as those lost due to injury (NOAA 2000). The losses and gains are discounted at a standard rate to express future quantities in present terms based on the assumption that present services are more valuable than future services.

Under the HEA method, the injuries are quantified in terms of the percent loss of ecological services (compared to pre-spill baseline levels) and the rate at which the lost services recover over time. Figure 5 shows a hypothetical curve of the reduction in services for a habitat after an incident and the expected rate of natural recovery. The inputs into such curves for each injured habitat are: 1) the percent loss in services immediately after the incident; and 2) the percent of baseline services at key points in time after the injury. Service losses might be due to lethal or sublethal impacts of oil on plants and animals, presence of oil in the environment and/or tissues, or habitat avoidance by organisms due to oil and/or cleanup activity. Key points in time where service losses might change could be associated with cleanup activities, monitoring events, or biological reproduction periods. The injury is Area A on Figure 5, and it is quantified using a term called a discounted-service-acre-year (DSAY) (i.e., the value or amount of services provided by one acre of habitat over one year).

FIGURE 5. Hypothetical Curve Showing the Lost Services Following an Injury Event and an Expected Rate of Natural Recovery



Injury (in DSAYs) is calculated separately for each unique combination of habitat type and oiling level. Habitats must be evaluated separately because the type and level of baseline services may differ between habitats. Areas with different oiling levels are evaluated separately in order to capture differences in the level of injury. The HEA model inputs that are needed for each area to calculate injury in terms of DSAYs are:

- acres exposed;
- discount rate;
- initial percent service losses immediately following the spill; and
- percent service losses over time until baseline services are returned (recovery curve).

The Aquatic TWG's calculations of the acres of nearshore areas exposed to oil from the Bouchard B-120 oil spill are shown in Section 3.4.1. The remaining parts of this section discuss the estimated service losses over time for the twelve injury categories identified by the Aquatic TWG.

3.4.2.2 Nearshore Injury and Recovery Rate Quantification

General Concepts

Injury was calculated for twelve injury categories – eight intertidal categories and four subtidal categories. The intertidal zone was divided into four habitats: coarse substrate, sand beach, marsh, and tidal flats. Heavy and moderate oiling was evaluated for each of these intertidal habitats. The subtidal zone was divided by oiling level and location rather than habitat/substrate. Heavy and moderate oiling was evaluated in the 0-3 ft depth zones across the study area. In addition, the subtidal area offshore of Barneys Joy was separated from other subtidal areas adjacent to heavily oiled shorelines. At this location, injury to the 0-3 ft subtidal zone and the extended subtidal area beyond the 3 ft depth was calculated separately from other subtidal areas. Therefore, the four subtidal injury categories are: 0-3 ft moderate oiling, 0-3 ft heavy oiling excluding Barney's Joy, 0-3 ft at Barney's Joy and Barneys Joy extended. The rationale for the separation of subtidal area offshore of Barneys Joy is discussed below in the subtidal habitat sub-section.

In order to evaluate the ecological service losses within a habitat due to the spill, the Aquatic TWG first considered a variety of issues that frame the injury assessment and provide for consistency in evaluating and quantifying injury using HEA. These issues are:

a) the types of ecological services provided by the five different habitats under consideration;

b) the possible and most likely injury pathways in the areas considered;

c) the primary types of service losses, and

d) the factors that affect the magnitude and duration of injury.

All habitat types provide a variety of services, including habitat for biota, food web support, fish and shellfish production, and water filtration. Some habitats also provide services such as primary production and shoreline stabilization. The degree to which each habitat provides the different services varies. Table 7 summarizes the types of ecological services provided by the five habitats. A full list of services and functions considered by the Aquatic TWG during the injury assessment is provided in Appendix D. Because the service types and magnitudes vary by habitat, injury under the HEA approach is always relative to the baseline services provided by the specific habitat.

The matrix in Table 7 represents the primary services provided by the habitat under baseline conditions; it is not a list of services lost due to the spill.

The Aquatic TWG considered several injury pathways during the injury assessment for the nearshore area and the extended Barneys Joy area. Three forms of oil could potentially result in service losses: tarballs, dissolved fractions of oil (primarily PAHs as they are the most ecologically toxic components of the oil), and oil droplets. Tarballs were seen on some shorelines and are the presumed source of oil found in the submerged oil surveys offshore of Barneys Joy. These tarballs likely formed as the oil picked up sediment during stranding on the shoreline and were moved offshore by tidal action and currents. Dissolved PAHs are a result of the dissolution of soluble factions of the oil and were found in some water samples collected within 48 hours after the spill. Dissolved PAHs may also have entered the nearshore waters when the intertidal zone was flooded during high tides and in some areas from the use of pressure washing with ambient temperature seawater or hot water (hotsy) during shoreline cleanup. Oil droplets could have been entrained in the shallow water near shore as the waves mixed oil from the surface into the water column itself; during hotsy treatment, booms were used minimize re-oiling and entrainment of oil coming off the rocks. The Aquatic TWG believes that the tarballs and entrained droplets could have caused physical fouling of organisms in the intertidal and subtidal habitats. Entrained oil droplets could have caused fouling of mouthparts and filter mechanisms of filter feeding aquatic organisms. Tarballs that formed in the area of visible oiling and/or in the shallow water prior to stranding could have moved across the intertidal and subtidal sediments contacting benthic organisms and potentially causing mortality, depending how much of and where the organism was oiled (mouthparts, carapace, etc.).[25] In addition, the entrained droplets and/or dissolved fractions could have entered the tissues of organisms through direct ingestion or filter feeding activities resulting in a PAH body burden. Tissue samples from bivalves collected after the spill demonstrated that this did occur. The body burdens could then potentially cause acute or sub-acute toxicity (effects on growth and reproduction) to the affected organisms or could impact food quality for predators. These pathways are shown schematically in Figure 6. In addition to these potential impacts caused directly by the oil, service losses in intertidal areas could also have occurred due to avoidance of oiled areas during cleanup operations.

TABLE 7. Service Matrix for the Habitats Evaluated by the Aquatic TWG

Service List	Habitat Type				
	Coarse	**Sand**	**Marsh**	**Tidal Flat**	**Subtidal**
Primary production	X		X		X
Habitat for biota	X	X	X	X	X
Food web support	X	X	X	X	X
Sediment/shore-line stabilization			X		
Water Filtration	X	X	X	X	X
Nutrient removal/transformation			X		
Sediment/toxicant retention/detoxification			X		
Soil development and biogeochemical cycling			X		
Biogeochemical and sedimentary processes			X		
Storm Surge Protection	X	X	X	X	X
Slow runoff from upland	X	X	X		
Shoreline protection	X		X		

[25] *The physical fouling described here is for areas outside the footprint of the oil.*

Of the multiple potential pathways discussed here and shown on Figure 6, the Aquatic TWG determined that in general, the primary pathways of concern were:

a) mortality due to physical fouling by entrained droplets or tarballs;

b) reduced food quality due to body burdens; and

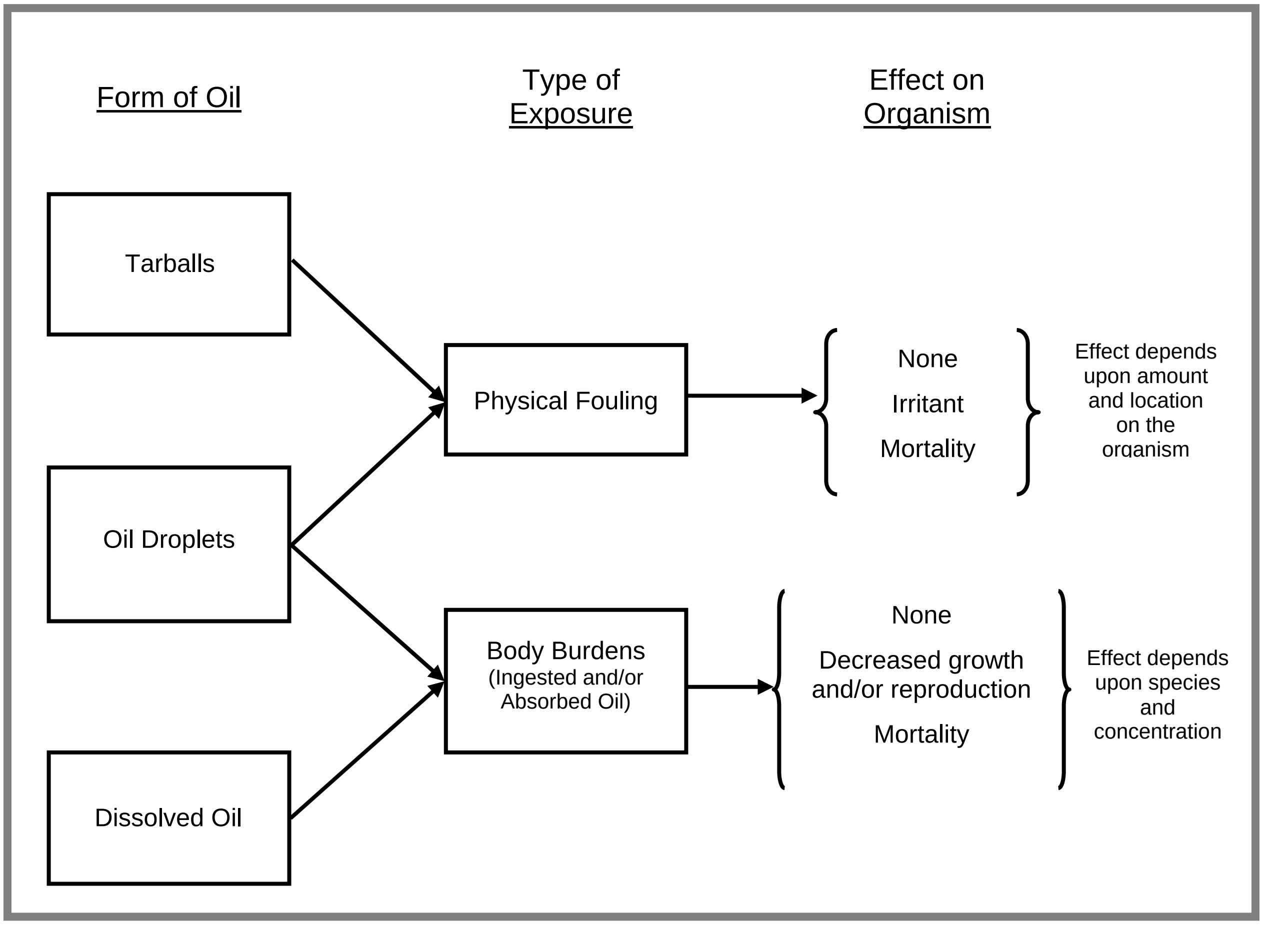
c) temporary avoidance of areas during cleanup operations.

Although the analytical data for the bivalves did confirm uptake of oil into the tissues, the Aquatic TWG did not believe that acute toxicity was a significant concern for this spill even in the shallow areas evaluated here. This is due to the type of oil spilled (low in water soluble components), weather conditions, weathering of the oil, and water temperatures that limited the concentrations of oil in the water column. Expected concentrations even in the nearshore areas would be well below toxicity thresholds for aquatic organisms, including zooplankton. This was supported by the extremely low dissolved aromatic concentrations found in water soon after the release. In addition, based on a comparison of the bivalve tissue data to benchmark concentrations (Section 3.2), it is also unlikely that organisms retained PAHs in their tissues at a high enough level for a long enough period of time to cause sub-lethal effects. Therefore, the main habitat services lost in the areas outside the footprint of the oil were food web support and habitat use. The primary causes of these service losses were avoidance of the area during cleanup, and lower food quality from PAHs in the organisms. In addition, but to a lesser degree, these service losses include the potential for a loss of food/prey due to the mortality of some of the more vulnerable invertebrates. Widespread mortality of organisms was not observed anywhere in the spill zone, but it is possible that some organisms outside the footprint, particularly small fragile organisms such as amphipods, contacted oil, died, and were not observed.

The Aquatic TWG identified a set of factors that affect the kinds of service losses that would occur, the magnitude of service losses, and the recovery of those services in each habitat. These factors were used to differentiate injury between habitats and oiling levels and quantify the potential injury consistently. These factors are:

- Types of organisms likely to have been present – different types of organisms can have different susceptibility to the oil (e.g., infauna vs. epifauna).
- Life history characteristics of injured organisms – this can affect the recovery times of habitats.
- Duration and type of cleanup – the type of cleanup used can affect the amount of oil in the habitat and cleanup duration can affect recovery times due to avoidance.

FIGURE 6. Potential Injury Pathways for Aquatic Organisms Exposed to Bouchard B-120 Oil



- "Oil fouling potential" – this is a broad term to capture the relative magnitude of oil available to cause physical fouling. It is a function of multiple factors including:
  a. Amount of oil on the shoreline (heavily or moderately oiled) – determines how much oil is potentially available to migrate into the intertidal and subtidal areas outside the footprint;[26]

  b. Distance from source of the oil (shoreline) – the potential exposure and subsequent injury/service losses are highest directly adjacent to the footprint and decrease farther away from the footprint; and

  c. The type of substrate and relative levels of wave energy – determines how much oil, if any, is mixed with sand, buried, or moved around after stranding.

[26] *The SCAT data indicated that 97% of the shorelines classified as moderate had less than 50% oil coverage and 40% had less than 10% oil coverage in a band >9 ft wide. 39% of the heavily oiled shorelines had 10-50% cover in bands 3->9 ft wide.*

Injury assessment information specific to each habitat is discussed below in separate sections. Injury to coarse substrate habitat was determined to be the highest and is discussed first. Injury to other habitats is discussed relative to the coarse substrate habitat injury.

Intertidal Habitats

Coarse Substrate

In the protected waters of Buzzards Bay, the substrates of the rocky intertidal and subtidal habitats consist primarily of mud, sand, gravel, rocks, and boulders. The biological community includes barnacles, gastropods, mollusks, crabs, shrimp, fish, macroalgae, and infaunal organisms. The organisms most at risk of exposure include the filter feeders such as barnacles and bivalves and less mobile epibenthic organisms such as *Littorina* and amphipods.

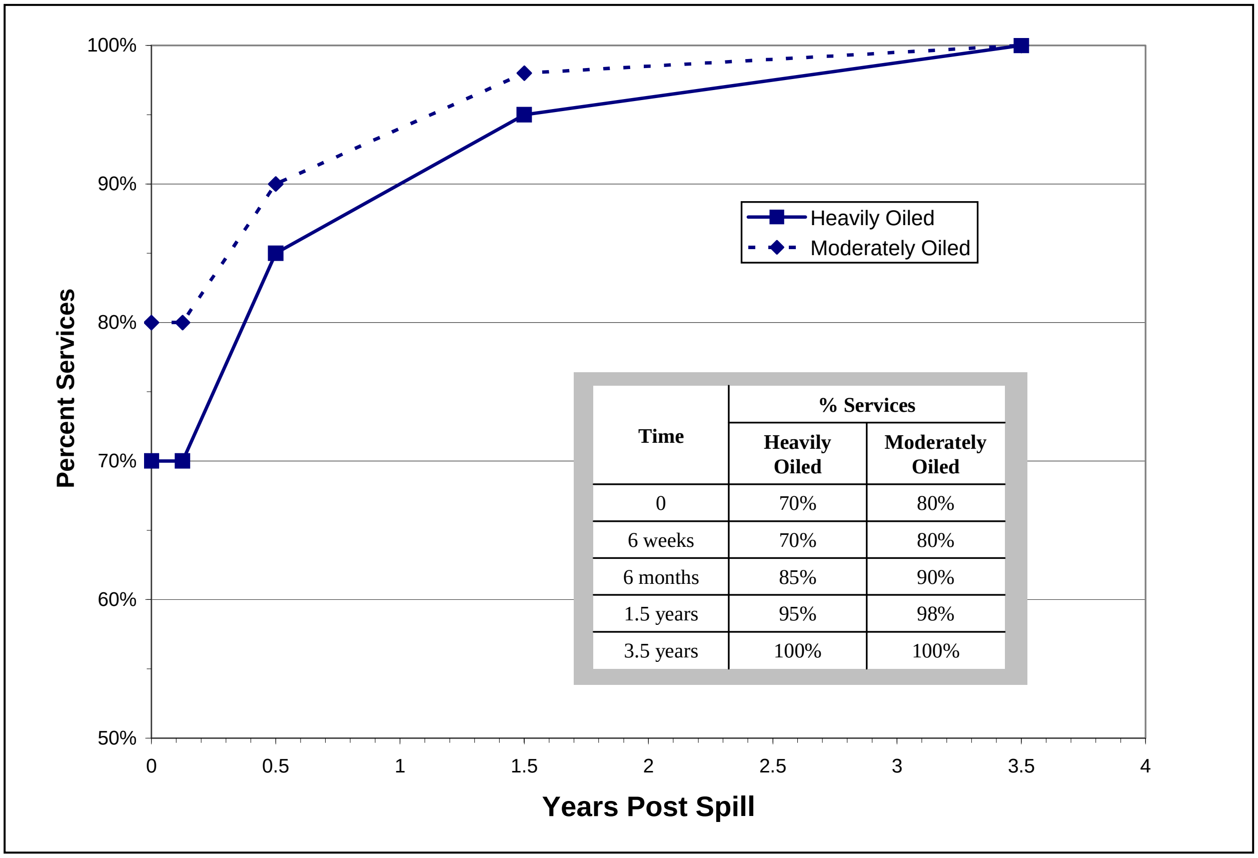
Most of the oil on coarse substrate was adhered to the rocks. This would make the oil less mobile than on a sand beach. Cleanup on coarse substrate habitats included flushing and hotsy operations. During hotsy operations, areas outside the footprint of the oil would have been exposed to the mobilized oil and warm water as they flowed downslope towards the water. Mitigating factors to this exposure include:

- Sorbent booms and/or pads were placed at the water's edge and/or around large individual boulders during hotsy cleaning to collect the oil mobilized off the rocks;
- Areas outside the footprint of the oil that were higher elevation than the footprint were not exposed to the remobilized oil; and
- Depending upon the tidal stage, some portion of the lower intertidal zone was submerged decreasing the direct exposure to mobile oil and warm water.

Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the heavily and moderately oiled coarse substrate shown in Figure 7.

The initial loss of services was estimated as 30% for heavily oiled areas and 20% for moderately oiled areas (reduced to 70% and 80% services, respectively). These service losses are due to avoidance of the areas by birds and potentially fish, decreased food quality, and some level of mortality of some organisms. These service losses were estimated as the average service loss across the area; areas closest to the footprint of the oil would have higher initial service losses than areas farther from the footprint. We conceptually divided the area considered into three equally sized zones and assigned services to each zone. For the heavily oiled area, the zone closest to the footprint was assigned 50% services, the middle zone was assigned 75% services, and the zone farthest from the footprint with the least potential exposure was assigned 85% initial services. Services losses for moderately oiled areas were lower because less oil in the footprint would result in less oil migrating into the intertidal areas adjacent to the footprint, and therefore, lower service losses.

FIGURE 7. Recovery Curve for Heavily and Moderately Oiled Coarse Substrate



Time	% Services	
	Heavily Oiled	Moderately Oiled
0	70%	80%
6 weeks	70%	80%
6 months	85%	90%
1.5 years	95%	98%
3.5 years	100%	100%

Initial service losses stayed at the same level for six weeks indicating no recovery during this period. This time period accounts for the first three weeks after the spill when oil was washing up on the shorelines and had the most potential to move around within the intertidal zone, and a subsequent three-week period during which the shoreline was cleaned with hotsy. The actual timing of the shoreline cleaning varied from shoreline to shoreline, but because the primary service loss during cleanup was avoidance, this cleanup period was assigned a single time period.

Services were assumed to increase linearly through the summer and by six months post spill to have reached 85% on heavily oiled shorelines and 90% on moderately oiled shorelines. This increase in services is due to restoring bird use of the area (avoidance no longer occurring), depuration of the environment and animal tissues of PAHs as demonstrated by the bivalve tissue data, and early recolonization of some organisms. This level of services is also supported by the observations made by the SAT during their September 2003 field efforts during which they noted wrack had re-accumulated on the shorelines and that the area below the footprint looked much better than the area within the footprint of the oil, even at Barneys Joy.

Recovery was conservatively estimated to continue through the second and third years until baseline services were reached at 3.5 years post spill on both heavily and moderately oiled shorelines. During this time, services associated with any organisms that died would be restored as organisms re-colonize the exposed areas through migration and reproduction and grow to replace the lost biomass. At the end of the second growing season (1.5 years), services provided were estimated to reach 95% for heavily oiled shorelines and 98% for moderately oiled shorelines. At this time, recolonization of most species impacted by the spill would be expected to be complete. Complete recovery (100% services) was estimated to occur at the end of the fourth growing season (3.5 years) and accounts for species that are longer lived and therefore may take longer to re-colonize and grow to replace any biomass that was potentially lost.

Sand Substrate

Sand habitats include fine, medium, and coarse grained sand beaches. The biological community includes mollusks, crabs, shrimp, fish, macroalgae, and infaunal organisms. The organisms most at risk of exposure include species such as the mole crab (*Emerita sp.*) and amphipods which are filter feeders and move up and down the beach with the tide.

Cleanup on sand beach habitats generally involved manually scraping the oil from the beach surface with shovels and removing any tarballs or oiled wrack that were present. Sand beaches were generally clean prior to Memorial Day (May 26, 2003).

Stranded oil in this habitat was more mobile than oil stranded on rocky shorelines because the oil adhered to individual sand granules and then moved around creating tarballs that could roll on the substrate. Due to the mobility of the oil on these shorelines, and the requirement of some species to move with the tide, exposure of organisms to oil may have been more uniform across the areas outside of the footprint than in rocky habitats.

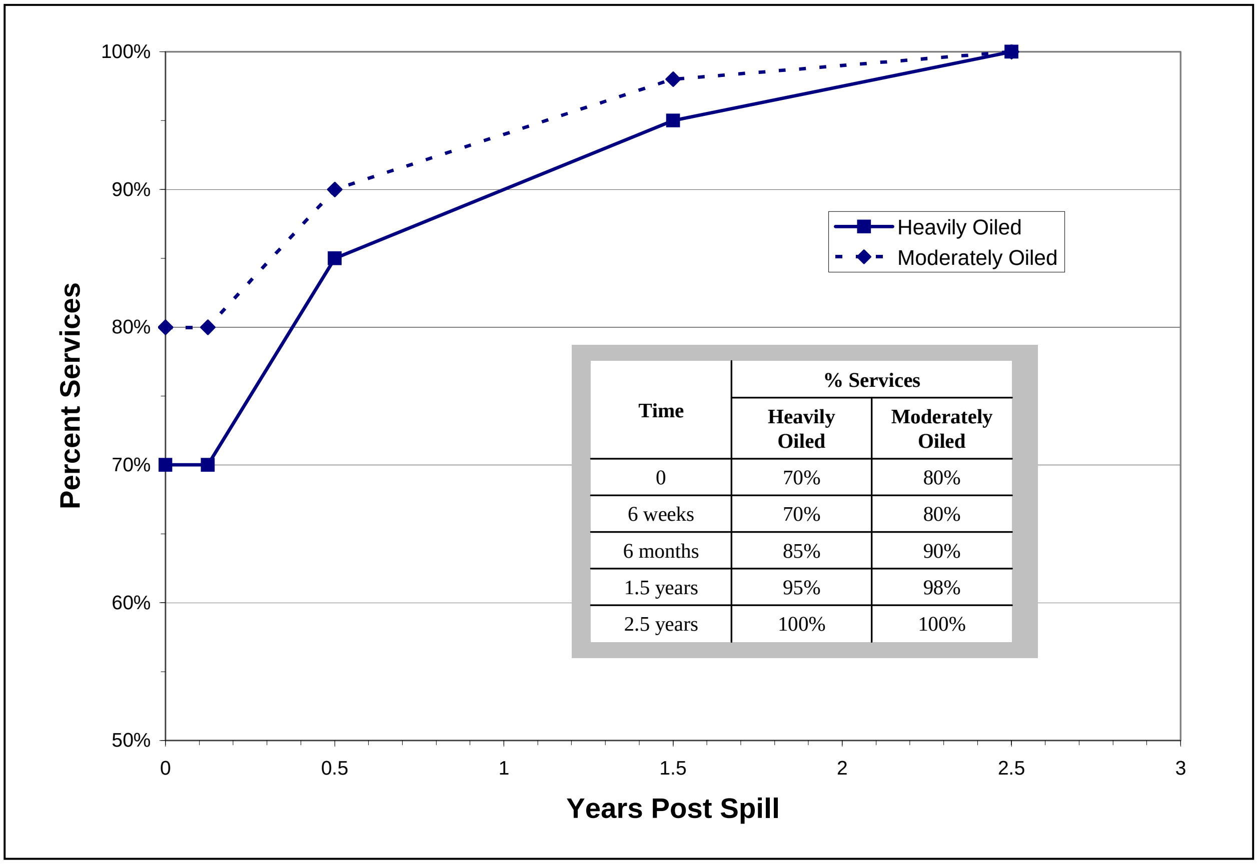
Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the heavily and moderately oiled sand substrate shown in Figure 8.

These curves and the rationale for them are similar to the rationale described for coarse substrate except that service losses were likely more uniform across the area and the total time to recovery is shorter (2.5 years) because the organisms impacted in this environment are shorter lived animals (e.g., mole crabs).

Marsh

Salt marshes are among the most biologically productive of ecosystems. Brackish and saltwater marsh habitats that are flooded daily by tides are considered low marsh habitats. In New England, they are dominated by the smooth cordgrass, *Spartina alterniflora.* Salt marsh food webs tend to be detritus-based, with most primary production reaching consumers via the decomposition of plant material. All salt marshes considered in this injury assessment were fringing marshes - marshes found in front of the dunes along the main bay shorelines in the mid and upper intertidal zone. Extensive marshes with tidal creeks found along tributaries to the Bay were not moderately or heavily oiled. The biological community in these fringing marshes includes mollusks [particularly ribbed mussels (*Geukensia demissa*)], crabs, shrimp, fish, and infaunal organisms. The presence of smooth cordgrass in this habitat is a key component of the service flows provided by marshes. Injury to smooth cordgrass outside the footprint of the oil was expected to be insignificant.

FIGURE 8. Recovery Curve for Heavily and Moderately Oiled Sand Substrate



Time	% Services	
	Heavily Oiled	Moderately Oiled
0	70%	80%
6 weeks	70%	80%
6 months	85%	90%
1.5 years	95%	98%
2.5 years	100%	100%

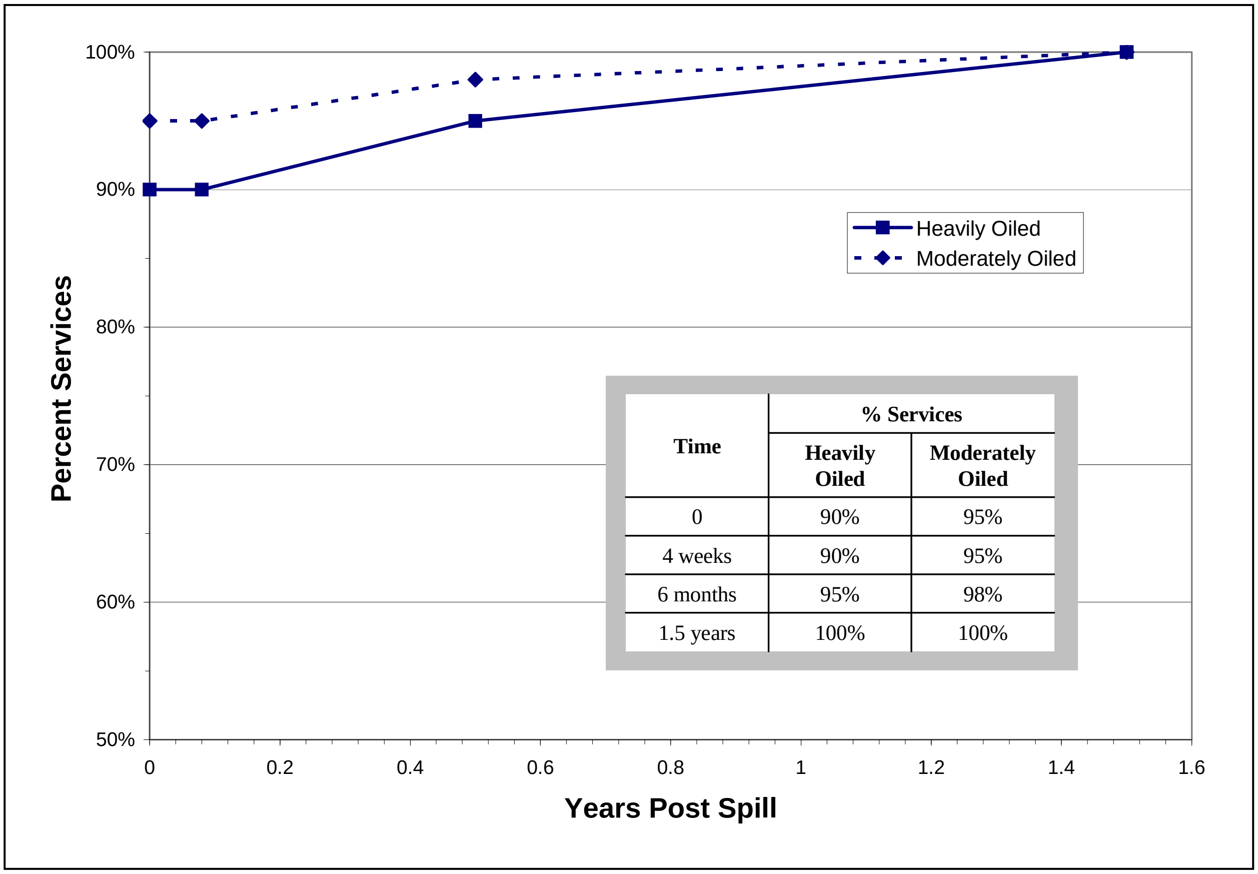
Initial cleanup activities in fringing marshes categorized as being moderately or heavily oiled were limited by Unified Command because the potential damage caused by intrusive, aggressive cleanup operations exceeded the potential benefits of removing the oil. However, small-scale cleanup operations were conducted under the MCP Immediate Response Action in salt marshes at Long Island, Howard's Beach, and Strawberry Point. All of the cleanup was conducted within the footprint of the oil and was considered by the SAT in determination of injury for that area.

Little remobilization of the oil outside the footprint is expected in this habitat as it does not promote tarball formation and cleanup methods consisted of physical removal. Although little oil was expected outside the footprint of the oil, some species present in the adjacent intertidal areas may still have been impacted by the footprint of the oil. For example, a key animal species in this habitat, the fiddler crab (*Uca* sp.), moves up and down the marsh with the tides, and therefore, may be exposed to oil in the footprint even though they or their burrows were not initially within the footprint.

Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the heavily and moderately oiled marsh shown in Figure 9.

These curves and the rationale for them are similar to the rationale described for coarse and sand substrate. They incorporate service losses due to avoidance of the area during cleanup operations on the adjacent shorelines, decreased food quality, and recovery of populations of a few species that may have had some mortality.

FIGURE 9. Recovery Curve for Heavily and Moderately Oiled Marsh



Time	% Services	
	Heavily Oiled	Moderately Oiled
0	90%	95%
4 weeks	90%	95%
6 months	95%	98%
1.5 years	100%	100%

Tidal Flats

Intertidal and shallow subtidal soft-sediment habitats occur where sediment accumulates and often occur as tidal flats along the margins of estuaries. The tidal flats included in this analysis are primarily muddy sand/sandy mud substrate. The biological community includes mollusks, crabs, shrimp, fish, macroalgae, and infaunal organisms. This habitat probably has a greater proportion of deposit feeders and burrowers than other habitats. These organisms are less vulnerable to physical fouling than filter feeding organisms. These habitats often support large predator populations including shorebirds that probe the sediments for worms, clams, and small crustaceans. At high tide, fish and crabs forage in the same habitats and often take the same prey as the shorebirds.

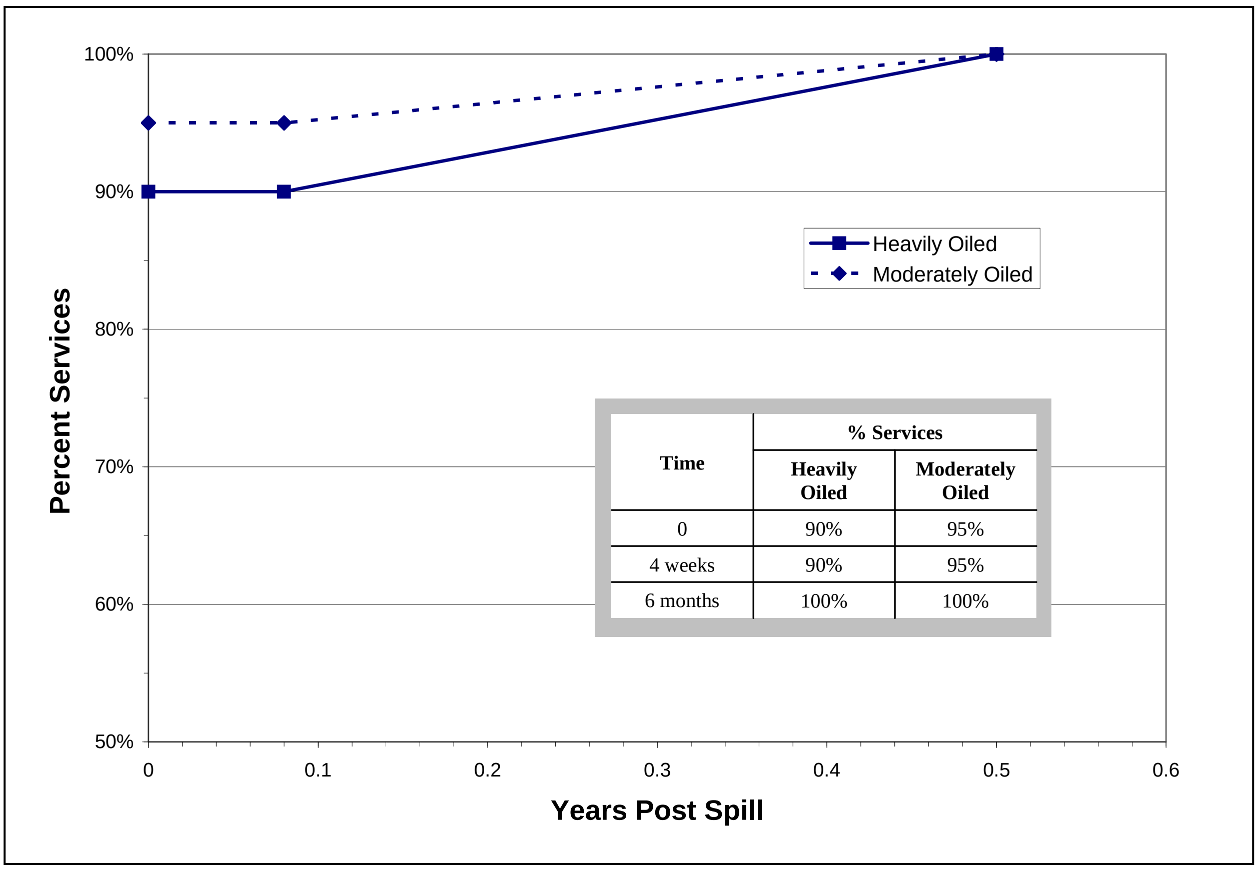
There was no stranded oil on tidal flats; therefore the entire tidal flat is included in the area outside the footprint. The source of oil for the exposure to this habitat is the adjacent shoreline habitat where the oil stranded. Tidal flats occur in front of most other shoreline types so cleanup on those areas could have displaced organisms using the tidal flats as well as the shoreward habitat.

Injury to this habitat is expected to be lower than in sand and coarse habitats because it is likely that they had less exposure to oil (oil fouling potential). Tidal flats are typically quite wide and are not directly adjacent to the footprint of the oil – they are farther from the source oil. In addition, they are typically in lower energy environments, which would result in less movement of the oil off the footprint.

Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the heavily and moderately oiled marsh shown in Figure 10.

These curves incorporate service losses due to avoidance of the area during cleanup operations on the adjacent shorelines and decreased food quality. Mortality in this habitat is expected to be insignificant, therefore the longer recovery "tails" to account for population recoveries are not included on these curves.

FIGURE 10. Recovery Curve for Heavily and Moderately Oiled Tidal Flats



Time	% Services	
	Heavily Oiled	Moderately Oiled
0	90%	95%
4 weeks	90%	95%
6 months	100%	100%

Subtidal Habitats

Four injury categories were established for subtidal areas in Buzzards Bay, based upon the degree of oiling on the adjacent shoreline, water depth, and location. The shoreline adjacent to the heavily oiled Barneys Joy shoreline was addressed separately from other subtidal areas due to the submerged oil survey results. This subtidal area is divided into two injury categories:

Barneys Joy 0-3 ft water depth and the extended Barneys Joy area. The other two injury categories capture all subtidal areas 0-3 ft water depth adjacent to moderately oiled shorelines and other heavily oiled shorelines.

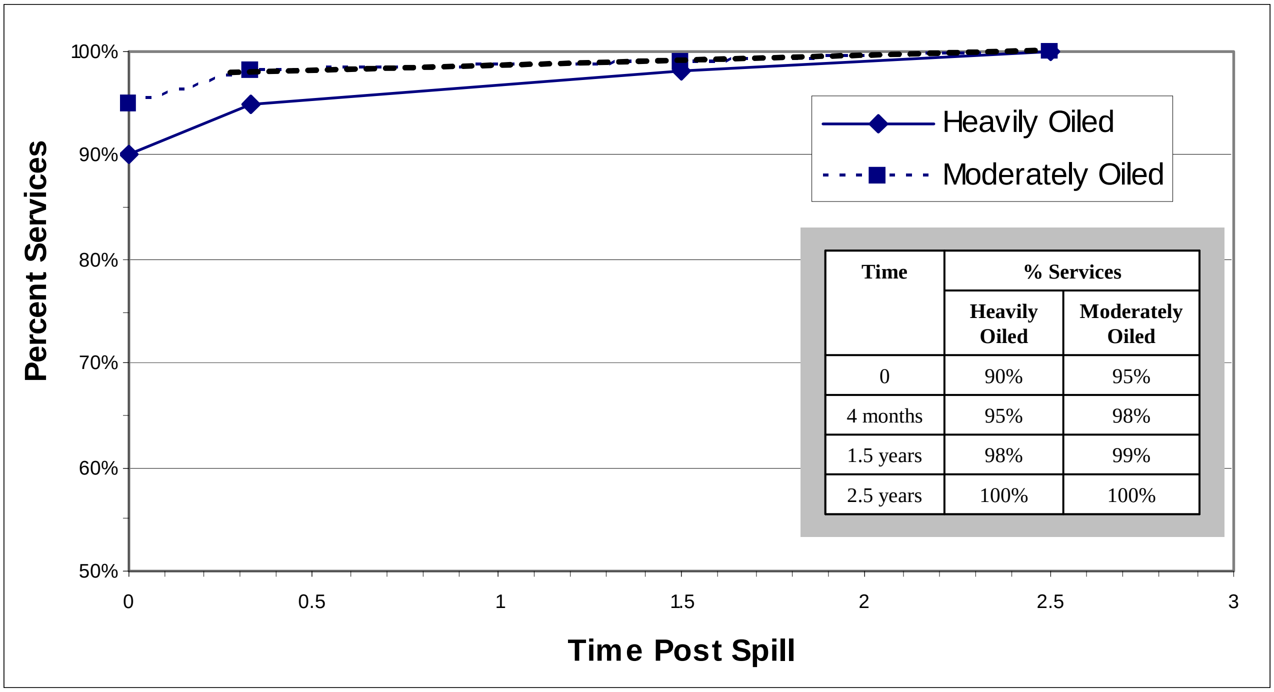
Little site-specific information is available regarding the shallow subtidal environment of Buzzards Bay. For the purposes of this assessment, we have generally assumed that these habitats, the services they provide, and the species that populate them are essentially an extension of, and similar to, those of the lower intertidal zone. The biological community includes mollusks, crabs, shrimp, fish, macroalgae, eelgrass, and infaunal organisms. The specific community at any one location will be dependent upon the physical conditions at the site, particularly the substrate type and presence or absence of eelgrass/macroalgae. Detailed and consistent substrate data were not available for the Bay therefore unlike the intertidal habitat; the subtidal habitat was not sub-divided by substrate type. This was not considered a significant problem as the low levels of expected injury in the subtidal zone would make differentiating injury levels by habitat less important. In addition, eelgrass and macroalgae were not expected to be injured by the oil; therefore, separation of these areas was not necessary. The primary determinant of injury levels in the subtidal zone is the amount of oil expected to be present in the different areas considered.

Subtidal Habitat 0-3 ft Excluding Barneys Joy - Heavily and Moderately Oiled

The source of the oil to the subtidal zone is the adjacent shoreline. Consistent with the approach used for the intertidal areas, the Aquatic TWG agreed that injury to this habitat is expected to be lower than adjacent intertidal habitats because it is likely that they had less exposure to oil because they are farther away from the source. (The average subtidal width from the 0-3 ft water depth was 311 ft.) In addition, the Aquatic TWG agreed that habitat avoidance was not a service loss in this habitat. Although shoreline cleanup was occurring in the intertidal zone in many areas, the Aquatic TWG determined that it was unlikely that birds, fish and shellfish were actively avoiding foraging in the nearby subtidal areas. In addition, to the extent that birds were avoiding shallow subtidal areas near shorelines with extended cleanup times that injury is being accounted for by the Bird and Wildlife TWG for this incident.

Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the heavily and moderately oiled subtidal habitat shown in Figure 11.

FIGURE 11. Recovery Curve for Heavily and Moderately Oiled 0-3' Subtidal Habitat Excluding Barneys Joy



Time	% Services	
	Heavily Oiled	Moderately Oiled
0	90%	95%
4 months	95%	98%
1.5 years	98%	99%
2.5 years	100%	100%

The average initial loss of services was estimated as 10% for heavily oiled areas and 5% for moderately oiled areas (reduced to 90% and 95% services, respectively). These service losses are due to potential low levels of mortality of some species that may have contacted suspended oil or tarballs and decreased food quality due to PAHs in bivalve tissues and the environment.

Services were assumed to increase linearly through the summer and by four months post-spill to have reached 95% on heavily oiled shorelines and 98% on moderately oiled shorelines. Recovery during this time period is due primarily to the recovery of food services. The shellfish tissue data indicate that depuration was rapid throughout the summer and PAH concentrations in exposed shellfish were at or near the range of PAH concentrations found in shellfish from reference areas by the August 2003 sampling date, four months after the spill.

Recovery was conservatively estimated to continue linearly through the third year until baseline services were reached at 2.5 years post-spill. This recovery time is consistent with the rationale described for other habitats, namely recovery of services associated with any organisms that died. Services would be restored as organisms re-colonize the exposed areas through migration and reproduction and grow to replace the lost biomass.

Subtidal Habitat Adjacent to the Heavily Oiled Shoreline at Barneys Joy

The subtidal areas offshore of Barneys Joy were treated separately from other subtidal areas because spill information indicated that this area was unique in several ways that could affect injury levels. First, the shorelines along Barneys Joy and offshore were the only subtidal areas where submerged oil was documented. Submerged oil surveys in June 2003 and re-oiling of Barneys Joy shoreline (tarballs) early in the response, document that there was oil in the subtidal area; therefore, there was the potential for organisms in this subtidal area to be exposed to and fouled by the oil. Second, although there were no large-scale fish or invertebrate kills observed anywhere in the spill area, this site was the only location where dead and oiled bivalves were seen and collected. A few live and dead surf clams collected at Barneys Joy in early May 2003 by MADMF personnel and submitted for tissue analysis had oil on the outside and inside the shell. Massachusetts Audubon Society also collected several small live and dead oiled surf clams and mole crabs in the oiled wrack in the vicinity of this area. Third, Barneys Joy has a long fetch and is a relatively high energy site, was heavily oiled, and was one of the first shorelines oiled. These factors suggest that there would be a greater potential for formation of entrained droplets at this site than many other sites. Entrained droplets can physically foul organisms and cause mortality.

Based on this information as well as the general concepts discussed in the beginning of this sub-section, the group agreed to the recovery curves for the subtidal habitat offshore of Barneys Joy shown in Figure 12.

These curves reflect the same types of service losses (reduced food quality and quantity) and recovery times as discussed above for subtidal nearshore areas outside of Barneys Joy. The Aquatic TWG determined that in the absence of additional data, the amount of oil present in the extended area at Barneys Joy was likely to be similar to the amount of oil in the 0-3 ft zone outside of Barneys Joy adjacent to heavily oiled shorelines. Therefore, the Aquatic TWG assigned these same service losses and recovery times to the extended Barneys Joy area.

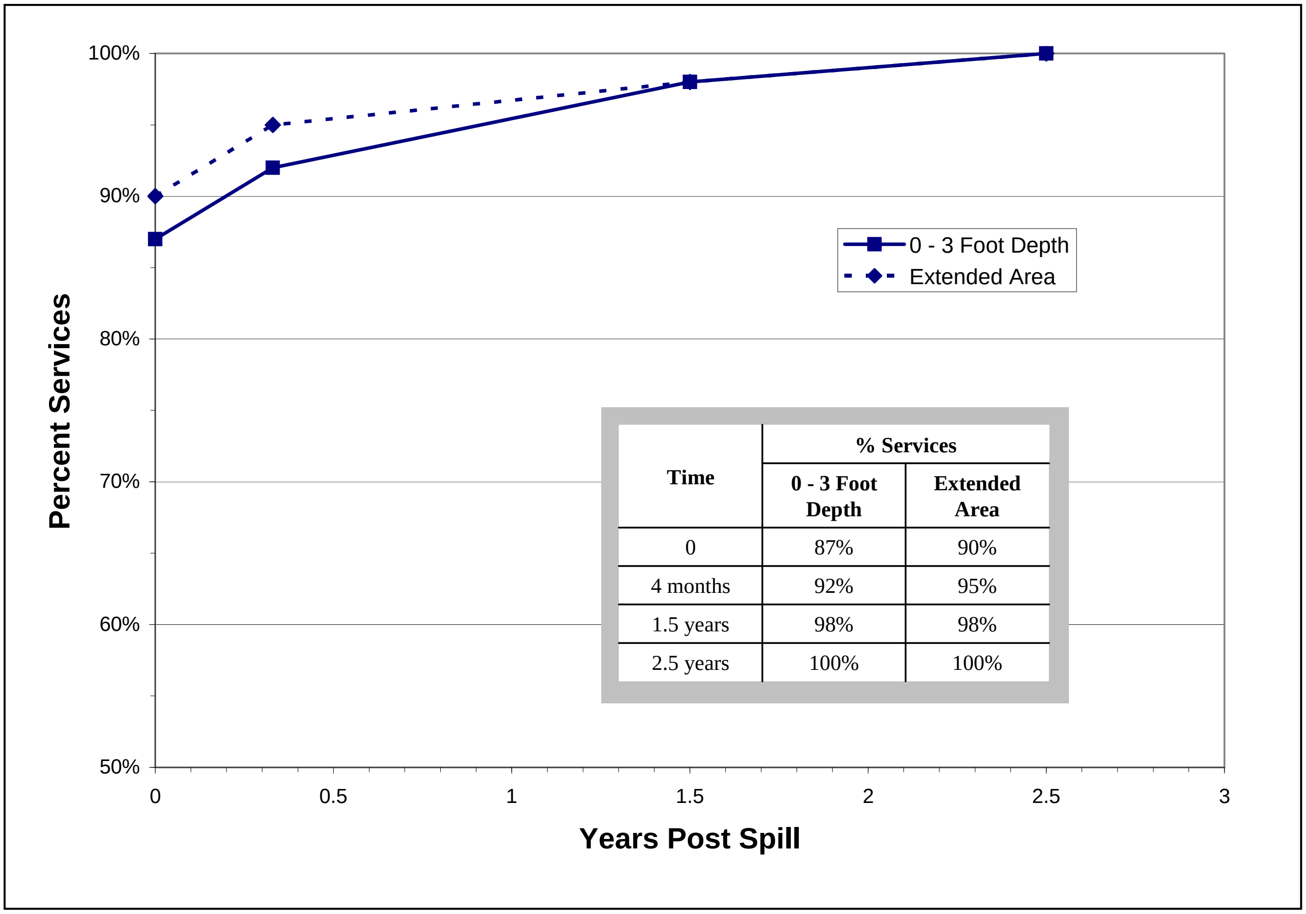
The Aquatic TWG assigned higher initial injury levels to the 0-3 ft zone at Barneys Joy than the extended area at Barneys Joy. Since the source of the tarballs in the subtidal zone is believed to be the stranded oil in the intertidal zone, it is likely that the areas closest to the shoreline had more oil than was documented in the submerged oil surveys offshore and therefore would have greater levels of initial injury and injury at four months post spill. The service losses at the end of the second and third growing season (1.5 and 2.5 years post spill) are the same in both Barneys Joy areas because it is assumed that re-population of the areas would be great enough to account for either injury level.

3.4.2.3 Nearshore Injury Summary

The Aquatic TWG calculated injury to 12 injury categories. Eight intertidal injury categories captured potential injury outside the stranded oil footprint along heavily and moderately oiled shorelines in four habitat types: coarse, sand, marsh, and tidal flats. Four subtidal injury categories captured potential injury in shallow water adjacent to these same shorelines as well as potential injury that occurred in deeper water offshore of Barneys Joy. Tables 8, 9, and 10 summarize the areas and DSAYs associated with each of these categories in Massachusetts, Rhode Island, and in total, respectively.

The total intertidal debit is 42.6 DSAYs if the debit is summed across habitats (these DSAYS have not been adjusted for habitat value differences). The total subtidal debit is 76.9 DSAYs, approximately half of which was from the large extended area offshore of Barneys Joy. All of the debit for heavily oiled areas and the vast majority of debit for moderately oiled areas (95%) were in Massachusetts.

FIGURE 12. Recovery Curve for Subtidal Habitat Offshore of Barneys Joy



Time	% Services	
	0 - 3 Foot Depth	Extended Area
0	87%	90%
4 months	92%	95%
1.5 years	98%	98%
2.5 years	100%	100%

TABLE 8. Summary of the Aquatic Debit for Intertidal and Subtidal Areas in Massachusetts

Habitat/Area	Total Aquatic Nearshore DSAYs		
	Heavy	**Moderate**	**Total**
Coarse	11.4	18.1	29.5
Sand	4.9	5.3	10.2
Marsh	0.6	0.4	1.0
Tidal Flats	0.4	0.2	0.6
Intertidal Total*	17.3	24.0	41.3
Subtidal 0-3 ft excluding Barneys Joy	19.2	19.4	38.6
Subtidal 0-3 ft at Barneys Joy	3.5	0	3.5
Subtidal Extended Barneys Joy Area	33.9	0	33.9
Subtidal Total*	56.6	19.4	76.0
Grand Total*	73.9	43.4	117.3

**Total DSAYs do not account for differences in habitat service value*

TABLE 9. Summary of the Aquatic Debit for Intertidal and Subtidal Areas in Rhode Island

Habitat/Area	Total Aquatic Nearshore DSAYs		
	Heavy	**Moderate**	**Total**
Coarse	0.0	0.8	0.8
Sand	0.0	0.6	0.6
Marsh	0.0	0.0	0.0
Tidal Flats	0.0	0.0	0.0
Intertidal Total*	0.0	1.4	1.4
Subtidal 0-3 ft excluding Barneys Joy	0.0	0.9	0.9
Subtidal 0-3 ft at Barneys Joy	NA	NA	NA
Subtidal Extended Barneys Joy Area	NA	NA	NA
Subtidal Total*	0.0	0.9	0.9
Grand Total*	0.0	2.3	2.3

**Total DSAYs do not account for differences in habitat service value.*
NA= not applicable

TABLE 10. Summary of the Total Aquatic Debit for All Intertidal and Subtidal Areas.

Habitat/Area	Total Aquatic Nearshore DSAYs		
	Heavy	**Moderate**	**Total**
Coarse	11.4	18.9	30.3
Sand	4.9	5.9	10.8
Marsh	0.6	0.4	1.0
Tidal Flats	0.4	0.2	0.6
Intertidal Total*	17.3	25.4	42.7
Subtidal 0-3 ft excluding Barneys Joy	19.2	20.3	39.5
Subtidal 0-3 ft at Barneys Joy	3.5	0	3.5
Subtidal Extended Barneys Joy Area	33.9	0	33.9
Subtidal Total*	56.6	20.3	76.9
Grand Total*	73.9	45.7	119.6

**Total DSAYs do not account for differences in habitat service value.*

4.0 SUMMARY AND CONCLUSIONS

The Aquatic TWG evaluated potential injury to three habitats and two resources of concern. These were:

1) acute injury to the water column habitat including fish, shellfish, and ichthyoplankton in the open Bay due to dissolved fractions of PAHs;
2) acute injury to subtidal benthic habitat due to the presence of submerged, pooled oil on the bottom of the Bay;
3) acute injury to nearshore habitats (intertidal areas outside the footprint of the stranded oil and shallow subtidal areas of the Bay) due to dissolved fractions and/or physical fouling;
4) sublethal effects on bivalves due to accumulated PAHs in their tissues; and
5) acute injury to the American lobster due to physical fouling or toxicity.

The potential exposure and acute injury to the open Bay water column habitat was evaluated using two models to produce estimates of water column concentrations of dissolved monocyclic and PAHs resulting from the spill. These concentration estimates were used to evaluate the potential for acute toxicity to aquatic biota in the subtidal waters affected by the spill. The models concluded that the concentrations from the spill were not high enough for a long enough duration to cause acute injury to aquatic organisms.

The potential exposure and injury to subtidal organisms in the open Bay due to submerged oil was evaluated though several submerged oil surveys. These surveys found no evidence of large amounts of oil on the bottom. However, at one location, offshore of Barneys Joy, the surveys found evidence of small amounts of oil on the bottom, probably in the form of tarballs from oil that mixed with sand when washed ashore, then re-transported to subtidal areas. The acreage of this area was estimated and injury to the area was calculated using the HEA methodology to determine service losses and recovery over time. The total debit for this area was 33.9 DSAYs.

The potential exposure to organisms living in nearshore habitats from fouling or dissolved hydrocarbons was estimated and injury was calculated using the HEA methodology to determine service losses and recovery over time. Nearshore habitats were defined as intertidal areas outside the footprint of the stranded oil and shallow subtidal areas (0-3 ft) adjacent to those shorelines. Injury was only calculated on and adjacent to shorelines classified by the SAT as having heavy or moderate oiling. The total intertidal aquatic debit is 42.6 DSAYs (here the debits for the four habitats are equally weighted and summed and not adjusted for relative habitat value). The total nearshore subtidal debit (not including the 33.9 DSAYs for the extended Barneys Joy area) is 43.0 DSAYs. The total subtidal debit including the extended Barneys Joy area is 76.9 DSAYs.

PAH concentrations in bivalve tissues clearly indicated that bivalves were exposed to and ingested/absorbed PAHs from the environment. The potential injury to bivalves from these body burdens was evaluated by comparing PAH concentration in the tissues of bivalves to EPA benchmark tissue concentrations for acute and chronic effects. This analysis suggested that PAH body burdens in bivalves (and by extension, other aquatic invertebrates) were not high enough for a long enough time to cause lethal or sublethal effects on those organisms. However, the effect of those body burdens on predators was considered in the HEA analysis as a potential loss of services due to reduced food quality.

The potential exposure of American lobster to oil through physical contact or dissolved concentrations and any subsequent injury was carefully evaluated. Specifically, the Aquatic TWG compared the life history of the lobster and the expected presence/absence of lobster lifestages and their location in the Bay with the known location and timing of oil from the Bouchard B-120 spill. The Aquatic TWG concluded that due to the time of year and water temperatures, it is unlikely that more than a few lobster larvae were exposed to the oil and therefore this lifestage was not significantly exposed or injured. Adult (including egg-bearing females), EBP and adolescent lobsters are expected to have been present at the time of the spill and these lobsters were potentially exposed to and injured by the oil, primarily through physical fouling from tarballs. The actual proportion of these lobsters in the Bay that were exposed to and injured by the oil is unknown but is expected to be relatively small based on an estimation of the amount of habitat in the Bay that was exposed to oil. This conclusion is consistent with the lack of conspicuous visual evidence of lobster mortality, continued commercial harvesting of Buzzards Bay lobsters in 2003 through 2004 at levels typical for the Bay in recent years (relative to harvesting in non-impacted areas of the Massachusetts portion of the Southern New England stock), and lack of oil on harvested lobsters in 2003. Potential injury to this species was captured in the injury assessment for the nearshore subtidal areas and extended subtidal areas offshore of Barneys Joy, in which the lobster was considered part of the benthic community.

5.0 REFERENCES

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Environmental Protection Agency (EPA), 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. U.S. Environmental Protection Agency. Office of Research and Development. Washington D.C. 175 pp.

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Appendix A
Evaluation of the Potential for Lethal or Sublethal Effects to Bivalves due to Concentrations of PAHs in Their Tissues.

E N T R X I

MEMORANDUM

TO: **Aquatic TWG for Bouchard B-120 Oil Spill**

FROM: **Jessie Webber and Ralph Markarian**

DATE: **October 14, 2005 (Finalized May 29, 2007)**

SUBJECT: **Literature-Derived Sublethal Toxicity Benchmarks for Tissue and the Bouchard B-120 Shellfish Tissue Data - FINAL**

cc: **John Dimitry**

One of the available and relevant data sets for the nearshore injury assessment using the Habitat Equivalency Analysis (HEA) model is the tissue polycyclic aromatic hydrocarbon (PAH) data from shellfish collected from May 2003 through May 2004. The degree of tissue PAH accumulation can provide some insight into potential acute and sublethal injuries suffered by shellfish. These data were compared to a toxicity benchmark from the literature to evaluate the likelihood of sublethal injury to the shellfish and the subsequent level of service losses that may have occurred due PAH body burdens. With the exception of two samples, shellfish collected for PAH analysis were live, therefore this analysis does not specifically address potential acute injury of shellfish from fouling that may have occurred due to the B-120 oil spill.

This memo is divided two main sections. The first main section is a summary of how, when and where the shellfish were collected, and the analytical results. The second main section is a discussion of the literature benchmark (USEPA 2003[1]) and the results of the comparison of the analytical data to the benchmark.

SHELLFISH DATA

Shellfish Tissue Collection and Analysis

Between May 5, 2003 and May 13, 2004, a total of 153 composite shellfish tissue samples were collected from areas identified within the intertidal and shallow subtidal zones along un-oiled, lightly oiled, moderately oiled, and heavily oiled beaches. Massachusetts Department of Marine Fisheries (MADMF) representatives identified five species of bivalves targeted for sampling based on their recreational and commercial

[1]*USEPA. 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. U.S. Environmental Protection Agency. Office of Research and Development. Washington D.C. 175 pg.*

importance and abundance: blue mussels (*Mytilus edulis*), oysters (*Crassostrea virginica*), quahogs (*Mercenaria mercenaria*), scallops (*Argopecten irradians*) and softshell clams (*Mya arenaria*). Using SCAT maps, MADMF and Town Shellfish Constables selected sampling locations (shellfish beds) located in the vicinity of oiled beaches where recreational shellfishing commonly occurred.

An initial sampling effort was conducted between May 5 and May 7, 2003 followed by five other sample collection efforts (Table 1), to document return of tissue PAH concentrations to background levels. Sample collection teams were composed of both Responsible Party and state and/or federal agency representatives.

Table 1. Shellfish Sampling Summary

Sampling Event	Collection Dates	Total Number of Samples	Total Number of Shellfish Areas Sampled
1	May 5, 2003 to May 7, 2003	49	17
2	May 19, 2003 to May 21, 2003	37	19
3	June 9, 2003 and June 10, 2003	18	10
4	July 8, 2003 to July 10, 2003	28	14
5	August 27, 2003 and August 28, 2003	13	8
6	October 23, 2003 and October 24, 2003	6	4
7	May 13, 2004	9	5

Composite samples of target species were collected at each location (Figures 1 – 4), as available. Three random locations within a shellfish bed were sampled using a clam rake. A total of 12 to 15 specimens of each available species were collected, yielding one composite sample per species at each station. The shells of each specimen were cleared of debris, sediment or visible oil using bay water.

Observations pertaining to the oiled shells and quantity of oiled shells collected were recorded on a data sheet. Photographs were taken of the individual shellfish, along with a display of the shellfish identity, site location, and date and time of sample. Each composite sample was double wrapped in aluminum foil, secured in a labeled, plastic ziploc bag and placed on ice in a field cooler. Samples were shipped to B&B Laboratories (B&B) in College Station, Texas, under proper chain of custody, where the animals were removed from their shells, homogenized and then analyzed for PAH compounds. Analytical procedures were conducted in accordance with approved U.S. Environmental Protection Agency (USEPA) and Massachusetts Department of Environmental Protection (MADEP) methodologies for an extended list of compounds. .

Following laboratory analysis, an assessment of the precision, accuracy, representativeness, completeness and comparability of the samples was conducted to validate the analytical data. Data were validated by ENTRIX using the USEPA Contract

Laboratory Program functional guidelines (USEPA 1994[2]) and method-specific requirements.

In addition to the 153 samples that were collected as live organisms, two surf clam samples were collected on May 6, 2003 by representatives of the MADMF, and were provided to ENTRIX for processing and shipment to B&B laboratories for analysis. B&B laboratories noted in their analytical report that there were large amounts of oil and sediment inside and outside the organisms in both of these two samples and that some organisms were dead. Although the samples were rinsed with deionized water and analyzed as described above, comparing levels found in these two samples to all the other bivalves collected following the sampling protocol indicates that that oil contaminates outside the shellfish were likely present and captured in the extraction. Based on the nature and condition of the samples, the PAH data are not representative of PAHs inside the tissue or gut of the animals and therefore are not included in this analysis (Table 3); however, the data are included in Table 2 for completeness.

Summary of Results

Total PAH concentrations measured in the shellfish tissue samples are summarized in Table 2[3]. Concentrations are shown in parts per billion (ppb) wet weight. Blank cells indicate that no sample was collected. The laboratory results indicated that most shellfish adjacent to oiled shorelines had total PAH concentrations above the observed background levels (mean 83 ppb max 206 ppb[4]) one to two weeks after the spill when they were first sampled. Within four months after the release (August 2003), only four locations had concentrations above background levels. The four locations included one location in Sconicut Neck (mouth of Nakata Creek), two in Fairhaven (Hacker Street and West Island-Bass Creek), and one location in Dartmouth (Cow Yard). Within six months after the release (October 2003), only one location was above background concentration (Long Island), and the shellfish in the vicinity of Long Island were documented to below background levels during the subsequent survey in May 2004 (approximately 12 months after the spill).

ANALYSIS OF POTENTIAL SUBLETHAL EFFECTS

Selected Shellfish Toxicity Benchmarks

The purpose of this analysis is to evaluate the potential for injury associated with the observed PAH body burdens in the shellfish following the Bouchard B-120 oil spill. Although there are many published papers on the bioaccumulation and depuration of PAHs in shellfish, as well as observed toxicity of PAHs to shellfish in laboratory settings, few of these papers are relevant for this purpose. The bioaccumulation/depuration papers tend to focus on rates of these two processes, usually in relation to sediment and/or water concentrations rather than the toxicological effects of the bioaccumulation. Most papers

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[2]USEPA 1994. USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review", EPA-540/R-94/012, February 1994.

[3] Total PAHs in this table are the sum of all 47 individual PAHs, PAH groups and PAH-like compounds analyzed by B&B for this project.

[4] The approximate maximum concentrations in tissue samples from areas documented to have received little to no oiling from the spill were also below approximately 200 ppb.

that address toxicity of PAHs to shellfish are studies that relate water column concentrations to effects (i.e., LC_{50}s or less often, EC_{50}s), rather than directly relating tissue concentrations to effects. One recent document builds on previously published research appears relevant:

> EPA. 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013. U.S. Environmental Protection Agency. Office of Research and Development. Washington D.C. 175 pg.

This document is summarized below and was accessed on September 28, 2005 at:

> http://www.epa.gov/nheerl/publications/files/PAHESB.pdf.

USEPA 2003

This equilibrium partitioning sediment benchmark (ESB) document recommends an approach for summing the individual toxicological contributions of mixtures of 34 PAHs[5] in sediments to determine if their combined concentration in any specific sediment would still be protective of benthic organisms. The method is based upon a combination of the concepts of equilibrium partitioning (EqP) between water and sediments, narcosis theory of toxicity, and additivity of individual PAH toxicities. These approaches were required because PAHs always occur in sediments as mixtures in a variety of proportions and can be expected to act jointly under a common mode of action. Therefore their combined toxicological contributions must be predicted on a sediment-specific basis. Tissue criteria and PAH-specific water criteria are developed in this document as interim steps (narcosis model and Final Chronic Value [FCV]) in the calculation of PAH-specific sediment benchmarks.

The narcosis model is used to describe the toxicity of all Type I narcotic chemicals. Type I narcotic chemicals are nonionic organic compounds, which include PAHs, and that have the same mode of action. The model was developed using a database of water-only acute (LC50/EC50) toxicity values for 156 chemicals and 33 species including fish, amphibians, arthropods, molluscs, annelids, coelenterates, and echinoderms. The specific model used here is the “Target Lipid Model”. This model assumes that mortality occurs when the chemical concentration reaches a threshold level in the organism’s lipid (i.e., fatty tissue) rather than the body in general. Specifically, the model assumes: a) the toxicities of narcotic chemicals are dependent on the octanol-water partitioning coefficient (K_{ow}), b) the target lipid has the same lipid-octanol linear free energy relationship for all species (i.e, the slope of the K_{ow}-toxicity relationship is the same for all species – the regression has a “universal slope”), and c) the critical concentration threshold (the y-intercept of this regression relationship) is species-specific.

[5] The PAH compounds include the 18 “parent” PAH that only contain fused aromatic rings and 16 groups of alkylated PAH compounds, which consist of some of parent PAH compounds with various combinations of attached carbon chains of different lengths.

The concepts and mathematical relationships of the Target Lipid Model allow the use of U.S. EPA National Water Quality Guidelines[6] to derive WQC FCVs for individual PAH and PAH mixtures. Using the toxicity database, mean acute values in µmol/g octanol (equivalent to lipid) are calculated for each organism genus in the database (GMAVs). Following EPA guidelines for developing water quality criteria, the five percentile critical target lipid concentration is estimated from the ranked ordering of the GMAVs. This value is called the Final Acute Value (FAV). The FAV at a K_{ow} of 1.0 for PAHs is 9.31 umol/g octanol. The FAV is then divided by an acute:chronic ratio of 4.16 (calculated from paired data in the dataset) to arrive at a Final Chronic Value (FCV) at a K_{ow} of 1.0 of 2.24 umol/g octanol. Because non-ionic chemicals partition similarly into octanol and lipid of organisms, the FCV at a K_{ow} of 1.0 approximately equals a tissue-based "acceptable" concentration of about 2.24 µmol/g lipid. This normalized toxicity of the PAH compounds is assumed equivalent and additive, therefore USEPA considers 2.24 µmol/g lipid as the acceptable concentration for the sum of the measured (dominantly observed) 34 individual and groups of PAH compounds. The FCV should protect 95% of the species used to develop water quality criteria.

The PAH-specific FCVs for water (mg/l) are then back-calculated from the critical tissue concentration of 2.24µmol/g lipid by applying the universal slope and PAH-specific K_{ow} values. Likewise, the PAH-specific FCVs for sediment (ESBs) are calculated from the water FAV and the partitioning coefficient between water and sediment (K_{ow}-K_{oc} relationship) (Table 3-4[7]).

<u>*Discussion of USEPA 2003*</u>

This approach to calculating acute and chronic toxicity thresholds assumes that the PAHs in the environment and the organisms are in equilibrium. This assumption may not be correct even with exposure to sediment-bound PAHs, and clearly is not true in this case where there was a single, rapid release, a primary pathway of PAHs to the bivalves through the water column, and rapid uptake and depuration. Further, a chronic threshold assumes there is a long-term exposure, which again in this case, is not supported by data collected after the spill. However, in lieu of other benchmarks, the FAV and FCV values developed by USEPA (2003) provide a conservative (protective) benchmark to compare against our data and assess the relative level of potential PAH effects and injury to bivalves. We therefore compared the Bouchard B-120 tissue data to both the ***FAV of 9.31 umol/g octanol or lipid and the FCV of 2.24 umol/l lipid.***

[6] *Stephan et. al 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses. PB85-227049. National Technical Information Service, Springfield, VA 98 pp.*

[7] *Note that there is a units error in Table 3-4 of USEPA (2003) for the PAH-specific FCV_i labeled µmol/L, which should be mmol/L calculated according to Eq. 3-3. That leads to a units error in Table 3-4 for the PAH-specific FCV_i labeled µg/L, which should be mg/L. If those units are corrected, then the correct $C_{OC,PAHi,FVCi}$ is calculated, which is the value shown in the table.*

Comparison of the Selected Benchmarks to the Bouchard B-120 Shellfish Tissue Data

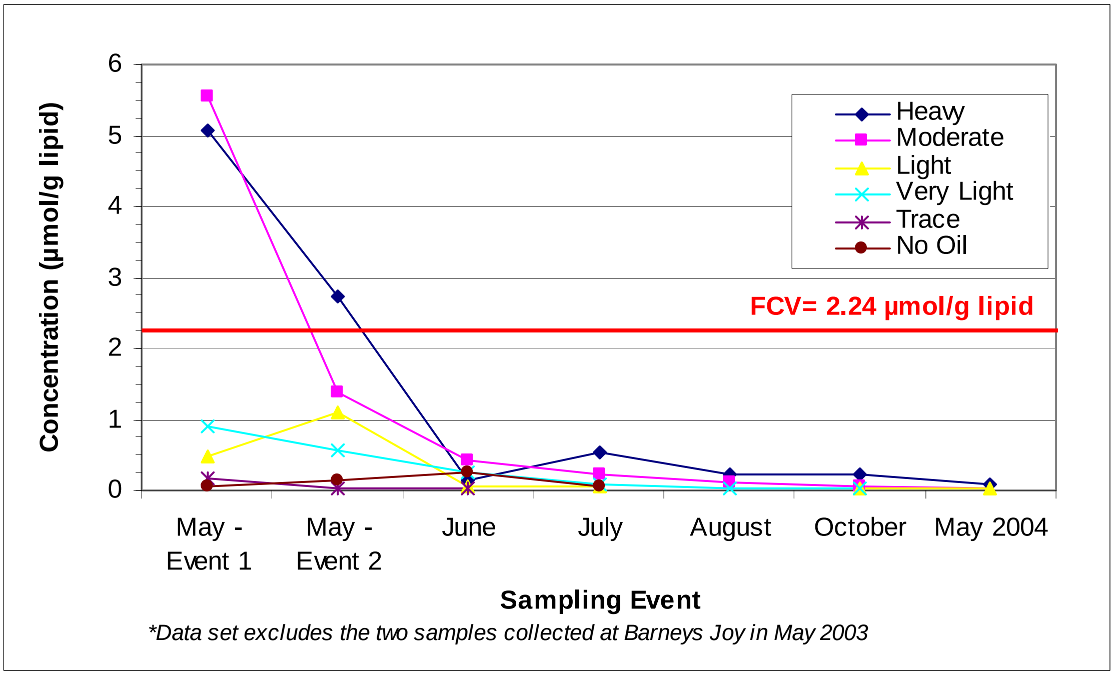
Table 3 compares the Bouchard B-120 shellfish tissue data to the FAV and FCV benchmarks. The total PAH value for the Bouchard samples is the sum of the same 34 PAH compounds and groups of compounds that are recommended by EPA (2003). Samples that exceed the FCV are highlighted in yellow. Note that this comparison assumes that the PAHs in the shellfish were incorporated into the fatty component of tissues (lipids) in the shellfish after passing through the digestive and metabolic organs, and therefore were acting as a true "body burden" interacting with the physiological systems of the shellfish. However, the whole body of the shellfish was included in the chemical analyses and therefore, in reality, it is likely that at least some of the PAHs reported as "tissue PAH" were in fact in the gut bound to sediment and/or organic matter or as tiny droplets of emulsified oil. Therefore, comparing the shellfish tissue results directly to the lab-based toxicity thresholds is a conservative comparison (i.e., overestimates potential for injury).

Of the 153 samples collected and included in this analysis (the analysis excludes the two Barneys Joy samples collected in May 2003), only 9 samples exceeded the FCV benchmark. All 9 samples were collected in May 2003 in the vicinity of Fairhaven:

- West central side of Sconicut Neck – one sample
- Mouth of Nakata Creek, Southeast side of Sconicut Neck – two samples
- Fairhaven Hacker Street – three samples
- The southwest side of Long Island – one sample
- Northwest side of Sconicut Neck near Hacker Street - one sample
- Bass Creek, East side of West Island of Nasketucket Bay - one sample

Average total PAH concentrations by shoreline oiling and sampling event are shown in Figure 5. On average (excluding the surf clams collected at Barneys Joy in May 2003), shellfish collected along or adjacent to heavily or moderately oiled shorelines had total PAH concentrations somewhat higher than the FCV benchmark in early May 2003. On average, shellfish tissue samples collected from less heavily oiled shorelines did not exceed the benchmark. Tissue concentrations declined rapidly in the following weeks. By mid-June, average tissue concentrations were well below the benchmark for all shoreline oiling types.

Figure 5. Average Total PAH Concentration over Time



This data set and benchmarks indicate that some portion of the bivalves adjacent to many moderately and heavily oiled shorelines slightly exceeded the calculated threshold associated with assumed chronic, sublethal effects in the most sensitive (95th percentile) of species in laboratory test environments. It is unlikely, however, that these exceedances translate to sublethal injury to the Buzzards Bay bivalves for two reasons:

1) Based on a short term pulse exposure, a significant proportion of the PAHs measured in the bivalves were likely to have been present in the gut rather than the tissue, therefore not incorporated into the organism in a way that would potentially exert a toxicological effect; and

2) The chronic benchmark was derived based on an extrapolation from acute exposures in experimental systems at equilibrium and assumes long term constant exposure in the environment under equilibrium conditions. In contrast, the data indicate that for this spill, the bivalves rapidly accumulated and began depurating the oil within weeks of the spill and that even in areas where concentrations exceeded the FCV values, they did so for a short period of time.

Legend

Shellfish Sampling Locations

ENTRIX

Figure 1
Shellfish Sampling Locations
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA

Legend

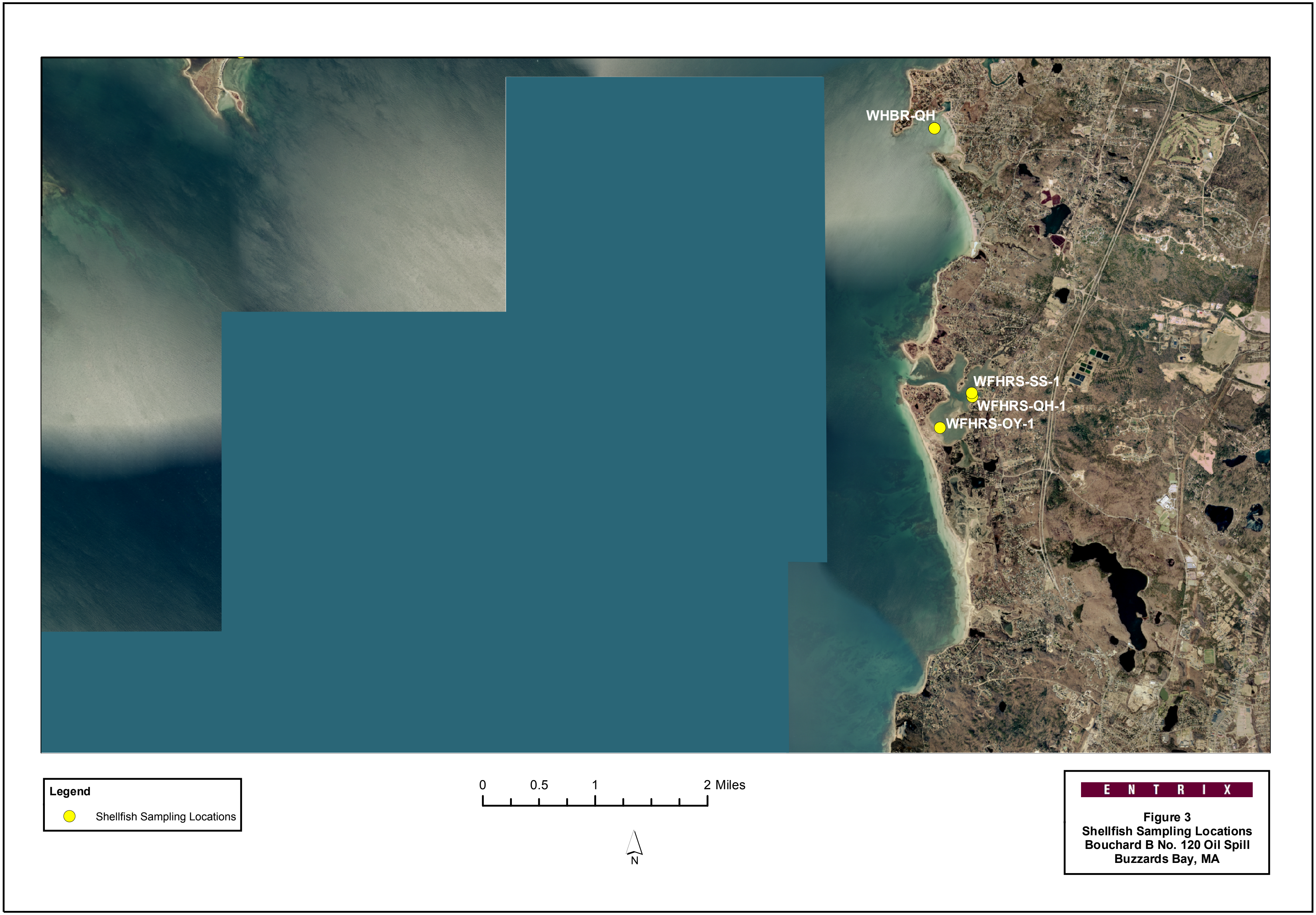
Shellfish Sampling Locations

0 0.5 1 2 Miles

N

ENTRIX

Figure 2
Shellfish Sampling Locations
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA



E N T R I X

Figure 3
Shellfish Sampling Locations
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA

Legend

Shellfish Sampling Locations

0 1.25 2.5 5 Miles

N

E N T R I X

Figure 4
Shellfish Sampling Locations
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA

Table 2. Summary of Total PAH Concentrations in Tissue Samples Over Time

Site ID	Species	Location	Collection Dates/Total PAH (ppb)[2]						
			2003						2004
			May 5 - 7	May 19 - 21	June 9 - 10	July 8-10	Aug 27 - 28	Oct 23 - 24	May 13
APPB-QH	Quahog	Apponaganset Beach, Dartmouth	38.4						
APPB-SS	Softshell Clam	Apponaganset Beach, Dartmouth	58.6						
BASS-BM	Blue Mussel	Bass Creek, East side of West Island of Nasketucket Bay	4,580			143			
BASS-OY	Oyster	Bass Creek, East side of West Island of Nasketucket Bay	2,343			172			
BASS-QH	Quahog	Bass Creek, East side of West Island of Nasketucket Bay	3,145			57			
BASS--SS	Softshell Clam	Bass Creek, East side of West Island of Nasketucket Bay	2,851			70			
BIMT-OY	Oyster	Brandt Island, Mattapoisett		3,799	1,733	297	158		
BIMT-QH	Quahog	Brandt Island, Mattapoisett		1,905	722	105			
BJB-A-SC	Surf Clam	Barneys Joy Beach ¾ mile west	59,625						
BJB-B-SC	Surf Clam	Barneys Joy Beach ¾ mile west	114,529						
BJB-SC	Surf Clam	Barneys Joy Beach ¾ mile west				260	48		
BMB-SS	Softshell Clam	Buttermilk Bay		53.2					
BRFF-QH	Quahog	Birchfield Farms, Dartmouth	34.4						
BRFF-SS	Softshell Clam	Birchfield Farms, Dartmouth	121						
BRM-QH	Quahog	Back River Mouth[1]	28.3						
Brook-OY	Oyster	Great Island, Northeastern part of Great Island[1]	82.1						
BVMA-QH	Quahog	Bayview Avenue, Marion		55.7					
CCRS-QH	Quahog	Clark's Cove Rogers Street		107					
CCWRF-QH	Quahog	Clark's Cove, West Rodney French		150					
Cherry-SC	Surf Clam	Cherry Point, Mouth of Westport Harbor	95.9						
COWY-QH	Quahog	Cow Yard, Dartmouth	2,241		407	68.8			
CWBWP-SC	Surf Clam	Cheriann Webb Beach, Westport, approx. 300 ft. offshore		78.6					
CWBWP-SC (Dup)	Surf Clam	Cheriann Webb Beach, Westport, approx. 300 ft. offshore		100					
EEHH-OY	Oyster	Eastern mouth of Eel Pond	3,674		812	282	188	121	
EEHH-OY (Dup)	Oyster	Eastern mouth of Eel Pond	3,849						
EPBR-SS	Softshell Clam	Eel Pond Back River[1]	85						
FCWA-SS	Softshell Clam	Cleveland Ave. in Fisherman's Cove, Wareham		56.9					
FHHS-OY	Oyster	Fairhaven Hacker Street Upper reach of New Bedford/ Fairhaven Bay, not in New Bedford Harbor	11,893			2,189	606	164	97.2
FHHS-QH	Quahog	Fairhaven Hacker Street Upper reach of New Bedford/ Fairhaven Bay, not in New Bedford Harbor	8,110			384	173		45
FHHS-SS	Softshell Clam	Fairhaven Hacker Street Upper reach of New Bedford/ Fairhaven Bay, not in New Bedford Harbor	14,545			818	280	154	137
FHIN-BS	Bay Scallop	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	1,768		930	538	53.6		

Table 2. Summary of Total PAH Concentrations in Tissue Samples Over Time

Site ID	Species	Location	Collection Dates/Total PAH (ppb)[2]						
			2003						2004
			May 5 - 7	May 19 - 21	June 9 - 10	July 8-10	Aug 27 - 28	Oct 23 - 24	May 13
FHIN-OY	Oyster	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	1,156		540	324	28.7		
FHKB-SS	Softshell Clam	Fairhaven Knolmere Beach, Upper reach of Nasketucket	191						
FHSB-QH	Quahog	Fairhaven Sandy Beach, Northeastern side of Sconticut Neck near Little Bay of Nasketucket Bay	114						
FHSB-SS	Softshell Clam	Fairhaven Sandy Beach, Northeastern side of Sconticut Neck near Little Bay of Nasketucket Bay	372			36.5			
FTPH-QH	Quahog	Fort Phoenix, Fairhaven		1,391		97			45.9
GBWP-QH	Quahog	East side of Gooseberry Island, Westport		931		34.6			
Great-SS	Softshell Clam	Great Island, Southeastern part of island, Island is in the middle of Eastern Branch of Westport River[1]	104						
LBBW-SS	Softshell Clam	Little Bay, Briarwood		64.6					
LBBW-SS	Softshell Clam	Little Bay, Briarwood		71.5					
LHWA-QH	Quahog	Little Harbor, Wareham		33.8					
LNGB-QH	Quahog	Long Beach Point, North side of Long Beach near Indian Neck[1]	64.7						
LNGB-SS	Softshell Clam	Long Beach Point, North side of Long Beach near Indian Neck	518		42.7				
MDWI-OY	Oyster	Meadow Island in Sippican Harbor	865		118				
MDWI-QH	Quahog	Meadow Island in Sippican Harbor	995		66.6			11.5	
MDWI-QH (Dup)	Quahog	Meadow Island in Sippican Harbor	890						
MDWI-SS	Softshell Clam	Meadow Island in Sippican Harbor	2,513		87				
MEHH--SS	Softshell Clam	Mouth of East Pond in Mattapoisett Harbor	1,309			145			
MHHH-QH	Quahog	Mattapoisett Harbor	564		131				
MHRS-OY	Oyster	Megansett Harbor[1]	96.8						
MHRS-QH	Quahog	Megansett Harbor[1]	47						
MHRS-SS	Softshell Clam	Megansett Harbor[1]	100						
MHRS-SS (Dup)	Softshell Clam	Megansett Harbor[1]	87.4						
MNHH-QH	Quahog	Mouth of Nakata Creek, Southeast side of Sconticut Neck	7,626			318	138		26
MNHH-SS	Softshell Clam	Mouth of Nakata Creek, Southeast side of Sconticut Neck	21,539				257	144	75
MOMA-SS	Softshell Clam	27 Mooring Road, Marion		257					
MONB-BS	Bay Scallop	Mattapoisett Outer Nasketucket Bay, Middle of mouth of Bay	1,865			599	76.7		
MPDA-QH	Quahog	East of Mishaum Point		1,368	378	104			
NBOHFR-QH	Quahog	New Bedford Outer Harbor, Frederick Street		236		65.3			
NEWI-QH	Quahog	Northeast side of West Island		532					
NEWI-SS	Softshell Clam	Northeast side of West Island		3,416					
NRCV-OY	Oyster	North Cove		202					
NRCV-QH	Quahog	North Cove		202					

Table 2. Summary of Total PAH Concentrations in Tissue Samples Over Time

Site ID	Species	Location	Collection Dates/Total PAH (ppb)[2]						
			2003						2004
			May 5 - 7	May 19 - 21	June 9 - 10	July 8-10	Aug 27 - 28	Oct 23 - 24	May 13
OBWA-SS	Softshell Clam	Onset Beach, Wareham		64.5					
PCMA-QH	Quahog	Near Angelica Point, Mattapoisett		1,020	168				
PPBR-OY	Oyster	Plow Penny Road, Back River[1]	34						
RBHI-SS	Softshell Clam	Red Brook Handy Point Side of Red Brook Harbor		131					
RI-QH	Quahog	Ram Island, South side of Big Ram Island in Eastern Branch of Westport River[1]	47.2						
Rt88-BM	Blue Mussel	Route 88 Bridge at Westport Point in Westport Harbor[1]	206						
SHCV-QH	Quahog	Shaw's Cove, Fairhaven		842	178				
SHCV-SS	Softshell Clam	Shaw's Cove, Fairhaven		3,458	291	73.6			
SLOC-OY	Oyster	Slocum	1,093		438	117			
SNNW-QH	Quahog	Northwest side of Sconticut Neck near Hacker Street		4,256					
SNNW-SS	Softshell Clam	Northwest side of Sconticut Neck near Hacker Street		5,765					
STAR-OY	Oyster	Star of the Sea	70.9						
Swift-QH	Quahog	Swift's Beach, Wareham		67.1					
Swift-SS	Softshell Clam	Swift's Beach, Wareham		533	184				
SWLI-QH	Quahog	The Southwest side of Long Island in Fairhaven		8,512		2,881	1,175	455	169
SWLI-QH (Dup)	Quahog	The Southwest side of Long Island in Fairhaven		8,228					
WCSN-QH	Quahog	West Central side of Sconticut Neck		2,099		96.9			22.4
WCSN-SS	Softshell Clam	West Central side of Sconticut Neck		27,423		191			64.7
WCSN-SS (Dup)	Softshell Clam	West Central side of Sconticut Neck							66.8
WFHRS-OY	Oyster	West Falmouth Harbor[1]	70.1						
WFHRS-QH	Quahog	West Falmouth Harbor[1]	79.6						
WFHRS-SS	Softshell Clam	West Falmouth Harbor[1]	107						
WHBR-QH	Quahog	Wild Harbor Basin, Falmouth		1,071	741	252	104		
WNMA-SS	Softshell Clam	East of Clapp Island in Wings Cove		152					
WRCC-QH	Quahog	Wareham River, Crab Cove		42.2					

[1] Collected as reference sample

[2] Full suite of 54 individual PAHs and PAH groups measured by B&B labs for this project.

Table 3. Comparison of Buzzard Bay Shellfish Data to Literature Derived Benchmarks

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species **9.31 umol/g lipid**
EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species **2.24 µmol/g lipid**

Abbreviated Sample ID[2]	Collection Date	Location	Shoreline Oiling[3]	Total PAHs[4] (ng/wet g)	Total PAHs[4] (umol/wet kg)	Total PAHs[4] (umol/kg lipid wet)	Total PAHs[4] (umol/g lipid wet)
APPB-QH-1	05/05/03	Apponaganset Beach	No Oil	32.80	0.17	52.04	0.05
APPB-SS-1	05/05/03	Apponaganset Beach	No Oil	51.90	0.26	32.54	0.03
BRFF-QH-1	05/05/03	Birchfield Farms, Dartmouth	Very Light	29.70	0.15	42.54	0.04
BRFF-SS-1	05/05/03	Birchfield Farms, Dartmouth	Very Light	106.50	0.54	42.36	0.04
COWY-QH-1	05/05/03	Cow Yard	Very Light	1,737.70	8.13	1,891.28	1.89
LNGB-QH-1	05/05/03	Long Beach Point, North or South side of Long Beach near Indian Neck[5]	No Oil	54.30	0.27	59.92	0.06
LNGB-SS-1	05/05/03	Long Beach Point, North or South side of Long Beach near Indian Neck	Trace	423.00	2.01	182.45	0.18
SLOC-OY-1	05/05/03	Slocum, South of Lld Center	Very Light	911.90	4.43	363.20	0.36
STAR-OY-1	05/05/03	Star of the Sea	No Oil	63.30	0.34	20.43	0.02
BRM-QH-1-	05/06/03	Back River Mouth[5]	No Oil	23.70	0.13	27.20	0.03
Brook-OY-1	05/06/03	Great Island, Northeastern part of Great Island[5]	No Oil	70.20	0.38	29.98	0.03
Cherry-SC-01	05/06/03	Cherry Point, Mouth of Westport Harbor	Light	80.70	0.40	59.06	0.06
EEHH-OY-1	05/06/03	Eastern mouth of Eel Pond	Very Light	3,110.00	14.97	1,543.57	1.54
EPBR-SS-1	05/06/03	Eel Pond Back River[5]	No Oil	76.20	0.38	22.36	0.02
Great-SS-1	05/06/03	Great Island, SE of island- Eastern Branch of Westport River[5]	No Oil	87.50	0.45	52.79	0.05
MDWI-OY-1	05/06/03	Meadow Island in Sippican Harbor	Light	736.90	3.55	270.93	0.27
MDWI-QH-1	05/06/03	Meadow Island in Sippican Harbor	Light	803.50	3.78	820.78	0.82
MDWI-SS-1	05/06/03	Meadow Island in Sippican Harbor	Light	2,009.50	9.35	742.31	0.74
MEHH-SS-1	05/06/03	Mouth of Eel Pond in Mattapoisett Harbor	Very Light	1,104.20	5.33	388.73	0.39
MHHH-QH-1	05/06/03	Mattapoisett Harbor	Very Light	473.30	2.27	428.56	0.43
MHRS-OY-1	05/06/03	Megansett Harbor[5]	No Oil	84.30	0.45	23.94	0.02
MHRS-QH-1	05/06/03	Megansett Harbor[5]	No Oil	41.10	0.22	37.04	0.04
MHRS-SS-1	05/06/03	Megansett Harbor[5]	No Oil	86.40	0.45	23.64	0.02
PPBR-OY-1	05/06/03	Plow Penny Road, Back River[5]	No Oil	28.10	0.16	12.51	0.01
RI-QH-1-A	05/06/03	Ram Island, South side of Big Ram Island East of Westport River[5]	No Oil	39.60	0.22	45.80	0.05
Rt88-BM-1	05/06/03	Route 88 Bridge at Westport Point in Westport Harbor[5]	No Oil	178.50	0.89	107.96	0.11
BASS-BM-1	05/07/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	3,771.30	17.92	1,480.75	1.48

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species **9.31 umol/g lipid**

EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species **2.24 µmol/g lipid**

BASS-OY-1	05/07/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	2,048.10	10.22	638.78	0.64
BASS-QH-1	05/07/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	2,523.40	11.80	2,458.29	2.46
BASS-SS-1	05/07/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	2,385.20	11.49	876.76	0.88
FHHS-OY-1	05/07/03	Fairhaven Hacker Street	Moderate	10,232.60	49.96	4,897.99	4.90
FHHS-QH-1	05/07/03	Fairhaven Hacker Street	Moderate	6,592.90	31.00	7,381.01	7.38
FHHS-SS-1	05/07/03	Fairhaven Hacker Street	Moderate	11,934.30	56.53	4,348.75	4.35
FHIN-OY-1	05/07/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	957.30	4.62	825.05	0.83
FHIN-SP-1	05/07/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	1,436.30	6.88	870.51	0.87
FHKB-SS-1	05/07/03	Fairhaven Knolmere Beach, Upper reach of Nasketucket	No Oil	170.50	0.88	68.93	0.07
FHSB-QH-1	05/07/03	Fairhaven Sandy Beach, Northeastern side of Sconticut Neck	No Oil	100.60	0.51	118.45	0.12
FHSB-SS-1	05/07/03	Fairhaven Sandy Beach, Northeastern side of Sconticut Neck	No Oil	330.20	1.66	144.59	0.14
MNHH-QH-1	05/07/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	6,202.10	29.15	8,329.18	8.33
MNHH-SS-1	05/07/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	17,426.70	82.84	5,959.69	5.96
MONB-SP-1	05/07/03	Mattapoisett Outer Nasketucket Bay, Middle of mouth of Bay	Heavy	1,514.90	7.26	896.61	0.90
WFHRS-OY-1	05/07/03	West Falmouth Harbor[5]	No Oil	61.40	0.34	23.08	0.02
WFHRS-QH-1	05/07/03	West Falmouth Harbor[5]	No Oil	66.40	0.34	71.51	0.07
WFHRS-SS-1	05/07/03	West Falmouth Harbor[5]	No Oil	94.10	0.48	54.27	0.05
BMB-SS-1-	05/19/03	Buttermilk Bay	No Oil	48.00	0.26	26.80	0.03
CCRS-Q-1	05/19/03	Clarks Cove Rogers Street	No Oil	95.50	0.47	88.24	0.09
CCWFR-Q-1	05/19/03	Clarks Cove West Rodney French	No Oil	125.30	0.60	109.60	0.11
FCWA-SS-1	05/19/03	Cleveland Ave in Fisherman's Cove	Trace	50.90	0.27	30.05	0.03
LBBW-SS-1	05/19/03	Little Bay	No Oil	57.80	0.31	27.27	0.03
LBBW-SS-2	05/19/03	Little Bay	No Oil	63.50	0.34	28.98	0.03
NBOHFR-Q-1	05/19/03	New Bedford Outer Harbor Frederick Street	No Oil	207.60	1.01	152.95	0.15
OBWA-SS-1	05/19/03	Onset Beach	No Oil	58.50	0.31	33.41	0.03
RBHI-SS-1	05/19/03	Red Brook Handy Point side of Red Brook Harbor	No Oil	117.90	0.62	35.11	0.04
BIMT-OY-1	05/20/03	Brandt Island	Moderate	3,305.60	15.47	1,218.16	1.22
BIMT-QH-1	05/20/03	Brandt Island	Moderate	1,613.50	7.48	1,558.77	1.56

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species **9.31 umol/g lipid**
EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species **2.24 µmol/g lipid**

BVMA-QH-1	05/20/03	Bayview Avenue	Light	48.20	0.24	49.04	0.05
CWBWP-SC-	05/20/03	Cheriann Webb Beach	Light	67.60	0.34	68.56	0.07
GBWP-QH-1	05/20/03	East side of Goosebury Island	Light	787.70	3.66	666.35	0.67
LHWA-QH-1	05/20/03	Little Harbor	No Oil	29.70	0.16	26.89	0.03
MOMA-SS-1	05/20/03	27 Mooring Rd.	Moderate	225.60	1.10	57.52	0.06
MPDA-QH-1	05/20/03	East of Mischaum Point	No Oil	1,110.20	5.02	1,024.77	1.02
NEWI-QH-1	05/20/03	Northeast side of West Island	Very Light	436.60	2.02	421.39	0.42
NEWI-SS-1	05/20/03	Northeast side of West Island	Very Light	2,797.40	12.72	1,188.91	1.19
NRCV-OY-1	05/20/03	North Cove	Very Light	179.60	0.88	134.88	0.13
NRCV-QH-1	05/20/03	North Cove	Very Light	169.50	0.82	199.02	0.20
PCMA-QH-1	05/20/03	Near Angelica Point	Very Light	845.00	3.84	872.41	0.87
SHCV-QH-1	05/20/03	Shaw's Cove	Heavy	673.40	3.07	590.30	0.59
SHCV-SS-1	05/20/03	Shaw's Cove	Heavy	2,758.40	12.49	1,040.63	1.04
Swift-QH-1	05/20/03	Swifts Beach	Light	57.40	0.30	34.54	0.03
Swift-SS-1	05/20/03	Swifts Beach	Light	436.00	2.03	124.64	0.12
WHBR-QH-1	05/20/03	Wild Harbor Basin	Moderate	881.90	4.08	715.68	0.72
WNMA-SS-1	05/20/03	East of Clapp Island in Wings Cove	No Oil	130.30	0.66	36.29	0.04
WRCC-QH-1	05/20/03	Wareham River, Crab Cove	No Oil	38.00	0.21	41.26	0.04
FTPH-QH-1	05/21/03	Fort Phoenix	Moderate	1,136.80	5.11	1,110.46	1.11
SNNW-QH-1	05/21/03	Northwest side of Sconicut Neck near Hacker Street	Moderate	3,469.30	15.59	2,834.49	2.83
SNNW-SS-1	05/21/03	Northwest side of Sconicut Neck near Hacker Street	Moderate	4,793.60	21.84	2,228.40	2.23
SWLI-QH-1	05/21/03	The southwest side of Long Island	Heavy	6,880.10	31.36	6,533.48	6.53
WCSN-QH-1	05/21/03	West central side of Sconicut Neck	Light	1,692.90	7.56	1,374.21	1.37
WCSN-SS-1	05/21/03	West central side of Sconicut Neck	Light	22,825.40	105.51	5,410.70	5.41
LNGB-SS-2	06/09/03	Long Beach Point, North or South side of Long Beach near Indian Neck	Trace	36.90	0.19	28.87	0.03
MDWI-OY-2	06/09/03	Meadow Island in Sippican Harbor	Light	106.80	0.53	41.50	0.04
MDWI-QH-2	06/09/03	Meadow Island in Sippican Harbor	Light	56.70	0.28	63.21	0.06
MDWI-SS-2	06/09/03	Meadow Island in Sippican Harbor	Light	73.90	0.36	50.06	0.05
PCMA-QH-2	06/09/03	Near Angelica Point	Very Light	137.60	0.64	136.47	0.14
Swift-SS-2	06/09/03	Swifts Beach	Light	152.60	0.72	77.15	0.08
WHBR-QH-2	06/09/03	Wild Harbor Basin	Moderate	603.80	2.74	449.63	0.45
BIMT-OY-2	06/10/03	Brandt Island	Moderate	1,440.20	6.61	398.22	0.40
BIMT-QH-2	06/10/03	Brandt Island	Moderate	571.70	2.60	400.00	0.40
COWY-QH-2	06/10/03	Cow Yard	Very Light	322.00	1.46	364.35	0.36
EEHH-OY-2	06/10/03	Eastern mouth of Eel Pond	Very Light	667.10	3.06	250.54	0.25
FHIN-OY-2	06/10/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	446.30	2.01	334.76	0.33
FHIN-SP-2	06/10/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	758.10	3.39	451.99	0.45

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species **9.31 umol/g lipid**
EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species **2.24 µmol/g lipid**

MHHH-QH-2	06/10/03	Mattapoisett Harbor	Very Light	105.80	0.50	92.67	0.09
MPDA-QH-2	06/10/03	East of Mischaum Point	No Oil	293.30	1.33	246.51	0.25
SHCV-QH-2	06/10/03	Shaw's Cove	Heavy	140.20	0.65	127.21	0.13
SHCV-SS-2	06/10/03	Shaw's Cove	Heavy	232.10	1.06	159.92	0.16
SLOC-OY-2	06/10/03	Slocum, South of Lld Center	Very Light	374.50	1.81	127.37	0.13
COWY-QH-3	07/08/03	Cow Yard	Very Light	55.60	0.27	39.60	0.04
FHHS-OY-2	07/08/03	Fairhaven Hacker Street	Moderate	1,812.70	8.18	499.07	0.50
FHHS-QH-2	07/08/03	Fairhaven Hacker Street	Moderate	309.70	1.40	292.39	0.29
FHHS-SS-2	07/08/03	Fairhaven Hacker Street	Moderate	664.50	2.97	412.74	0.41
FHIN-OY-3	07/08/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	277.00	1.25	152.90	0.15
FHIN-SP-3	07/08/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	448.70	2.02	217.67	0.22
FHSB-SS-2	07/08/03	Fairhaven Sandy Beach, Northeastern side of Sconticut Neck	No Oil	31.90	0.16	16.91	0.02
MONB-SP-2	07/08/03	Mattapoisett Outer Nasketucket Bay, Middle of mouth of Bay	Heavy	497.70	2.25	220.39	0.22
MPDA-QH-3	07/08/03	East of Mischaum Point	No Oil	80.30	0.37	79.00	0.08
SLOC-OY-3	07/08/03	Slocum, South of Lld Center	Very Light	99.90	0.48	45.74	0.05
WCSN-SS-2	07/08/03	West central side of Sconicut Neck	Light	162.50	0.74	98.87	0.10
WHBR-QH-3	07/08/03	Wild Harbor Basin	Moderate	203.70	0.95	169.68	0.17
BASS-BM-2	07/09/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	115.40	0.55	53.63	0.05
BASS-OY-2	07/09/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	148.40	0.72	32.78	0.03
BASS-QH-2	07/09/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	47.10	0.23	30.63	0.03
BASS-SS-2	07/09/03	Bass Creek, East side of West Island of Nasketucket Bay	Very Light	58.40	0.28	45.89	0.05
FTPH-QH-2	07/09/03	Fort Phoenix	Moderate	79.00	0.38	56.13	0.06
MNHH-QH-2	07/09/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	249.20	1.12	215.27	0.22
NBOHFR-QH	07/09/03	New Bedford Outer Harbor Frederick Street	No Oil	59.00	0.30	51.04	0.05
SHCV-SS-3	07/09/03	Shaw's Cove	Heavy	61.20	0.29	40.68	0.04
SWLI-QH-2	07/09/03	The southwest side of Long Island	Heavy	2,254.30	10.01	2,086.39	2.09
WCSN-QH-2	07/09/03	West central side of Sconicut Neck	Light	77.90	0.36	74.33	0.07
BIMT-OY-3	07/10/03	Brandt Island	Moderate	250.00	1.16	97.85	0.10
BIMT-QH-3	07/10/03	Brandt Island	Moderate	85.30	0.41	80.07	0.08
BJB-SC-2	07/10/03	Barney's Joy Beach	Heavy	197.90	0.87	137.63	0.14
EEHH-OY-3	07/10/03	Eastern mouth of Eel Pond	Very Light	237.00	1.10	95.61	0.10
GBWP-QH-2	07/10/03	East side of Goosebury Island	Light	28.60	0.14	30.71	0.03

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species **9.31 umol/g lipid**

EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species **2.24 µmol/g lipid**

MEHH-SS-2	07/10/03	Mouth of Eel Pond in Mattapoisett Harbor	Very Light	122.80	0.58	59.94	0.06
BIMT-OY-4	08/27/03	Brandt Island	Moderate	131.30	0.64	52.43	0.05
EEHH-OY-4	08/27/03	Eastern mouth of Eel Pond	Very Light	160.10	0.76	60.14	0.06
FHHS-OY-3	08/27/03	Fairhaven Hacker Street	Moderate	476.60	2.18	170.33	0.17
FHHS-QH-3	08/27/03	Fairhaven Hacker Street	Moderate	137.70	0.65	103.64	0.10
FHHS-SS-3	08/27/03	Fairhaven Hacker Street	Moderate	225.60	1.04	97.00	0.10
FHIN-OY-4	08/27/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	26.00	0.15	24.92	0.02
FHIN-SP-4	08/27/03	Fairhaven Inner Harbor in Nasketucket Bay, north of West Island	Very Light	49.00	0.25	30.91	0.03
MNHH-QH-3	08/27/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	107.80	0.52	93.64	0.09
MNHH-SS-2	08/27/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	202.50	0.92	112.48	0.11
MONB-SP-3	08/27/03	Mattapoisett Outer Nasketucket Bay, Middle of mouth of Bay	Heavy	68.00	0.36	18.41	0.02
SWLI-QH-3	08/27/03	The southwest side of Long Island	Heavy	886.30	3.92	890.18	0.89
WHBR-QH-4	08/27/03	Wild Harbor Basin	Moderate	84.70	0.41	80.57	0.08
BJB-SC-3	08/28/03	Barney's Joy Beach	Heavy	40.40	0.20	33.90	0.03
EEHH-OY-5	10/23/03	Eastern mouth of Eel Pond	Very Light	103.70	0.49	30.06	0.03
FHHS-OY-4	10/23/03	Fairhaven Hacker Street	Moderate	141.40	0.68	37.41	0.04
FHHS-SS-4	10/23/03	Fairhaven Hacker Street	Moderate	131.10	0.61	72.80	0.07
MDWI-QH-3	10/23/03	Meadow Island in Sippican Harbor	Light	10.00	0.05	14.74	0.01
MNHH-SS-3	10/23/03	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	112.70	0.51	62.90	0.06
SWLI-QH-4	10/23/03	The southwest side of Long Island	Heavy	350.70	1.58	367.24	0.37
FHHS-OY-5	05/13/04	Fairhaven Hacker Street	Moderate	86.70	0.42	25.56	0.03
FHHS-QH-5	05/13/04	Fairhaven Hacker Street	Moderate	39.60	0.20	40.44	0.04
FHHS-SS-5	05/13/04	Fairhaven Hacker Street	Moderate	121.80	0.57	54.97	0.05
FTPH-QH-5	05/13/04	Fort Phoenix	Moderate	41.10	0.20	40.01	0.04
WCSN-QH-5	05/13/04	West central side of Sconicut Neck	Light	19.40	0.10	32.45	0.03
WCSN-SS-5	05/13/04	West central side of Sconicut Neck	Light	56.30	0.27	33.03	0.03
MNHH-QH-5	05/13/04	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	22.10	0.11	32.34	0.03
MNHH-SS-5	05/13/04	Mouth of Nakata Creek, Southeast side of Sconticut Neck	Heavy	64.30	0.31	27.23	0.03
SWLI-QH-5	05/13/04	The southwest side of Long Island	Heavy	129.20	0.59	177.50	0.18

[1] EPA. 2003. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. U.S. Environmental Protection Agency. Office of Research and Development. Washington D.C. 175 pg. EPA-600-R-02-013.

[2] Duplicate samples are excluded from this data set. In addition, this data set does not include the two samples collected at Barneys Joy in 2003. These samples were not collectec

EPA 2003[1] - Final Acute Value - protective of acute effects in 95% of species	**9.31 umol/g lipid**
EPA 2003[1] - Final Chronic Value - protective of chronic effects in 95% of species	**2.24 µmol/g lipid**

The Total PAH[3] (umol/g lipid wet) for was 36.32 for BJP-SC-A and 24.48 for BJP-SC-B.
[3] according to protocol, and gross oil contamination is suspected.
Shoreline Oiling Levels are based on the most recent oiling maps.
[4] In this table, the Total PAH is the sum of the 34 individual PAH and PAH groups recommended by EPA (2003).
[5] Samples collected as reference samples

Appendix B
Evaluation of the Potential for Exposure of the American Lobster (*Homarus americanus*) to Oil from the Bouchard B-120 Spill

EVALUATION OF THE POTENTIAL FOR EXPOSURE OF THE AMERICAN LOBSTER (*HOMARUS AMERICANUS*) TO OIL FROM THE BOUCHARD B-120 SPILL

Prepared by:

Aquatic Technical Working Group

October 24, 2008

EXECUTIVE SUMMARY

In the days, weeks, and months following the Bouchard B-120 Oil Spill, information and data were gathered to facilitate cleanup efforts and assist in the evaluation of the potential risk and magnitude of any injury to natural resources as a result of the spill. Based on knowledge of the life history of the American lobster *(Homarus americanus)*, information regarding the behavior of the spilled oil, and data collected immediately and during the months following the spill, there was little basis to conclude that lobsters suffered significant amounts of exposure and/or injury. However, these same data indicated that there may have been some potential for minimal exposure levels to certain life stages. The primary objective of this report is to provide a detailed evaluation of the exposure potential and likelihood of significant injury to all lobster life stages and populations in and around Buzzards Bay as a result of the Bouchard B-120 Oil Spill.

In this report, life stages are combined into three groups based on similarities in habitats typically used, as this defines the degree and type of oil they would have been exposed to. These three groups are:

- adults, adolescents, and eggs;
- larval and post-larval lobsters; and
- early benthic phase (EBP) lobsters.

Adults (including females with eggs) and adolescents (lobsters greater than 40 millimeters [mm] carapace length) are expected to have been present in the Bay at the time of the spill, including subtidal areas potentially impacted by oil (referred to in this report as the “subtidal zone of concern”). The most likely injury pathway for these lifestages is physical exposure to oil on the substrate (e.g., tarballs). A comparison of the area of habitat in the subtidal zone of concern and the total area of potential habitat in the Bay suggests that the proportion of adult and adolescent lobsters in the Bay exposed to oil was relatively small (less than 1 percent). The qualitative and quantitative analysis of potential exposure and injury is consistent with the lack of conspicuous visual evidence of lobster mortality from the spill, continued commercial harvesting of Buzzards Bay lobsters in 2003 and 2004 at levels typical for the Bay in recent years (relative to harvesting in non-impacted areas of the Massachusetts portion of the Southern New England stock), and lack of oil on harvested lobsters in 2003.

Our analyses indicate that it is unlikely that there were pelagic larval stage lobsters in the Bay at the time of, or within weeks after, the spill. Due to the colder-than-normal temperatures in the winter and spring of 2002 - 2003, the onset of egg hatching likely occurred no earlier than late May, approximately 4 weeks after the spill, and the peak of hatching likely occurred no earlier than late June, about 7 to 8 weeks after the spill. If larvae were present during the first week after the spill, there would have been very few. If these few potentially present larvae came in contact with oil on the surface they may have been injured. However, oil was only present on the vast majority of the Bay for a relatively short time, decreasing the likelihood of direct contact with the oil. In addition, modeling indicates that dissolved concentrations, even immediately after the spill, were not high enough for a long enough duration, to cause mortality to aquatic organisms. Based on this information, the degree of exposure and potential injury to the larval population is considered insignificant.

EBP lobsters (lobsters 5-40 millimeters [mm] [0.2 – 1.6 inches [in]] carapace length in size) are expected to have been present in the Bay at the time of the spill and some may have sustained injury through direct contact with either oil and/or dissolved constituents of the oil. EBP lobsters are found on a range of substrate types, but occur at the highest densities on shelter-providing substrates such as cobble, rock and peat reefs in shallow waters ranging from Mean Low Water to approximately 20 meters (m) (65 feet [ft]) deep. Based on the life history and habitat use of lobsters in the Bay and the shoreline oiling data, EBP lobsters were potentially exposed to and injured by oil from the Bouchard B-120 oil spill. Calculations suggest that approximately 1.2 percent of the EBP lobster habitat in the Bay may have been in the subtidal zone of concern for the spill. The actual proportion of EBP habitat (and by extension, the proportion of EBP lobsters) exposed to oil is uncertain and may be higher or lower depending upon how much of the preferred EBP habitat in the Bay is in the subtidal zone of concern. Barneys Joy, where much of the area of the subtidal zone of concern is located, is a high energy area that is believed to be good habitat for EBP lobster, however there are other areas of the Bay that are also believed to be good EBP lobster habitat that are not in the subtidal zone of concern.

Although the calculated values for EPB, adult and adolescent lobsters are not definitive, they do indicate the level of magnitude of exposure that might be expected. A more precise evaluation of the lobster habitat and number of lobsters potentially exposed to oil could not be conducted without a more detailed evaluation of substrate types and actual densities on different habitat types within the Bay. Further, actual potential losses of lobsters within the exposed area would be difficult to determine in the context of natural mortality and given the uncertainties about the degree of oil in the exposed area, and potential impacts of contact or ingestion of small oil particles or oil-contaminated substrates. However, the lack of a conspicuous visible mortality event even at Barneys Joy, which received heavy oiling, is a relatively high energy shoreline, and is believed to have good EBP lobster habitat, supports the conclusion of relatively low injury for EBP, adolescent, and adult lobsters.

Due to the estimated low levels of injury to lobster lifestages due to the oil and the difficulty in increasing the precision of the estimate of exposure as well as the degree of injury to exposed lobsters, a resource-specific injury assessment is not warranted for lobsters. Instead, the potential injury to lobsters discussed in this report has been incorporated into the overall aquatic injury assessment of the benthic community. This potential injury will be compensated for by implementation of appropriate restoration projects funded by the Responsible Party.

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1.0 INTRODUCTION

1.1 PURPOSE AND STRUCTURE OF THIS REPORT

In the days, weeks, and months following the Bouchard B-120 Oil Spill, information and data were gathered to facilitate cleanup efforts and assist in the evaluation of the potential risk and magnitude of any injury to natural resources as a result of the spill. The American lobster (*Homarus americanus*) is an important component of the ecosystems of Buzzards Bay, and the potential for injury to this species was carefully evaluated. Based on knowledge of the life history of the lobster, information regarding the behavior of the spilled oil, and data collected immediately and during the months following the spill, there was little basis during the pre-assessment phase to conclude that lobsters suffered significant amounts of exposure and/or injury. However, these same data indicated that there may have been some potential for minimal exposure levels to some life stages. The primary objective of this report is to provide a more detailed evaluation of the exposure potential and likelihood of significant injury to American lobster life stages and populations in and around Buzzards Bay as a result of the Bouchard B-120 oil spill.

This report was prepared based on a review of literature regarding lobster biology, population dynamics, population surveys, fishery management plans, and similar topics, as well as information regarding the specific circumstances of the spill and input from lobster specialists in the Massachusetts Department of Fish & Game, Division of Marine Fisheries (MA DMF), and academic institutions (Dr. Michael Clancy at Boston University, and Dr. Richard Cooper Professor Emeritus, at University of Connecticut).

A summary of the status of the lobster fishery is presented later in this introductory section. The remainder of this report provides the following:

- Summary information on the incident, cleanup efforts, physical surveys, and the modeling conducted after the spill (Section 2.0, Spill Information). This information is presented at the front of the report to provide the reader with background information on the spill that can be considered in relation to the location and timing of the occurrence of the various lobster life stages in the Bay.
- Summary descriptions of the life stages of the American lobster (Section 3.0, Lobster Life Cycle), including information specific to the lobster population of the Bay. This information is important to understand the potential for impacts to the various life stages that may have been present in the Bay during and after the spill.
- Evaluation of the potential exposure of each life stage of lobster to the B-120 spill (Section 4.0, Potential Lobster Exposure and Injury). This evaluation is an integration of the life history information presented in Section 3.0 and information on the amount, location, and behavior of the spilled oil as presented in Section 2.0.
- Conclusions regarding the potential for exposure and injury to each life stage of the lobster (Section 5.0, Conclusions).

1.2 LOBSTER FISHERY

The lobster fishery is one of the largest commercial fisheries on the East Coast. Most of the large populations of harvestable lobster occur in deep water and in embayments along the coast of New England. Pringle and Burke (1993) state that the principal depth of distribution for lobsters is from the sublittoral fringe to 50 meters (m) (164 feet [ft]), but they can also be fished to depths of 700 m (2,297 ft) on the edge of the continental shelf (Cooper and Uzmann 1971). Historically, the lobster fishery has been economically important to Massachusetts and other New England states. However, lobster populations have precipitously declined since the late 1990s in several southern New England areas, including Long Island Sound, Rhode Island Sound and Narragansett Bay, and southeastern Massachusetts (including Buzzards Bay). Selberg et al. (2003) stated in their review of the Atlantic States Marine Fisheries Commission (ASMFC) Fisheries Management Plan for lobster that: (1) the stock in southern New England was at or close to its all-time low; (2) there was an observable, consistent decline in pre-recruit, recruit, and legal lobster indices in surveys from the previous 5 years (i.e., 1998 through 2002); and (3) the technical committee for the ASMFC Fisheries Management Plan found that the low abundance of lobsters in southern New England was particularly alarming. As a result of this decline in the abundance of legal-sized lobsters, regulators tightened fishery regulations. In the fall of 2002, the ASMFC stated that the waters from south of Cape Cod to eastern Long Island Sound (including Buzzards Bay) were considered to be in "emergency status." The ASMFC formally declared the emergency in January 2003, several months prior to the B-120 spill. Experts cite multiple reasons for the population crash including shell disease, overfishing, and increased predation (Gibson 2003).

Buzzards Bay itself supports a commercial and recreational lobster fishery, although it is a relatively small proportion of the total Massachusetts and Southern New England stock harvest. From 1999 through 2002, the reported commercial catch in Buzzards Bay (MA DMF Statistical Reporting Area 14) was approximately 7 to 13 percent of the total Massachusetts portion of the Southern New England stock harvest (McBride and Hoopes 2000, McBride et al. 2001, Dean et al. 2002 and 2004; ASMFC 2006; Glenn 2007) (see Table 1). The recreational catch is a relatively small proportion of the total harvest; for all of Massachusetts, the recreational catch was approximately 3.3 to 4.4 percent of the total territorial commercial catch during these same years[1] (McBride and Hoopes 2000; McBride et al. 2001; Dean et al. 2002 and 2004). Based on the MA DMF lobster trawl surveys, the abundance of adult lobsters in Buzzards Bay has shown the same population decline that has occurred throughout the region since the mid 1990's (Figure 1).

The lobster fishery in the Bay does not appear to have been affected by the B-120 Oil Spill in 2003. There was no closure of the lobster fishery in the Bay in 2003 and the 2003 and 2004 commercial catch in the Bay was 9 to 15 percent of the total Massachusetts portion of the Southern New England stock harvest (Dean et al. 2005 and 2006; ASMFC 2006; Glenn 2007) (see Table 1), which is comparable to the percent of total catch in prior years. In addition, anecdotal reports from lobstermen who were fishing in the late spring and early summer of 2003 indicated that there was essentially no oiling of their pots or lobsters in the pots; only one

[1] *Total territorial commercial catch includes all harvest within state waters (0-3 miles from land). This includes MA DMF Statistical Reporting Areas 1-14.*

fisherman reported minor oiling of some equipment in early May, and that was likely due to surface oil contacting the equipment as the pots were raised (Hickey 2003).

Table 1. Proportion of Buzzard Bay Commercial Catch Relative to the Massachusetts Portion of the Southern New England Stock Commercial Catch.

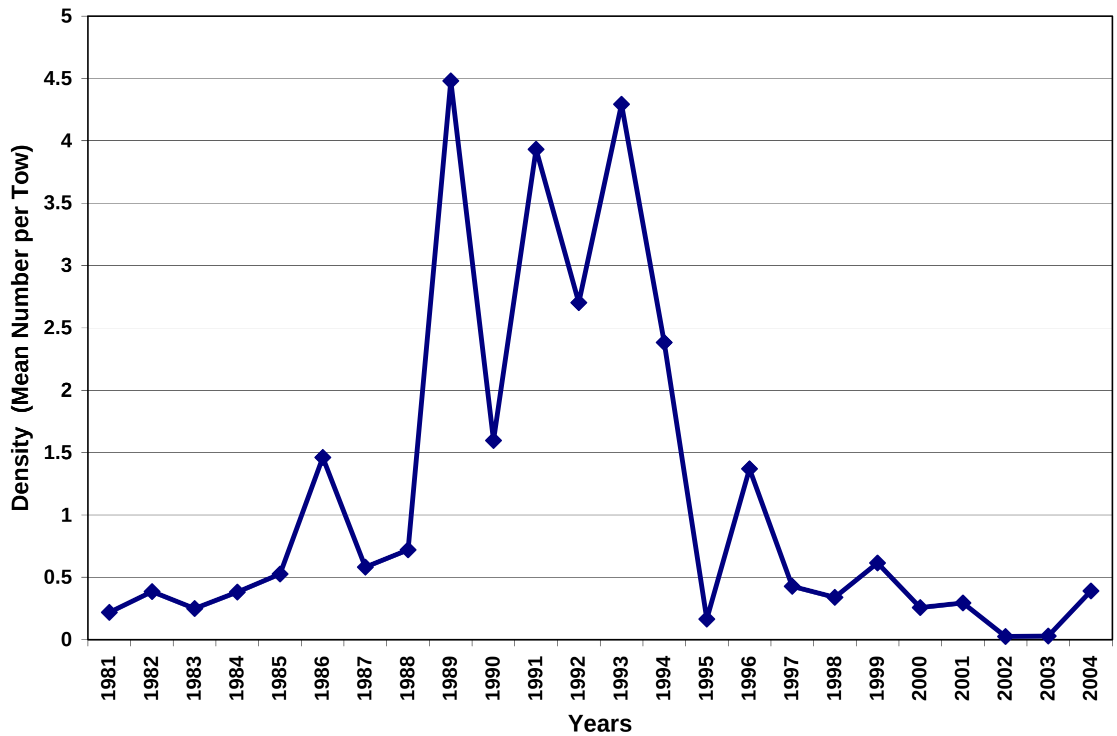
Year	MA SNE landings (pounds)[a, c]	Buzzard's Bay commercial harvest (pounds)[b, c]	Percent of MA SNE landings
1999	2,180,372	276,583	13%
2000	1,629,216	109,440	7%
2001	1,649,058	114,805	7%
2002	1,653,467	131,030	8%
2003	1,000,899	88,493	9%
2004	788,247	116,083	15%

[a] *Values for 1999-2003 converted to pounds from values obtained from ASMFC (2005); Value for 2004 obtained from Glenn et al. (2007).*

[b] *Values obtained from Massachusetts Lobster Fisheries Statistics Reports available on-line at: http://www.mass.gov/dfwele/dmf/publications/technical.htm#tr; Values for 1999-2002 were calculated from data provided in the reports (product of the total territorial commercial harvest and Area 14 percent of total territorial commercial harvest). Values for 2003-2004 were taken directly from tables in the reports.*

[c] *Landings are influenced by fishing effort (e.g., number of licenses, number of fishing days). This data is not adjusted for differences in fishing effort between years.*

Figure 1. Lobster Trawl Densities in Buzzards Bay from 1981 – 2004. Data from MA DMF annual fall trawl surveys (MA DMF 2005). Due to the type of sampling gear used, these data only include lobsters greater than 59 mm carapace length.



2.0 SPILL INFORMATION

The following sections provide relevant information on the spill incident, spill cleanup efforts, physical surveys conducted after the spill (submerged oil surveys, subtidal sediment sampling surveys, and water column sampling), and the aquatic toxicity modeling conducted by the Natural Resource Trustees (Trustees) and Responsible Party (RP) to estimate the concentration of oil in the water column after the spill. This information provides a delineation of the distribution, severity, and duration of oiling in various water column and shoreline habitats and is used together with the lobster life history information presented in Chapter 3 to evaluate the potential exposure and injury to the different lobster life stages (Chapter 4).

2.1 SPILL INCIDENT

Soon after entering the western approach of Buzzards Bay on April 27, 2003, the B-120 struck submerged rocks near Buoy G1 at the mouth of the Bay, and subsequently released up to 98,000[2] gallons of No. 6 fuel oil as it was towed up the Bay in the shipping channel. After the spill was detected, the B-120 was towed to Buoy BB in central Buzzards Bay, then was ordered to Buoy 10 (Anchorage Lima) by the US Coast Guard where it anchored and had the remaining contents of the ruptured cargo tanks transferred to Barge B-10 (Figure 2).

Immediately after the spill, oil was present as sheen and slick from the grounding location to Buoy BB. The estimated area of the slick on the evening of April 27, based on GPS points taken during a National Oceanic and Atmospheric Administration (NOAA) helicopter overflight, was approximately 21,800 acres, or approximately 10 percent of the total surface area of the Bay. Within 24 hours, the remaining oil on the water broke up and was present as discontinuous sheen, slick, tarballs, and patties. Based upon observations and data collected during the initial response and subsequent studies, it is believed that the majority of the oil remained neutrally or positively buoyant and did not sink and settle on the bottom in large mats or pools.

Oil first washed ashore in Dartmouth and Mattapoisett, but in the days following the spill, winds and currents drove the bulk of the remaining oil to the northwest, north, and to a lesser extent, the northeast and pushed the oil onto the shorelines. Oil was unevenly distributed along shorelines and was generally concentrated at exposed points on peninsulas in the western portion of the Bay. There were additional sporadic occurrences of predominately light and very light oiling on the east side of the Bay and in Rhode Island (e.g., Block Island and Little Compton). Most of the shorelines within the general spill area were unoiled or experienced only very light or light oiling.

2.2 SPILL CLEANUP EFFORTS

Emergency response activities were initiated on the evening of April 27, 2003, and by the next day cleanup contractors had arrived on scene. Recovery and cleanup operations included the use of skimming boats, deployment of boom and sorbent material, power washing along the shorelines, and the use of other manual removal techniques. Skimming was conducted for about 1 week after the spill, and was then discontinued since there was little oil remaining on the surface.

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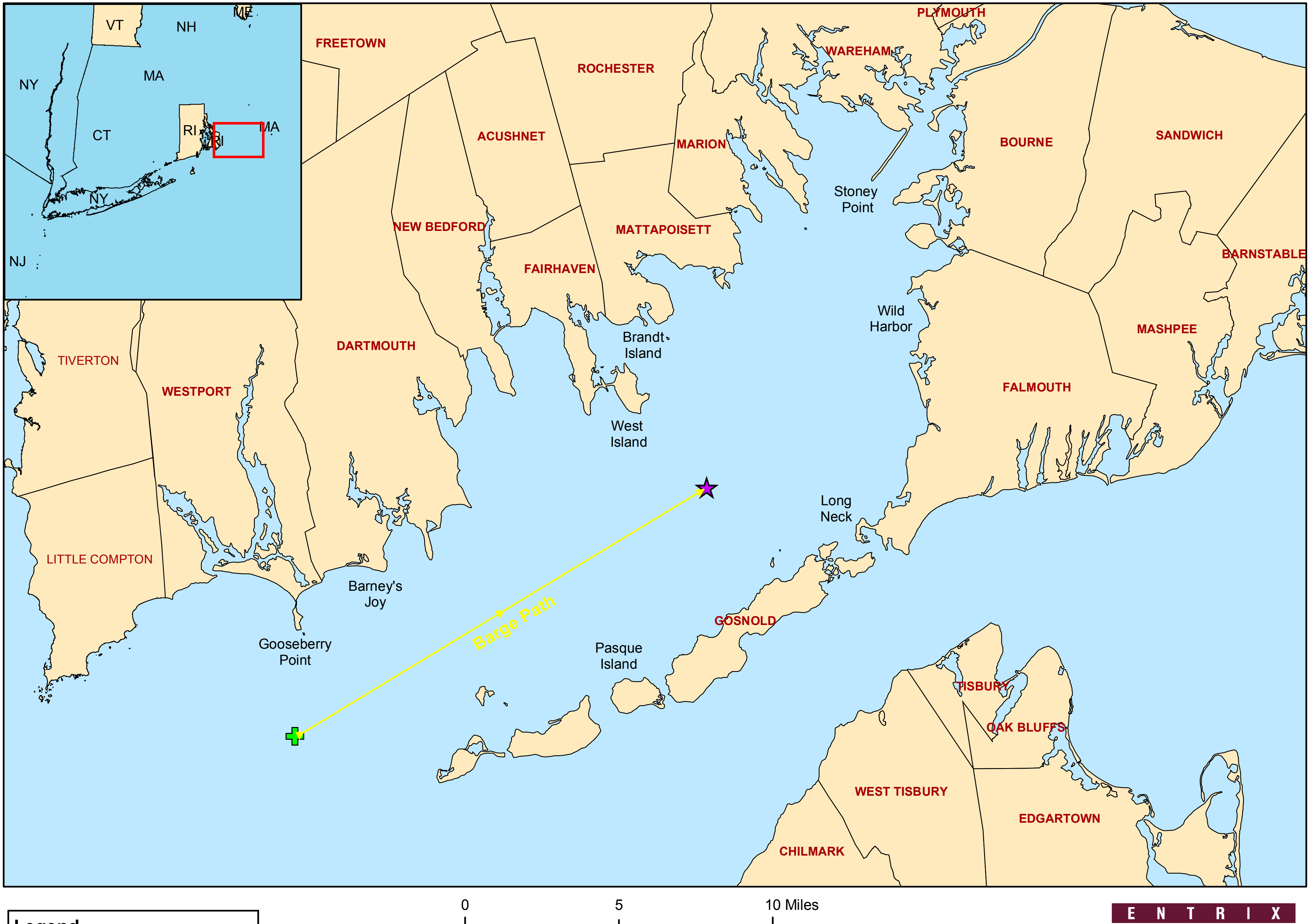
[2] *Spill estimates range from 22,000 gallons to 98,000 gallons (Independent Maritime Consulting, LTD 2003; USCG 2004).*



Legend

- Presumed Grounding Location
- BB10/Anchorage Lima

ENTRIX

Figure 2.
Site Overview
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA

The majority of oil and oiled vegetation was removed from the shorelines within about 3 months of the spill, although cleanup activities continued until September 3, 2003, when the Unified Command Post was deactivated and responsibility for cleanup was transferred to the Massachusetts Department of the Environment (MADEP) under the state's Massachusetts Contingency Plan (MCP) regulations. Under the MCP, targeted, small-scale cleanups were conducted in the upper intertidal zone along a few shoreline segments into 2004, 2005, and 2006.

Following the spill, shorelines around the Bay were walked by Trustee and RP representatives, other government agency personnel, and volunteers to document the degree of oiling, search for oiled and/or dead wildlife (particularly birds), and clean up oiled shorelines. During the first month after the spill, between these various groups, at least 80 percent of the Bay shoreline was walked at least once. Many shorelines were walked multiple times, especially the shorelines with the heavy and moderate oiling. During this time, six dead lobsters were found on the shoreline by cleanup personnel. Four large juveniles were found in Mattapoisett on May 15, 2003, and two adult, egg-bearing females were found near Planting Island Cove in the Sippican Harbor area on May 22, 2003. The lobsters were delivered to MA DMF where they were evaluated by an agency lobster specialist. Reports of these examinations (Estrella 2003a and 2003b) stated that the four juveniles did not exhibit any visible signs of oil or an odor of oil. In addition, although the two adults had oil sheens on their shells, they were stored and transported in a plastic bag that contained water and oil, making it impossible to determine whether the oiling occurred prior to or after death. There was no documentation linking the deaths of these six specimens to the spill, and as noted by the agency lobster specialist (Estrella 2003a), lobsters die naturally from a variety of causes and are occasionally found on the shorelines of the Bay.

2.3 Relevant Physical Surveys

Qualitative and quantitative surveys conducted jointly by the RP and state and federal agency representatives within 2 months after the release included submerged oil surveys (lobster pot, chain drag, and absorbent pad swipe surveys), sediment sampling, and water sampling. In addition, the RP conducted underwater dive surveys in the summer of 2003 to assess the potential presence of submerged oil, especially in the vicinity of Barney's Joy and along the suspected trajectory of the vessel from the point of suspected grounding to Anchorage Lima. In April 2004, the RP and Trustees jointly conducted chain drags in the vicinity of the grounding site.

2.3.1 Submerged Oil Surveys

Periodic re-oiling of a few shoreline segments in the vicinity of Barney's Joy and West Island during the first month after the release prompted field investigations to evaluate whether or not a residual source of submerged oil was present offshore of these segments and if so, whether or not it could be removed. Four separate survey methods were used in the field investigations: lobster pots with snare, chain drags with snare, absorbent pad swipe, and dive surveys. Submerged oiling data and maps are provided in the Pre-Assessment Data Report (Massachusetts Executive Office of Environmental Affairs [MA EOEA] et al. 2004).

Lobster Pot Surveys

The Massachusetts Division of Marine Fisheries (MA DMF) conducted initial lobster pot surveys on May 2 and 14, 2003. Four lobster traps loaded with snare were deployed for twelve days on the seabed just offshore of Barneys Joy Point, north of West Island (between West Island and Ram Island) and Southwest of West Island (between Wilbur Point and West Island - east of Long Island). Lobster pot surveys were generally conducted at a distance of 1,100 to 7,500 feet (ft) offshore. Upon retrieval, none of the snare was oiled. The traps were then re-deployed northeast of West Island for 7 days. Upon retrieval, one of the snares had small spots of oil on it. NOAA, MADMF, and the RP agreed to conduct additional investigations for potential subsurface oil.

Additional lobster pot surveys were conducted between May 30 and June 13, 2003 to further assess the potential occurrence of mobile oil in the subtidal habitat, especially offshore of heavily oiled shorelines experiencing periodic re-occurrence of tarballs. Sampling was conducted at six locations in the vicinity of Hen and Chickens Rock, Barneys Joy, and West Island at depths of 11.5 to 59 ft. No oiling of snare within lobster pots was observed at five of the six locations, with the exception being the Barneys Joy location.

Approximately 40 percent of the lobster pots with snare deployed in the vicinity of Barneys Joy (11 out of 27[3]) had light oiling (staining) indicating there was some movement of tarballs along the seafloor in this area, which agrees with the intertidal shoreline observations that the greatest magnitude of tarball occurrence was at Barneys Joy. Heavy oiling that would be indicative of a pool of submerged oil or large numbers of tarballs was not observed on any of the recovered snare.

Chain Drag Surveys

Chain drag surveys were conducted to evaluate the potential for deep subtidal oil on the substrate surface. During each survey, a 10-feet section of heavy chain with three to four snares attached was deployed from a boat and dragged along the seafloor bottom in a straight line; the chain was then raised and the chain and snare inspected for oil. In May and June 2003, 30 chain drag surveys were conducted in the general vicinity of Black Rock, Barneys Joy, and West Island, which were the most heavily oiled areas. These surveys were conducted approximately 1,100 to 2,600 ft offshore at depths of 11.5 to 21 ft. The drag length ranged from 0.1 to 0.7 miles. No oiling was observed at four of the five locations with the exception being Barneys Joy. At Barneys Joy, 29 percent of the chain drag surveys (5 out of 17) had light oiling on the snare.

In April 2004, additional chain drag surveys were conducted in the vicinity of the suspected grounding site at the request of the Natural Resource Trustees. The surveys were intended to document whether or not oil had quickly sunk upon grounding on April 27, 2003. Eight chain drag surveys were conducted within 0.5 miles of Buoy 1 near Gooseberry Point. Drag lengths ranged from 0.4 to 1.1 miles. No oiling was observed on the chain or snare.

Absorbent Pad Swipe Surveys

Absorbent pad swipe surveys were conducted between May 5 and 21, 2003 at shellfish sampling stations during low tide. At each intertidal station, absorbent pads were swabbed along the

[3] *The 11 lobster pots that had staining on the snare were located in 12 to 30 ft of water 1,378 to 2,247 ft offshore of Barneys Joy.*

exposed surface within an approximate 20-ft diameter area in the intertidal zone. Presence/absence of oiling on the pads was noted. For subtidal bed sampling, absorbent pads were individually wrapped around the heads of clam rakes and secured with adhesive tape. The pads were then submerged and swabbed along the bottom in a 20-ft diameter area. The pads were brought to the surface and observations of oiling were recorded. The used absorbent pads were placed in labeled plastic bags for future reference. Minor oil spotting was observed on two absorbent pads collected at the Fairhaven Hacker Street and Sconticut Neck shellfish sample locations. No oil was observed on any of the other swipes.

Dive Surveys

Dive surveys were conducted between July 31 and August 4, 2003. Ocean Technology Foundation and Aquas, LLC conducted 6 dive surveys at depths ranging from 17 to 64 ft and included visual assessment of the sediment surface and collection of sediment samples. The surveys were conducted at two locations along the path of the barge and four locations where submerged oil would most likely be present, based on proximity to heavily oiled shorelines, currents, and bathymetry (e.g., Barneys Joy Point and West Island). At each location, with the exception of Barneys Joy, the divers traversed approximately 250 ft in each direction (North, East, South, and West) from the center location. Because of the bathymetry at Barneys Joy, the traverse followed the 17 to 19 ft depth contour generally in a west to east traverse. There were no tarballs, oil pancakes, or other observations of oil at any of the dive sites. In addition, there was no staining observed on any sampling gear, including gloves and air hoses (which were dragged along the seafloor). A total of 29 sediment samples were collected from several locations (Section 2.3.2).

2.3.2 Subtidal Sediment Sampling

Initial subtidal sediment sampling was conducted along both the western and eastern shores of the Bay in May 2003. Samples were collected 190 to 2,600 ft offshore in 2 to 16 ft of water with a Petit Ponar Grab Sampler. The total and individual Polycyclic Aromatic Hydrocarbon (PAH) concentrations in all five samples were at least an order of magnitude below available screening benchmarks for marine sediments (ERLs[4]). These subtidal sediment data are provided in the Pre-Assessment Data Report (MA EOEA et al. 2004.)

During the underwater dive surveys in July and August 2003, 29 sediment samples were collected. Four of the 29 samples were not analyzed because they consisted largely of rock. Total PAH concentrations in the samples analyzed ranged from less than 0.1 ppm to 2.0 ppm and were below federal benchmarks for protection of aquatic life. In addition, all samples were below federal benchmarks for individual PAHs except one analyte in one sample (acenaphthene in sample 2N). Geochemical evaluation of this sample and comparison to B-120 source oil indicates that the B-120 is not the potential PAH source based on the overall PAH fingerprint and relative weathering behavior of individual PAHs.

2.3.3 Water Column Sampling

Water column sampling was initiated within 48 hours of the spill. A total of 51 water column samples were collected on five occasions from April 29 through May 12, 2003. Samples were

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[4] *Effects Range - Low (ERL) (Buchman 1999).*

collected at nine stations in the spill area and two reference stations.[5] Sample locations were established offshore of oiled shorelines, and under and near surface oil slicks or tar mats in open water. GPS coordinates were recorded for each sample location and subsequent samples were collected at the same approximate sampling locations for consistency. Total PAH detected in the water samples were below 1 ppb with one exception, which was the sample collected within 48 hours of the spill near Barneys Joy (where the PAH concentration was 2.7 ppb)[6]. Total PAH and individual PAH analytes for all samples were below available screening benchmarks for the protection of aquatic life in marine water (LOELs)[7]. The water column data were used to calibrate the aquatic toxicity models and are presented in the Pre-Assessment Data Package (MAEOEA et al. 2004).

2.4 MODELING

Aquatic toxicity modeling was performed to produce estimates of water column concentrations of dissolved monocyclic and polycyclic aromatic hydrocarbons (aromatics) resulting from the spill. These concentration estimates were used to evaluate the potential for acute toxicity to aquatic biota in the subtidal waters affected by the spill.

In a cooperative process, the Trustees and the RP representatives agreed upon a set of input parameters and conditions to be used in the modeling. The Trustees used the Spill Impact Model Analysis Package (SIMAP) model and the RP used the Chemical/Oil Spill Impact Module (COSIM) model to convert these inputs into estimates of dissolved PAH concentrations through space and time.

Consensus data sets included the models' spatial domain and grid, bathymetry, water and air temperatures, tidal and other currents, total suspended solids, neat oil chemistry and winds. The modelers also agreed to either point estimates or ranges for the horizontal dispersion coefficient and wind drift angle. Finally, the modeling group agreed to investigate a range of potential release scenarios, including volumes up to and including 98,000 gallons, the upper range estimated by the U.S. Coast Guard and others. Within each potential release scenario the volume released, location of release, trajectory of the leaking barge, and release rate were varied. After reaching agreement with respect to the use of these conditions, the models were run separately to generate water column concentrations of dissolved aromatics over three-dimensional space and time. The oil mass was also partitioned into several phases including surface water slick, air (evaporation), shoreline, dissolved aromatics, and submerged oil droplets.

Using the results from both models, the modelers concluded that for all scenarios, the concentrations of dissolved aromatics were too low and the durations of exposure were too short to cause significant injury to water column biota in the open subtidal areas of Buzzards Bay and Rhode Island Sound.

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[5] *Reference locations were east of the Elizabeth Islands and were established based on observations of no oiling and prevailing wind direction since the time of the spill.*

[6] *Based on the relative PAH concentrations in this sample, it is likely that the sample contained oil droplets rather than only dissolved PAHs.*

[7] *EPA Ambient Water Quality Criteria Maximum Concentrations (CMCs) for marine water. For PAHs these are Lowest Observed Effect Level (Buchman 1999).*

3.0 LOBSTER LIFE CYCLE

The American lobster is a large and prominent member of the decapod crustacean community in the northwestern Atlantic Ocean. Lobsters inhabit the coastal and oceanic waters of the Atlantic from Labrador, Canada, south to North Carolina. It has a complex life cycle with many lifestages and habitats. Multiple terms and classification schemes have been proposed by researchers to describe the different developmental phases based upon: (1) the recognition of pronounced morphological, physiological, and behavioral changes accompanying the metamorphic molt into the fourth stage; (2) acknowledgement of the behavioral differences occurring within the early stages of benthic existence; and (3) consideration of the impact of reproductive maturation on lobster movement and social interaction (Lawton and Lavalli 1995). For example, one or more terms such as early benthic phase (EBP), adolescent phase, juvenile, shelter-restricted juvenile, emergent juvenile, and more have been used to describe lobsters in the 5 to 40 millimeter (mm) (0.2 to 1.6 inches [in]) carapace length (CL) size range[8]. For the purpose of this report, we are generally following the terminology and classification used by Wahle and Steneck (1991). Larvae are lobsters in molt stages I, II, and III and post-larvae are stage IV lobsters. Early benthic phase lobsters are small, cryptic, juvenile lobsters typically found in shelter-providing habitats. The size of these EBP lobsters range from 5 mm (0.2 in) CL to between 20 to 40 mm (0.8 to 1.6 in). The larger, inshore, more conspicuous pre-reproductive lobsters are termed adolescent phase lobsters, and reproductive phase lobsters (adult lobsters) are sexually mature. The size at sexual maturity is dependent upon water temperatures and can range from 65 to 110 mm (2.6 to 4.3 in) CL for females (Wahle and Steneck 1991). Consistent with Wahle and Steneck (1991), we use 40 mm (1.6 in) as our upper size for EBP.

This section discusses these lifestages and habitat requirements. For the purposes of this report, the life stages are combined into three groups based on similarities in habitat typically used, as this defines the degree and type of oil they could potentially have been exposed to. These three groups are:

- adults, adolescents, and eggs – adult and adolescent lobsters typically use benthic habitats within a wide range of depths and substrate types; this grouping includes the eggs since fertilized eggs are carried on the underside of the females lobsters' abdomens until hatching (addressed in Section 3.1);
- larval and post-larval stages – these life stages are present seasonally near the water surface (addressed in Section 3.2); and
- the early benthic phase (EBP) lobsters – these life stages are benthic but appear to inhabit shallower water and more restricted habitats than the adolescent and adult lobsters (addressed in Section 3.3).

3.1 ADULT AND ADOLESCENT LOBSTERS AND EGGS

This group includes all lobsters greater than 40 mm (1.6 in) in CL without regard to sexual maturity or legal size. As lobsters grow in size beyond 40 mm (1.6 in) CL, predation pressures decrease, their movements outside shelters increase, and the types of habitats they occupy are

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[8] *See Figure 1 in Lawton and Lavalli (1995) for a description of alternate classification schemes for lobster history phases.*

more varied. Adolescents are found in nearshore areas, forage nocturnally up to 300 m (984 ft), and usually exhibit annual movements of a few kilometers (Cooper et al. 1975; Krouse 1980a, 1981; Munro & Therriault 1983; Ennis 1984; Campbell and Stasko 1985, 1986). Adults are most commonly found in waters up to approximately 50 m (164 ft) (Pringle and Burke 1993). However, they are fished to depths of 700 m (2,297 ft) on the edge of the continental shelf (Cooper and Uzmann 1971) although most offshore lobsters are found in water 250 m (820 ft) or less (Cooper 2006). Adults exhibit a wider range of movement patterns than adolescents including nomadism, migration, and homing. Migration patterns appear to differ somewhat between inshore and offshore populations. The movements of inshore lobsters appear to be relatively local with only small percentage of the population migrating to deeper waters or offshore canyons (Fogarty et al. 1980; Cobb and Wang 1985; Miller et al. 1989; Stasko 1980; Krouse 1980b). In the Gulf of Maine, lobsters engage in small-scale movements from shallow water into deeper water, apparently in response to strong winds and turbulence rather than the seasonal thermal regime (Cooper et al. 1975b). A larger proportion of offshore lobsters appear to undertake well defined migratory movements towards shallower water in the spring and summer (Cooper and Uzmann 1971; Uzmann et al. 1977), complemented by an offshore migration in the fall and winter. Adolescent and adult lobsters are found on a variety of habitats (Cooper and Uzmann 1980). Inshore populations are found on mud, cobble, bedrock, peat reefs, eelgrass beds, and (in certain locations) within sandy depressions (Thomas 1968; Cooper 1970; Cobb 1971; Cooper et al. 1975; Hudon 1987; Able et al. 1988; Heck et al. 1989; Wahle and Stenek 1991; Lawton and Robichaud 1992). Offshore populations are found on similar substrates, as well as on clay, which makes up much of the outer continental shelf (Cooper and Uzmann 1980).

Adult lobsters typically molt (shed the outer body shell) once or twice a year. This can be dependent upon the ambient water temperature. Colder waters can extend the time between molts, while warmer waters can increase the frequency of the molting process (Romanowsky 2000). Because lobster growth is dependent upon molting, lobsters inhabiting warmer waters will reach reproductive maturity at smaller size, as compared to those in cold waters. A female lobster can mate only after it has just molted and may go two years between molts when they are carrying eggs, whereas a male can mate immediately before or after molting (Romanowsky 2000). In southern New England (which includes Buzzards Bay) sexual maturity usually occurs when the lobsters are just below the minimum legal size for the commercial fishery.[9] After a sexually mature female molts and mates (mating must be accomplished while females have a soft shell and typically occurs in the summer months in southern New England), the new shell hardens, and about 11 to 13 months after mating, the female places (extrudes) the fertilized eggs on her abdomen and cements them there. The number of eggs in each clutch ranges from about 3,000 to 115,000 eggs (McKenzie and Moring 1985). The fertilized (extruded) eggs develop and remain attached to the female for approximately 9 to 11 months. During that time, the young lobsters molt and grow inside the eggs. Female lobsters are long-lived, can carry thousands of eggs on their abdomens, and have the potential to reproduce many times in their lives. However, since most female lobsters in southern New England mature just before the minimum legal size for harvest, most will reproduce only one time before they become vulnerable to harvest by the commercial fishery. The proportion of landings that are new recruits (i.e., just molted into legal size) is nearly 98% from the South of Cape Cod to Long Island Sound area (Idoine 2004).

[9] *In Lobster Management Area 2, which includes Buzzards Bay, the minimum legal size is 3-3/8 in (86 mm) CL.*

3.2 Larval and Post-Larval Lobsters

The presence of Stage I larvae in surface waters indicates that hatching occurs over a broad expanse of offshore and coastal water. The time of onset of hatching and the duration varies from year to year and over the geographic range of the lobster. Overall, hatching takes place from May through much of September. Within this time period, the hatching season tends to begin earlier and continue somewhat longer in the southern part of the lobster's range. In any one area, both the start and duration of the season can vary between years by several weeks (Ennis 1995). Water temperature is a key factor that determines the timing of hatching (Cobb and Wahle 1994; MACSIS 1996); first larval appearance coincides with a narrow range of water temperature (Ennis 1995; Cobb and Wahle 1994). As discussed in detail below, the literature indicates that this threshold surface water temperature is 12 to 15°C (54 to 59°F), and in southern New England, this typically occurs in mid-late May.

Collings et al. (1981 and 1983) studied lobster larvae in Buzzards Bay, the Cape Cod Canal, and Cape Cod Bay, including three years of field studies from 1976 through 1978. They reported that in Buzzards Bay the minimum surface water temperature when larvae were present was 14.0°C (57°F), that hatching commenced during the third week in May, and that the earliest appearance of Stage I lobster larvae (the larvae that are released from the eggs during hatching) was on May 20. During the period when Stage I larvae were collected, surface water temperatures ranged from 14.0 to 25°C (57 to 77°F), and bottom temperatures ranged from 10.0° to 24.5°C (50 to 76°F). They also reported that the peak of Stage I larvae, and therefore the peak of hatching, occurred in mid-June, with a smaller peak observed in the last week of May that is apparently due to the earlier hatching of eggs extruded during the prior summer in comparison to eggs extruded in the prior fall. The authors also stated that this smaller peak in late May has been reported by other authors for other areas in New England. Overall, the hatching season in the Bay extended over an 8-week period (Collings et al. 1981).

The Collings et al. (1981 and 1983) data on hatching periods within the Bay are consistent with findings of other studies conducted in Massachusetts and southern New England (which includes Buzzards Bay). McKenzie and Moring (1985) reported that in Massachusetts, hatching usually begins in late or mid-May when water temperatures reach 15°C (59°F). Cobb and Wahle (1994) reported that hatching occurs in spring and early summer and is primarily controlled by temperature, with hatching generally occurring in southern New England when bottom water temperatures are in the range of 11 to 13°C (52 to 55°F). Cobb and Wahle (1994) also indicated that in southern New England the peak of Stage I larvae (i.e., hatching) occurs in about mid-June. Ennis (1995) reported that in the coastal waters of southern New England, Stage I larvae were present in late May through mid-August, with peak hatching from late June through early July. MACSIS (1996) reported that in Massachusetts, eggs typically begin hatching in mid or late May when water temperatures are about 15°C (59°F) and peak hatching occurs in June and early July when water temperatures reach 20°C (68°F.) Larval densities in Buzzards Bay peaked when the surface water temperature was about 19°C (66°F) and the bottom water temperature was about 17°C (62°F). Clancy (2005) stated that in southern New England, small numbers of post-larvae can be found in early June, implying that in some years, a small amount of hatching may occur as early as late April or early May.

Because the timing of hatching and larval development is strongly dependent on water temperature, the lower-than-normal temperatures in the Bay during the winter of 2002 – 2003 and in the early spring of 2003 likely delayed both hatching and larval development in the Bay in

2003. The lower surface water temperature limit associated with the presence of lobster larvae in Buzzards Bay is 14°C (57°F). The 5-year average surface water temperatures (1998 through 2002) for the Bay were 7.5°C (46°F) for April, 11.2°C (52°F) for May, and 15.9°C (61°F) for June. In 2003, the averages for the same months were approximately 2°C colder.[10] On the day of the spill, the average surface water temperature in the Bay was approximately 6.6°C (44°F), and did not reach 14°C (57°F) until mid-June. Water temperature data was obtained from NOAA Buoy Station BUZM3.

In summary, based on the above information, the timing and "density" of hatching in the Bay can be visualized as a bell curve. Under normal temperature regimes, a very small percentage, if any, of the total hatching may occur as early as late April or early May. Typically, hatching commences in late May and increases significantly through June, with a large peak generally occurring in the middle of June. After that, smaller numbers hatch, with the number of Stage I larvae decreasing through about the middle of August when very few are present in the Bay. However, during years when the temperature is lower than normal, such as 2003, it would be expected that the bell curve would shift to the right, with the degree of shift dependent upon the water temperatures. In 2003, the onset of hatching was likely delayed until at least late May and possibly as late as mid-June when the surface water temperatures reached 14°C (57°F). Therefore, we would expect that the first peak of hatching likely occurred no sooner than early June, and the primary peak was likely in late June or possibly early July. This delay in hatching was observed in the data collected for the lobster notching program conducted as compensation for the North Cape Oil Spill (Ocean Technology Foundation 2005).

After hatching, lobster larvae develop through three stages. At the time of release from the female, the larvae are considered at Stage I. The Stage I larvae swim to the surface and become part of the plankton. Stages II and III follow rapidly after the initial stage as a result of three molts; Stage III is typically reached two to three weeks after hatching under average environmental conditions. However, as described below, development from Stage I through the end of Stage III (i.e., to the post-larval stage) may take up to 35 days under normal environmental conditions. Larval Stages II and III are also present primarily at the surface, and although these larvae have some control over horizontal movement, they are usually unable to overcome the currents that carry them along with other components of the plankton. The Stage III larvae are able to migrate vertically, but typically only within the top 2 to 3 m (6.6 to 9.8 ft) of the water column.

The size of post-larval lobsters typically ranges from about 3 to 5 mm (0.1 to 0.2 in) CL. Generally, the post-larval stage is reached about 25 to 35 days after hatching, although colder temperatures will increase the time required to reach the post-larval stage. Based on this development time and the hatching times discussed above, and assuming a normal temperature regime, a very small number of post-larval lobsters, if any, may be present in southern New England waters, including those of the Bay, as early as June. However, the population would generally peak in July, with a small number of post-larvae present through at least August. This timing is consistent with the data collected by Collings et al. (1981 and 1983); they collected some Stage IV larvae (post-larval stage) in the Bay as early as the first week of June and noted a peak abundance in July and a continuing presence of Stage IV larvae (terminology used in Collings et al. 1983) into September.

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[10] *5.0°C (41°F) in April, 9.7°C (50°F) in May, and 13.6°C (57°F) in June*

The post-larval lobsters swim vertically from the surface to the bottom to search for suitable bottom habitat and therefore may be distributed throughout the water column and on the bottom. They may make several trips between the surface and the bottom before finding acceptable shelter.

As with most aquatic organisms, of the thousands of eggs produced by any one female lobster, very few reach the adult stage. Natural mortality rates of all lifestages are highly uncertain and variable on an annual basis, but larval mortality rates are estimated to be very high. As part of the restoration efforts for the 1996 North Cape oil spill off the coast of Rhode Island, Gibson et al. (1997) developed an empirical relationship of instantaneous annual mortality rates and body size for larval lobsters and benthic lobsters up to 82.6 mm (3.3 in) based on survival rates in the literature. This relationship results in a total mortality of 99.6 percent between hatching and 7 mm (0.3 in) CL (settlement). Field data cited in the same paper indicated a total larval mortality of 93.9 percent.

3.3 EARLY BENTHIC PHASE LOBSTERS

When post-larval lobsters have settled on the bottom they begin the benthic portion of their life cycle. As discussed in Section 3.0, the early benthic phase includes lobsters from 5 to 40 mm (0.2 to 1.6 in) CL. Depending upon growth rates, which vary by region and individual, lobsters within this size class would represent two or three age classes (Clancy 2006).

Early benthic phase lobsters are vulnerable to predation, physical disturbance (e.g., currents) and physiological stress (Wahle and Steneck 1991) and are dependent upon habitats that provide shelter. Densities are highest on cobble substrates (Wahle and Steneck 1991), rocks on sand (Hudon 1987), and peat reefs (Able et al. 1988). They have also been collected from eelgrass beds, cobble/boulder substrates (Heck et al. 1989; Wahle and Steneck 1991), and mud flats (they are adept burrowers) (MacKay 1929; Cooper and Uzmann 1980), although densities are typically lower. In areas around Cape Cod, vegetation root mats have been shown to harbor newly settled lobsters (Steneck et al. 1998). Early benthic phase lobsters are rarely found on featureless soft or bedrock substrates, but if bedrock is colonized by kelp-mussel beds, then densities of these juveniles are nearly the same as in cobble (Wahle and Steneck 1991). In addition, in areas where human refuse has been discarded (coves, harbors, mooring areas, etc.) the refuse within a sand/mud substrate can provide a firm matrix for tunnel construction; Cooper (2006) has found high densities of EBP lobster in areas such as this in Boothbay, Maine.

EBP lobsters typically occupy shallow subtidal waters (Lawton and Lavalli 1995). The presence of EBP lobsters has been documented in waters ranging in depth from just below Mean Low Water (MLW) to 10 m (32.8 ft), however, in good substrate, EBP lobsters can be found in large densities down to at least 20 m (66 ft) (Cooper 2006). Palma et al. (1998) reported that the highest settlement densities for lobsters is in water between about 5 and 10 m deep (16.4 to 32.8 ft), and Lawton and Lavalli (1995) reported that many authors found that the greatest densities of juveniles in the "shelter-restricted phase" (essentially the EBP as used in this report) occur at depths between 2 and 10 m (6.6 and 32.8 ft). The MA DMF annual survey of the density of EBP lobsters in Buzzards Bay (MA DMF 2004) is conducted within this depth zone; sampling in the MA DMF survey is conducted at up to 5 locations at water depths of about 12 ft at most sampling sites (Glenn 2004). A report of a study conducted in Maine is the only known documentation of the presence of some EBP in habitats less than 2 m (6.6 ft) below MLW (Cowan 1999). That report stated that the densities of "juvenile" lobsters appeared to be higher at depths of 0.4 to 5 m (1.3 to 16.4 ft) below MLW than the densities at 10 m (32.8 ft) below MLW. There is no evidence that EBP or lobsters are present above the mean low water line (intertidal zone).

EBP lobsters remain in their burrows with very limited movement outside their shelters during this phase, especially in lobsters less than 25 mm (1.0 in) CL. The smallest lobsters rarely leave their burrows; they use both raptorial and suspension feeding modes which may enable them to remain in their burrow for an extended period of time (Lavalli and Barshaw 1989). Lawton and Lavalli (1995) state that lobsters 15 to 25 mm (0.6 to 1.0 inch) CL, exhibit only limited movement outside of their shelters, but that EBP lobsters 25 to 40 mm (1.0 to 1.6 in) CL will forage further from their burrows. In contrast, Cooper (2006) rarely encountered lobsters less than 45 to 50 mm (1.8 to 2.0 in) CL foraging outside their shelters during nighttime diving across prime lobster habitat.

In summary, the majority of EBP lobsters in Buzzards Bay are likely in cobble and rock substrates at depths ranging from 2 to 20 m (6.6 to 66 ft) deep. Lobsters may also be present in other habitats at lower densities and shallower water below MLW. The young lobsters remain either in or very near their original burrows or shelters until they reach a carapace length greater than approximately 25 mm (1.0 inch), at which point they will exhibit limited movement outside their shelter in search for food; EBP lobsters would not be foraging widely.

The natural mortality rate of EBP lobsters is size dependent with mortality deceasing as lobsters increase in size (Caddy 1986). There are few estimates of natural mortality rates in the literature for lobsters in this size range and natural mortality rates would be expected to be highly variable from year to year. However, in general, natural mortality rates are thought to be quite high for EBP lobsters, especially in the smaller sizes classes. As discussed in Section 3.2, one estimate was developed as part of the restoration efforts for the 1996 North Cape oil spill off the coast of Rhode Island. Gibson et al. (1997) developed an empirical relationship of instantaneous annual mortality rates and body size for lobsters from larval stage through 82.6 mm (3.3 in) based on survival rates in the literature. This relationship results in a total mortality of 99.2 percent from 7 to 42 mm (0.3 to 1.7 in) CL (McCay et al. 2003).

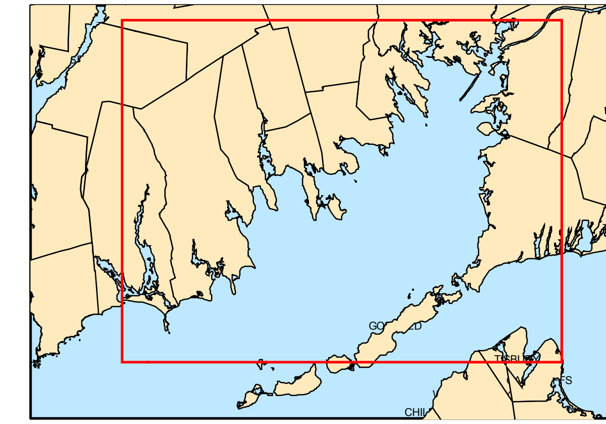
4.0 POTENTIAL LOBSTER EXPOSURE AND INJURY

The potential for exposure to oil from the B-120 for each life stage of the lobster population of Buzzards Bay are addressed in the following sections. These evaluations are based on comparisons of the expected presence and abundance of the life stages (as described in Section 3.0) to the presence and amount of oil in the relevant habitat for each life stage (as described in Section 2.0), taking into account specific spill conditions. Potential exposure of larvae was determined by evaluating data regarding the presence of larvae at the time of the spill and the amount and duration of surface oil and dissolved oil in the water column throughout the Bay. The potential exposure of adult, adolescent and EBP lobsters was determined by evaluating the amount (percentage) of potential habitat and lobsters in the Bay that were in the "subtidal zone of concern."

This "subtidal zone of concern" is the subtidal area identified by the Aquatic Technical Working Group as potentially impacted by oil. It is defined as the subtidal zone from 0 to 3 ft below MLW along heavily and moderately oiled shorelines plus an area off Barney's Joy which extended 2,500 ft from shore and to depths exceeding 24 ft (Figure 3). These two areas are included in the zone of concern because they have either assumed or known oil in the water column or on the substrate. The Aquatic Technical Working Group (TWG) for the Bouchard B-120 spill has agreed that the dynamic, very shallow nearshore areas directly adjacent to shorelines may have experienced higher concentrations of dissolved oil fractions and entrained oil droplets than subtidal areas at greater depths due to the relatively small volume of water present, and in some areas, the relatively greater turbulence of the water. In addition, tarballs (formed by the addition of sand to the stranded oil) washed up on some shorelines; in these locations, the tarballs would likely also be present along the bottom in shallow areas nearest to the shoreline. On shorelines with light, very light and trace oil, the degree of injury in the subtidal area would decrease rapidly as compared with shoreline segments characterized by heavier oiling. Therefore, the Aquatic TWG agreed that the greatest potential for the presence oil in shallow nearshore areas was in areas adjacent to heavily and moderately oiled shorelines. The deeper area offshore of Barneys Joy was included in the subtidal zone of concern because of the relatively small amounts of oil found on the bottom in this area during the submerged oil surveys (see Section 2.3.1). In this area, minor amounts of oil (indicative of random tarballs rather than pooled oil) were documented on less than half of the chain drags and lobster pots in this particular area. Sampling for submerged oil in other areas of the Bay (dive surveys, chain drags at the grounding site, and lobster pot surveys) indicated that the submerged oil found at Barneys Joy was limited to that area. It appears the submerged oil found offshore of Barneys Joy was unique. The oil there likely originated from the oil that stranded on the shoreline; Barneys Joy experienced some of the heaviest shoreline oiling, is an exposed shoreline, and has sandy beaches, all of which facilitates formation and movement of tarballs into nearshore subtidal habitats.

4.1 ADULT AND ADOLESCENT LOBSTERS AND EGGS

Adult and adolescent lobsters (lobsters greater than 40 mm CL) in coastal areas are commonly found in subtidal areas up to depths of 50 m (164 ft) on a wide variety of substrates including cobble, bedrock, and mud substrates as well as eelgrass beds. These lobsters are not highly shelter dependent, would be expected to be moving across areas of the bottom during nocturnal



Legend

Subtidal*

*Depth contour lines are 0-6 ft, however, the zone of concern is 0-3 ft with the exception of Barneys Joy which extends to 2500 ft from shore.

0 2.5 5
Miles

N

E N T R I X

Figure 3
Schematic of the
Subtidal Zone of Concern
Bouchard B No. 120 Oil Spill
Buzzards Bay, MA

Map Document: (J:\Arcview\7079607 - BuzzardsBaySpill\Intertidal Zone\Figure 3 Subtidal 9-17-06.mxd) foraging. Eggs are carried on the abdomen of the sexually mature females until hatching. Although adults, adolescents, and female adults with eggs attached would have been present in the Bay at the time of the spill, it is likely that the population in the Bay was relatively low, due to the overall population decline of lobsters throughout southern New England described in Section 1.2.

For these lobster phases to have been exposed to oil from the B-120 spill, oil would have had to have been present on the subtidal sediment surface either as liquid oil, tarballs, or patties, or present in the water column near the bottom as dissolved components or emulsified droplets. Based on the known depth and habitat distribution of adolescent and adult lobsters and the time of year, it is possible that these lobsters could have been exposed to oil from the Bouchard B-120 spill.

The primary route of exposure to adult and adolescent lobsters was likely through physical contact with oil on the bottom; it is unlikely that adult and adolescent lobsters were exposed to dissolved oil at concentrations that would be high enough to cause injury. Since the No. 6 oil that was spilled did not have a large soluble component, high concentrations of dissolved oil (PAHs) would not have been present in the water column. Furthermore, since the spill was a surface spill and the oil did not sink upon contact with the water, concentrations of soluble components of the oil would have been much lower at the bottom than at the surface. Field data and aquatic toxicity modeling support this hypothesis. Measured concentrations of total dissolved PAHs within the top 12 in of the water surface at locations across the Bay were less than 1 ppb during the first sampling event **(**approximately 48 hours after the spill) and decreased during the following sampling events (through May 12). Concentrations in all field samples were below available federal benchmarks for protection of aquatic life. Based on the water column concentrations estimated by the aquatic toxicity models (discussed in Section 2.4), the concentrations of dissolved aromatics were too low and the durations of exposure were too short to cause significant injury to water column biota, including lobsters, in the open subtidal areas of Buzzards Bay and Rhode Island Sound.

Based on the known and assumed locations of oil on the bottom, and adult and adolescent lobster distribution, there is potential for exposure of these lifestages to subtidal oil, although the areas where exposure is likely are relatively small compared to the available habitat. As discussed in Section 4.0, the Aquatic TWG has assumed that oil in the form of droplets or tarballs would be present in the very shallow areas nearest to the heavily and moderately oiled shorelines. In addition, submerged oil surveys were found relatively small amounts of oil offshore of Barneys Joy in water up to approximately 12 to 30 ft deep. These two areas (shallow nearshore waters and deeper water off Barneys Joy) included in the subtidal zone of concern are areas in which adult and adolescent lobsters could have been present during the spill, particularly the deeper waters offshore of Barneys Joy. To quantify the potential magnitude of exposure to adult and adolescent lobsters, we estimated the percentage of potential habitat that is in the subtidal zone of concern; assuming lobsters are evenly distributed throughout the potential habitat, this provides a "ballpark" estimate of the potential for exposure of these lifestages to the oil. For this analysis we assume the entire Bay is habitat for adult and adolescent lobsters due to their wide depth and habitat requirements. Buzzards Bay is approximately 210,903 acres. There are approximately 1,388 acres of adult and adolescent habitat in the "subtidal zone of concern" (areas 0 to 3 ft below MLW that were adjacent to heavily and moderately oiled shorelines and 2500 ft offshore of the heavily oiled portion of Barneys Joy). Therefore, approximately 0.7 percent ([1,388 acres

/ 210,903 acres] x 100) of the potential habitat for adult and adolescent lobsters in the Bay is in the subtidal zone of concern. If it is assumed that adult and adolescent lobsters were evenly distributed throughout the Bay then less than 1 percent of the population would have been present in the subtidal zone of concern and potentially exposed to oil. Since it is unlikely that lobsters are evenly distributed, and these lobsters are mobile and may move in and out of the "area of concern" this number is not absolute and might be higher or lower depending upon the interaction between the highest densities of lobsters and the location of submerged oil; however it does indicate the level of magnitude of exposure that might be expected. Further, this number only estimates the proportion of adult and adolescent lobsters potentially exposed; it does not reflect the proportion of lobsters that actually encountered the oil and/or were injured in some way by the oil (e.g., oiling of the legs or carapace of the lobster may not cause injury whereas oiling on the mouthparts or ingestion of small pieces of oil may cause injury). It would be expected that the proportion of lobsters injured would be lower than the proportion potentially exposed. The qualitative and quantitative analysis of potential exposure and injury discussed here is consistent with the lack of conspicuous visual evidence of lobster mortality from the spill (see Section 2.2), continued commercial harvesting of lobsters in 2003 and 2004 at levels typical for the Bay in recent years (relative to harvesting in non-impacted areas of the Massachusetts portion of the Southern New England stock), and lack of oil on harvested lobsters in 2003.

In summary, it is unlikely that adult and adolescent lobsters and the eggs on sexually mature females were exposed to a significant amount of oil from the B-120 spill for several reasons: (1) based on field sampling and modeling, concentrations of the soluble components of the oil were estimated to be below the level that would result in injury to biota; (2) the estimated proportion of lobsters in the Bay that would have been exposed to submerged oil on the substrate surface is small; (3) there was no documented evidence of a major loss of lobsters at these life stages; (4) lobsters collected in commercial lobster pots in the Bay in the late spring and early summer were not oiled; and (5) the 2003 and 2004 commercial lobster harvest in the Bay was comparable to recent, pre-spill years. As a result, it is also unlikely that there was an adverse effect on this segment of the population due to the spill.

4.2 LARVAL AND POST-LARVAL LOBSTERS

As described in Section 3.2, under normal temperature regimes, hatching normally begins in mid-May when surface water temperatures reach approximately 14°C (57°F), and peak around the middle of June. A very small percentage, if any, of the total hatching may occur as early as late April or early May. However, due to colder than normal water temperatures in the winter of 2002 – 2003 and spring of 2003, the onset of hatching was likely delayed until at least late May and possibly as late as mid-June when surface water temperatures reached 14°C (57°F), and the peak would have been delayed until late June or possibly early July. As a result, it is unlikely that there were any larvae in the Bay at the time of, or for several weeks after the spill.

Although it is not likely that larvae were present in the Bay at the time of or shortly after the spill, if a small number were present due to an unexpected early onset of hatching, there would have been two potential pathways for exposure and injury for the individuals present. After hatching, Stage I larvae swim vertically towards the surface of the water and remain near the surface until the post-larval stage. As a result, if larvae were in the Bay at the time of the spill or shortly after the spill, it is possible that they could have been impacted by either exposure to dissolved components in the water column or possibly by directly contacting oil on the surface (in such forms as sheen, ribbons, or patties). Neither of these pathways is considered significant for this spill. Modeling conducted jointly by the RP and Trustees indicated that the magnitude and duration of dissolved concentrations of aromatics were too low even immediately after the spill to cause injury to aquatic organisms, including larval life stages. As described in Sections 2.1 and 2.2, oil was only on the surface of the Bay for a very short period of time, less than one week. The initial sheen on the first day covered approximately 16 percent of the Bay. Within 24 hours, the slick broke into discontinuous sheens, ribbons, and patties, and nearly all of the oil had been deposited on the shoreline within a few days.

In summary, it is unlikely that more than a few lobster larvae (and no post-larvae) in 2003 were exposed to the oil because those life stages and surface oil were likely not present at the same time. Specifically: (1) even under normal temperature regimes; the onset of hatching likely would not have begun in the Bay until at least two to three weeks after the spill; and at most, only a very small amount of hatching would have occurred at that time; (2) the lower-than-usual water temperatures in 2003 likely delayed the onset of hatching until at least four weeks after the spill; and (3) surface oil (such as sheens, slick, and patties) that would injure larvae upon contact was no longer present on the vast majority of the Bay within one week after the spill, and was therefore no longer present when the larvae were present. In addition, water column concentrations were not high enough for a long enough duration to cause injury to any larvae that may have been present.

4.3 EARLY BENTHIC PHASE LOBSTERS

Based on the life history information provided in Section 3.3, EBP lobsters were present in the Bay at the time of the spill and were potentially exposed to the oil. EBP lobsters typically occupy shallow waters; sampling for these lobsters is usually conducted in water ranging in depth from just below MLW to 10 m (32.8 ft), however, in good substrate, EBP lobsters can be found in large densities down to at least 20 m (66 ft). EBP lobster densities are highest on substrates providing good shelter such as cobble, rock on sand, and peat reefs, although they can be found in lower densities in other habitats such as mud substrate and eelgrass beds.

Any EBP lobsters present in the subtidal zone of concern could have experienced mortality or sublethal effects from: (1) physical fouling by oil tarballs or oil droplets (e.g., due to smothering or interference with filter feeding); and/or (2) toxicity from dissolved fractions of the oil. To quantify the potential magnitude of exposure and injury to EBP lobsters, we estimated the percentage of potential EBP lobster habitat that could be in the subtidal zone of concern.

There are approximately 120,164 acres in the Bay that are 20 m (66 ft) deep or less and are therefore considered potential EBP lobster habitat (regardless of substrate type)[11]. Of this area, approximately 1,388 acres are located in the subtidal zone of concern. Therefore, approximately 1.2 percent ([1,388 acres / 120,164 acres] x 100) of the potential habitat for EBP and juvenile lobsters in the Bay is in the subtidal zone of concern. If it is assumed that EBP lobsters were evenly distributed within this 0 to 20 m (66 m) zone, then approximately 1.2 percent of the EBP population in the Bay would have been present in the subtidal zone of concern and therefore considered potentially exposed to oil. However, since EBP lobsters are substrate selective, they are not evenly distributed throughout this depth zone and would be expected to be present at higher densities on cobble/rock substrates. Therefore, this estimated proportion of exposed EBP

[11] *This value is actually for 18.2 m, the closest contour line to 20 m in the NOAA bathymetry data.*

lobsters is not absolute and might be higher or lower depending upon how much of the preferred EBP habitat in the Bay is in the subtidal zone of concern. Barneys Joy, where much of the area of the subtidal zone of concern is located, is a high energy area that may be good habitat for EBP lobster, however there are other areas of the Bay that are also believed to be good EBP lobster habitat that are not in the subtidal zone of concern. Further, this number only estimates the proportion of EBP lobsters potentially exposed; it does not reflect the proportion of lobsters that actually encountered the oil and/or were injured in some way by the oil (e.g., oiling of the legs or carapace of the lobster may not cause injury whereas oiling on the mouthparts or ingestion of small pieces of oil may cause injury). It would be expected that the proportion of lobsters injured would be lower than the proportion potentially exposed.

Although the 1.2 percent value is not definitive, it does indicate the level of magnitude of exposure that might be expected. A more precise evaluation of the EBP habitat and number of EBP lobsters exposed to oil could not be calculated without a more detailed evaluation of benthic habitat substrate types and actual densities on different habitat types within the Bay. Further, actual potential losses of EBP lobsters within the exposed area would be difficult to determine in the context of natural mortality and given the uncertainties about the degree of oil in the exposed area, and potential impacts of contact or ingestion of small oil particles or oil-contaminated substrates.

5.0 CONCLUSIONS

Based upon the life history and habitat preferences of the lobster and the spill characteristics, we conclude that there was little exposure and injury to lobster eggs, larvae, adolescents and adults. The potential for exposure of EBP lobsters was higher than the other lifestages, and the uncertainty surrounding the analysis of potential exposure and injury is higher, however, we conclude that the exposure and injury to EBP lobsters was also relatively low.

Lobster larvae and post-larvae are pelagic lifestages and it is unlikely that more than a few were present during the period of time that oil was present on the water surface and as dissolved constituents in the water column, and therefore these populations were not significantly exposed or injured. Early benthic stage, adolescent, and adult lobsters (including adults carrying eggs) were likely present in the Bay during and following the oil spill and some of these lobsters were likely exposed to oil in the water column or on bottom substrate. The exact number and proportion of these lifestages exposed and injured is uncertain and difficult to quantify, particularly for EBP lobster which have more specific substrate and depth preference than adult and adolescent lobsters. However, estimates of the proportion of the habitat in the Bay for these lifestages that was potentially impacted by oil (within the subtidal zone of concern) (0.7 percent for adults and adolescents and 1.2 percent for EBP lobsters) suggest that, although the actual values could be higher or lower, a relatively small proportion of the lobsters in the Bay were exposed to oil. Further, actual potential losses of EBP lobsters within the exposed area would be difficult to determine in the context of natural mortality and given the uncertainties about the degree of oil in the exposed area, and potential impacts of contact or ingestion of small oil particles or oil-contaminated substrates. However, the lack of a conspicuous visible mortality event even at Barneys Joy, which received heavy oiling, is a relatively high energy shoreline, and may have good EBP lobster habitat, supports the conclusion of relatively low injury for EBP, adolescent, and adult lobsters.

Due to the estimated low levels of injury to lobster lifestages due to the oil, and the difficulty in increasing the precision of the estimate of exposure as well as the degree of injury to exposed lobsters, a resource-specific injury assessment is not warranted for lobsters. Instead, the potential injury to lobsters discussed in this report has been incorporated into the overall aquatic injury assessment of the benthic community. This potential injury will be compensated for by implementation of appropriate restoration projects funded by the RP.

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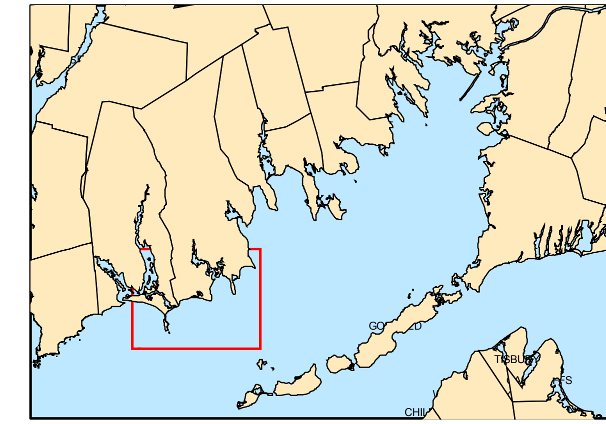
Appendix C
Oiling and Habitat Maps for the Nearshore Areas and the Extended Barneys Joy Area.



Legend

- Intertidal Heavy
- Intertidal Moderate
- Subtidal Heavy
- Subtidal Moderate
- Extended Area at Barney's Joy

Shoreline Habitat Codes

1 - Coarse
2 - Sand
3 - Marsh
4 - Tidal Flat

With the exception of the extended area at Barneys Joy, the subtidal areas depicted here are the 0 - 6 foot MLW polygon provided in the NOAA bathymetry data.

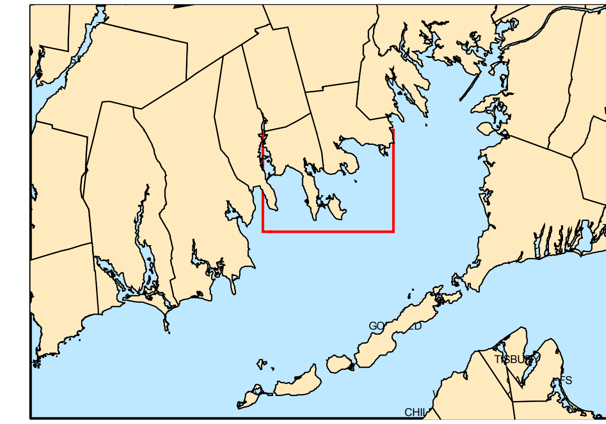
0 0.5 1 Miles

N

E N T R I X

Aquatic Oiling Exposure and Shoreline Habitats
Bouchard B-120 Oil Spill
Buzzards Bay, MA
Page 1

Map Document: (J:\Arcview\7079607 - BuzzardsBaySpill\Aquatic\Intertidal_ESI Codes.mxd)



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- Intertidal Heavy
- Intertidal Moderate
- Subtidal Heavy
- Subtidal Moderate
- Extended Area at Barney's Joy

Shoreline Habitat Codes

1 - Coarse
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With the exception of the extended area at Barneys Joy, the subtidal areas depicted here are the 0 - 6 foot MLW polygon provided in the NOAA bathymetry data.

0 0.5 1 Miles

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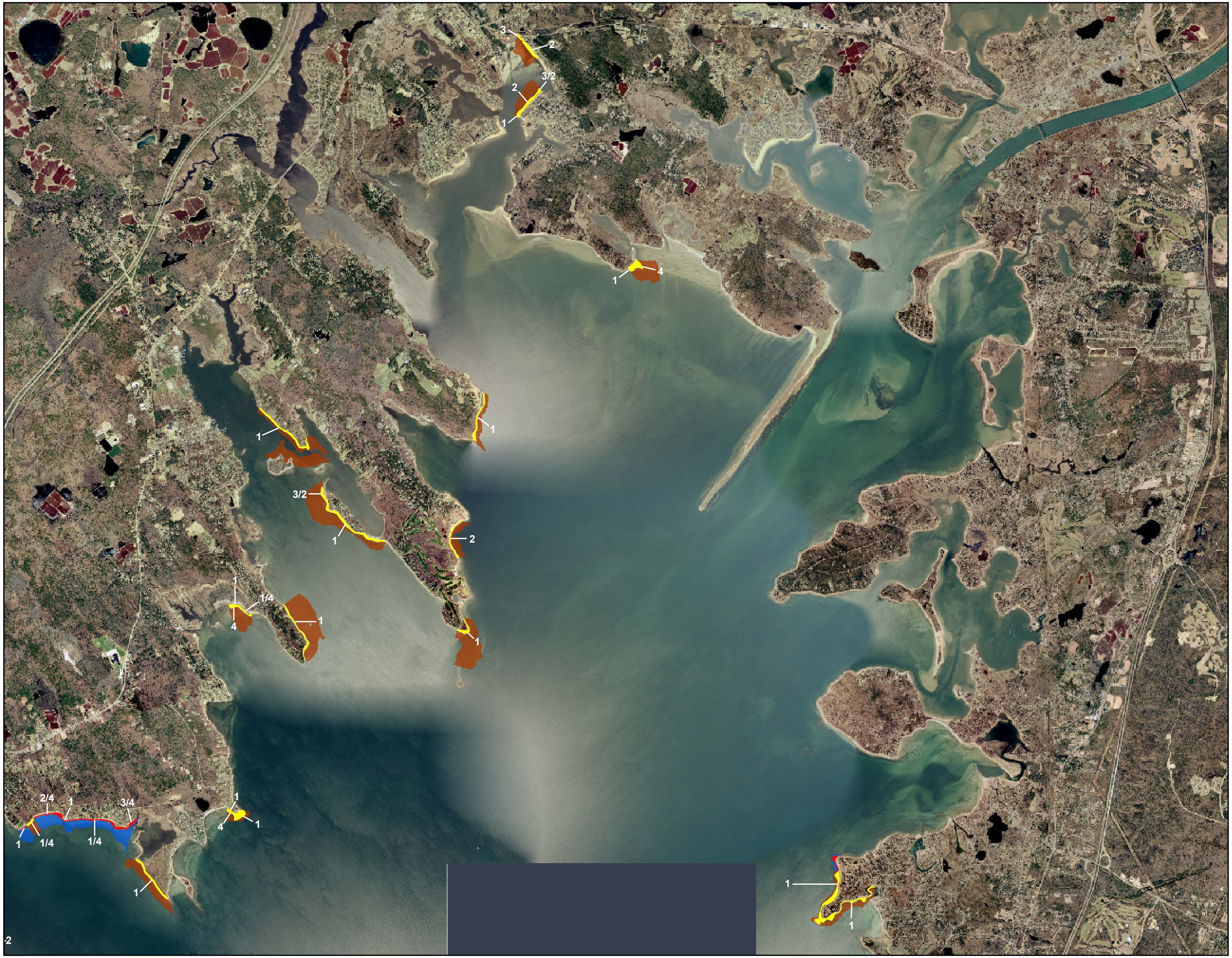
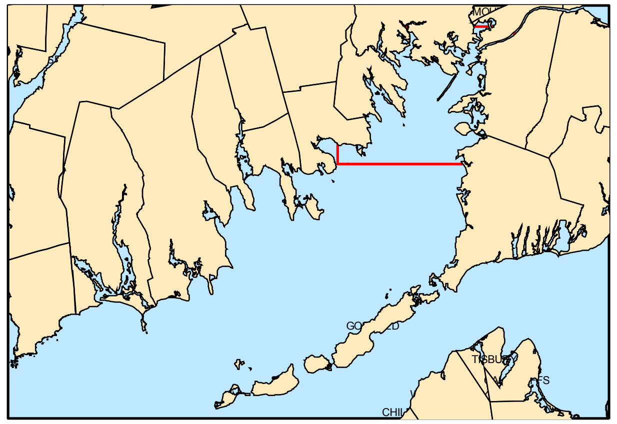
E N T R I X

Aquatic Oiling Exposure and Shoreline Habitats
Bouchard B-120 Oil Spill
Buzzards Bay, MA
Page 2

Map Document: (J:\Arcview\7079607 - BuzzardsBaySpill\Aquatic\Intertidal_ESI Codes.mxd)





Legend

- Intertidal Heavy
- Intertidal Moderate
- Subtidal Heavy
- Subtidal Moderate
- Extended Area at Barney's Joy

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0 0.5 1 Miles

N

E N T R I X

Aquatic Oiling Exposure and Shoreline Habitats
Bouchard B-120 Oil Spill
Buzzards Bay, MA
Page 3

Map Document: (J:\Arcview\7079607 - BuzzardsBaySpill\Aquatic\Intertidal_ESI Codes.mxd)

Appendix D
Habitat Services and Functions

TABLE D-1. Ecological Services and Functions of Salt and Brackish Marsh Habitats.

Ecological Services	Function	Types of Potential Injury
Primary production	Production from vascular plants and phytoplankton forms the base of the primary food web and the detrital food web. Much of the salt marsh vascular plant production is exported to adjacent habitats as detritus.	Loss of above ground or below-ground biomass Changes in plant species composition, richness, diversity, evenness
Habitat for biota	Marshes serve as physical habitat for a variety of organisms including birds, mammals, reptiles (diamond back terrapin), insects, fish and a suite of invertebrates. The type and density of the vegetation is often the primary determinant of which species are served.	Changes in canopy architecture of vegetation Decreased above-ground biomass Changes in species composition, richness, diversity, evenness Decreased use by fish, birds, terrapins, mammals, or other animals.
Food web support	Related to primary productivity but encompasses the entire system including invertebrates that are food for higher trophic levels that may only spend minor amounts of time in the wetland (e.g., dead salt marsh grass→bacteria→crab larvae→mummichog→striped bass→osprey)	Decreased density or biomass of living vegetation, infauna and epifauna Decreased macrophyte or benthic algae detritus Changes in species composition, richness, diversity, or evenness Decreased use by higher trophic levels
Fish and shellfish production	Marsh edge and ponds are important nursery areas for fish and shellfish. Dense shellfish beds provide microhabitat for a diverse assemblage of organisms that contribute to overall system productivity and species composition.	Change in density or biomass Changes in species composition, richness, diversity, or evenness Changes in population demographics or size/age class distributions
Sediment/shore-line stabilization	Marsh vegetation serves to stabilize the soil and prevent erosion during normal tides, wave action or storm events	Increased shoreline erosion Removal of sediment
Water Filtration	The physical removal of particles and nutrients from water flowing through the wetlands.	Decreased water quality – Increase in turbidity
Nutrient removal/transformation	Nutrients can be removed and converted to plant material within the wetland and thereby reduce the occurrence of algal blooms and the resulting anoxic conditions in the bay.	Decreased water quality – Increase in dissolved nutrients
Sediment/toxicant retention/detoxification	Toxicants adhering to sediment particles can be filtered out in the wetland rather than being transported to the bay.. Wetlands encourage redox reactions around plant roots that can detoxify many compounds	Decreased water quality – Increase in pollutant loads
Soil development and biogeochemical cycling	The soil is a living system that converts chemicals from one form to another and supports the growth of higher plants through biogeochemical cycling and the breakdown of detritus.	Changes in soil and pore water nutrient concentrations Changes in soil organic matter content Changes in nitrogen fixation/denitrification rates
Storm Surge Protection	Wetland vegetation can absorb wave energy and reduce the impacts to habitats further inland.	Increase in storm surge height or velocity
Slow runoff from upland	Marsh surface absorbs runoff from upland and vegetation reduces flow rates allowing more runoff to be absorbed	Increase in flood height / decrease in base flow (increase in stream flashiness)

TABLE D-2. Ecological Services and Functions of Coarse Substrate (sand and gravel beaches, gravel beaches, rocky shorelines, seawalls, and riprap habitats).

Ecological Services	Function	Types of Potential Injury
Primary production	Gravel shorelines serve as a substrate for algal colonization that forms the base of some grazing food webs. Phytoplankton in the water column also contribute to primary productivity. Rock ledge or boulders (more stable substrates) may support higher algal biomass and consequently higher primary production. Some rocky shore production is exported to adjacent habitats.	Loss of above-ground biomass Reduction in microalgae or phytoplankton Reduced macroalgae biomass on rock ledge/boulder shores
Food web support	Rock and gravel shorelines support algal growth by providing attachments substrates. Many species of sessile invertebrates also attach to rocky substrates. Both the attached algae and invertebrates provide habitat for smaller algae and invertebrates. They support a different assemblage of organisms, most of which are only found on rocky shores (habitat specialists).	Decreased invertebrate biomass or density Changes in species composition, richness, diversity, or evenness Decreased recruitment or larval production Decreased algal or invertebrate growth rates Decrease in attached macrophytes/algae, percent cover or biomass Decreased use by higher trophic levels
Fish and shellfish production	Dense shellfish beds provide microhabitat for a diverse assemblage of organisms that contribute to overall system productivity and species composition. Fish use the shallow waters for cover and feeding.	Decreased species biomass or density Changes in species composition, richness, diversity, or evenness Changes in species size/age class distributions
Habitat usage	These shorelines are used by a variety of invertebrates, birds, mammals, fish and other organisms for loafing or roosting.	Decreased use by animals Changes in animal species composition, richness, diversity, or evenness
Filtration of water (filter feeders)	Water is filtered by the filter feeders such as barnacles, amphipods, bivalves, tunicates, hydroids, sponges, polychaetes, brittle stars, etc. Water percolating through the gravel or underlying sand can be filtered prior to re-entering the bay. The particles may then be used by benthic epifauna and infauna.	Increased water turbidity Changes in phytoplankton primary productivity
Biogeochemical and sedimentary processes	Biogeochemical process within the pore water can result in chemical transformations including denitrification and the breakdown of organic matter.	Decreased denitrification rates Increase in water column nutrients Changes in sediment organic matter or nutrient levels
Shoreline protection	Armoring of the shoreline provides protection during severe storm events.	Increased erosion rates Removal of substrate
Storm Surge Protection	Gravel berms can reduce storm surge impacts.	Increased height of storm surges Removal of substrate

TABLE D-3. Ecological services and functions of sand beach habitats.

Ecological Services	Function	Types of Potential Injury
Food web support	Sand beaches provide habitat for many invertebrates that derive nutrition from particulates and detritus brought in on tides and waves. These organisms serve as food for higher trophic levels particularly birds and fish.	Decreased microalgae or phytoplankton primary production Decreased infaunal/epifaunal biomass or density Changes in species composition. richness, diversity or evenness Decreased invertebrate re-colonization rates Decreased use by higher trophic levels
Habitat usage	Habitat for invertebrates and other organisms, particularly birds and fish. Listed bird species (e.g., Roseate Terns, Piping plover) and reptiles (Diamond backed terrapin) use sandy beaches. Many species of fish forage over sand flats.	Decreased bird, terrapin or fish usage Changes in animal species composition, diversity, richness or evenness Changes in animal behavior
Fish and shellfish production	Dense shellfish provide microhabitat for a diverse assemblage of organisms that contribute to overall system productivity and species composition. Fish forage in the shallow waters.	Changes in species abundance or density Changes in species composition. richness, diversity or evenness Changes in species size/age class distribution
Biogeochemical cycling and sedimentary processes	Biogeochemical processes within the pore water can result in chemical transformations including denitrification and the breakdown of organic matter.	Decreased denitrification rates Increased water column nutrients Changes in sediment organic matter or nutrient levels
Filtration of water (filter feeders)	Water is filtered by filter feeders such as barnacles, amphipods, bivalves, etc.. Water percolating through the sand is filtered prior to re-entering the bay. The particles may then be used by benthic epifauna and infauna.	Increased water turbidity
Storm Surge Protection	Storm damage prevention and flood control.	Increased storm damage Removal of substrate

TABLE D-4. Ecological services and functions of tidal flats.

Ecological Services	Function	Types of Potential Injury
Food web support	Tidal flats provide habitat for many invertebrates that derive nutrition from particulates and detritus brought in on tides and waves. These organisms serve as food for higher trophic levels particularly birds and fish.	Decreased microalgae or phytoplankton primary production Decreased infaunal/epifaunal biomass or density Changes in species composition. richness, diversity or evenness Decreased invertebrate re-colonization rates Decreased use by higher trophic levels
Habitat usage	Foraging habitat for many species of shorebirds during lower tides. Many species of fish forage over sand flats during higher tides..	Decreased bird or fish usage Changes in animal species composition, diversity, richness or evenness Changes in animal behavior
Fish and shellfish production	Dense shellfish provide microhabitat for a diverse assemblage of organisms that contribute to overall system productivity and species composition.	Changes in species abundance or density Changes in species composition. richness, diversity or evenness Changes in species size/age class distribution
Biogeochemical cycling and sedimentary processes	Biogeochemical processes within the pore water can result in chemical transformations including denitrification and the breakdown of organic matter.	Decreased denitrification rates Increased water column nutrients Changes in sediment organic matter or nutrient levels

TABLE D-5. Ecological services and functions of subtidal habitats.

Ecological Services	Function	Types of Potential Injury
Primary production	Production from submerged aquatic plants and phytoplankton forms the base of the primary food web.	Loss of biomass Changes in plant species composition, richness, diversity, evenness
Food web support	Subtidal areas provide habitat for many benthic invertebrates (infauna and epifauna) that derive nutrition from particulates and detritus. These organisms serve as food for higher trophic levels particularly birds and fish.	Decreased microalgae or phytoplankton primary production Decreased infaunal/epifaunal biomass or density Changes in species composition. richness, diversity or evenness Decreased invertebrate re-colonization rates Decreased use by higher trophic levels
Habitat usage	Subtidal estuarine areas are habitat for a wide variety of resident and migratory fish; Many bird species (cormorants, terns, loons) are pisciverous.	Decreased bird, or fish usage Changes in animal species composition, diversity, richness or evenness Changes in animal behavior
Fish and shellfish production	Subtidal estuarine areas are spawning and/or nursery habitat for many migratory (and resident) fish species. Dense shellfish provide microhabitat for a diverse assemblage of organisms that contribute to overall system productivity and species composition.	Changes in species abundance or density Changes in species composition. richness, diversity or evenness Changes in species size/age class distribution
Biogeochemical cycling and sedimentary processes	Biogeochemical processes within the pore water can result in chemical transformations including denitrification and the breakdown of organic matter.	Decreased denitrification rates Increased water column nutrients Changes in sediment organic matter or nutrient levels