# 4. Injury to Natural Resources

## 4.1 Approach to the Injury Assessment

### What Is in This Section?

- **Introduction (Section 4.1.1):** When in the NRDA process was the injury assessment conducted, how is the injury assessment presented in Chapter 4, and how do the assessment results relate to restoration planning?
- **Regulatory Framework for the Trustees' Injury Assessment (Section 4.1.2):** What is the regulatory basis for and how did that basis frame the Trustees' injury assessment?
- **The Trustees' Ecosystem Approach to Injury Assessment (Section 4.1.3):** Why did the Trustees choose an ecosystem approach to the injury assessment and which scales of biological organization did the Trustees study?
- **Injury Assessment Timeline and Stages (Section 4.1.4):** What were the stages of the Trustees' injury assessment process?
- **Injury Assessment Methods (Section 4.1.5):** What methods did the Trustees use to conduct the injury assessment and why?
- **Trustees' Data Management Process and Systems (Section 4.1.6):** What data management systems and processes did the Trustees use?
- **Road Map to the Trustees' Injury Assessment (Section 4.1.7):** What are the major sections of the injury assessment presented in this chapter?
- **References (Section 4.1.8)**



### Executive Summary

The Trustees conducted the injury assessment presented in this chapter under the authority of and in accordance with Oil Pollution Act (OPA) regulations. The injury assessment establishes the nature, degree, and extent of injuries from the *Deepwater Horizon* incident to both natural resources and the services they provide. Injury assessment results are used to inform restoration planning so that restoration can address the nature, degree, and extent of the injuries.

Under OPA, injury assessment involves determining whether resources or their services were injured, and then quantifying the degree and extent of those injuries and service losses:

- **Injury determination.** To determine injury, the Trustees evaluated whether a pathway could be established from the discharge to the exposed resource, whether the resource had been exposed to oil, and the injury caused by that exposure. The Trustees evaluated not only the extent of injuries to natural resources, but also to the services those resources provide. They also evaluated injuries resulting from response activities, including fishery and beach closures, beach excavation, removal of oil from marshes and beaches, boat activities, and placement of protective boom (see Chapter 2, Incident Overview, for further discussion of response activities).

- **Injury quantification**. To quantify the degree and extent of the injuries, the Trustees compared the injured resources or services to baseline conditions—i.e., the condition of the natural resources or services that would have existed had the incident not occurred. The Trustees did not quantify all injuries they determined. Rather, they focused injury quantification where it could best aid restoration planning. The Trustees' approaches to quantifying injuries varied by resource type and scientific study. Generally, the Trustees did not quantify effects in terms of population size or status (due to infeasibility), and they placed limited reliance on collected or observed counts of animals killed by the incident (because so many animals killed were not observable).

Based on the vast scale of the incident and potentially affected resources, the Trustees employed an ecosystem approach to the assessment. This involved evaluating injuries to a suite of representative habitats, communities, and species, rather than to all potentially affected individual species and habitats. The Trustees also evaluated injuries to representative ecological processes and linkages.[1] The Trustees conducted their assessment at multiple scales of biological organization, including the cellular, individual, species, community, and habitat levels.

The Trustees' injury assessment started as soon as news of the spill was received and continued with a multi-phased iterative approach, in which planning and design decisions were informed by the data collected and evaluated. The Trustees used a variety of assessment procedures, including field and laboratory studies, and model- and literature-based approaches. They used scientific inference to make informed conclusions about injuries not directly studied.

Field data collection by the Trustees involved roughly 20,000 trips, which generated over 100,000 samples of water, tissue, oil, and sediment and over 1 million field data forms and related electronic files. Testing of samples generated millions of additional records. The Trustees developed rigorous protocols and systems to manage sample collection, handling, and data storage. To store data, the Trustees developed a "data warehouse," referred to as the Data Integration, Visualization, and Reporting system (DIVER), which is publicly accessible at *https://dwhdiver.orr.noaa.gov/*.

Sections 4.2 to 4.10 of this chapter present the Trustees' injury determination and quantification methods, results, and findings for seven resource categories: water column, benthic resources, nearshore marine ecosystems, birds, sea turtles, marine mammals, and lost recreational use. The length and detail level in these sections vary because of the differing scopes of the assessment efforts and the different number of individual resources within each resource category. Section 4.11 summarizes the Trustees' injury assessment key findings and conclusions, which were based on the results of the resource-specific assessments, as well as the Trustees' understanding of the inherent connectivity across these habitats and biota within the northern Gulf of Mexico ecosystem.



[1] "Ecological linkages" refers to the interactions between organisms—from microbes to plants to animals—and their chemical, biological, and physical environment. See Chapter 3, Ecosystem Setting, for further information.

The Trustees used the results of the injury assessment to develop their restoration plan, described in Chapter 5. Though some studies are ongoing, the Trustees do not expect that further study will change selection of the preferred alternative presented in this Final PDARP/PEIS.

### 4.1.1 Introduction

As described in Chapter 1, the Trustees performed the Natural Resources Damage Assessment (NRDA) in accordance with OPA regulations (33 USC 2701 *et seq.*) at 15 CFR Part 990. Per OPA regulations, the *Deepwater Horizon* NRDA involves three main phases (15 CFR §§ 990.12, 990.40–990.66):

- **Preassessment,** in which the Trustees evaluate the potential for injuries to natural resources resulting from the *Deepwater Horizon* incident.
- **Restoration planning,** in which the Trustees evaluate and quantify injuries to natural resources to determine the need for, type of, and extent of restoration.
- **Restoration implementation,** in which the Trustees ensure that restoration is implemented.

The Trustees' injury assessment, presented in this chapter, was conducted across both the preassessment and restoration planning phases. Chapter 4 presents the approach to and results of this injury assessment, as follows (see Section 4.1.7 for a more detailed road map):

- **Section 4.1 (Approach to the Injury Assessment)** provides an overview of the regulatory framework for and approaches the Trustees used to determine and quantify injuries to natural resources.
- **Section 4.2 (Natural Resources Exposure)** describes the nature and extent to which natural resources were exposed to contamination from the *Deepwater Horizon* incident.
- **Section 4.3 (Toxicity)** describes the approach to and results of characterizing the toxic effects of *Deepwater Horizon* oil.
- **Sections 4.4 through 4.10** describe the methods, results, and conclusions specific to each of the resources assessed: water column (Section 4.4), benthic resources (Section 4.5), the nearshore marine ecosystem (Section 4.6), birds (Section 4.7), sea turtles (Section 4.8), marine mammals (Section 4.9), and lost recreational use (Section 4.10).
- **Section 4.11 (Summary of Injury Effects and Quantification)** presents the Trustees' key findings and conclusions resulting from the injury assessment.

The Trustees' injury assessment establishes the nature, degree, and extent of injuries from the *Deepwater Horizon* incident to both natural resources and the services they provide. As described in Chapter 5 (Restoring Natural Resources), the Trustees have used the assessment results presented in Chapter 4 to formulate restoration approaches targeted to restoring the full range of resources and ecosystem services injured from this incident.

## 4.1.2 Regulatory Framework for the Trustees' Injury Assessment

**Injury** is defined in the OPA regulations 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. Injury incorporates the terms "destruction," "loss," and "loss of use" as provided in OPA (15 CFR § 990.30).

OPA regulations identify several potential **types of injuries**, including (but not limited to):

> adverse changes in: survival, growth, and reproduction; health, physiology and biological condition; behavior; community composition; ecological processes and functions; physical and chemical habitat quality or structure; and public services [15 CFR § 990.51(c)].

As described in Sections 4.2 to 4.11, *all of the above types of injury occurred as a result of the Deepwater Horizon incident*.

Under OPA, injury assessment involves two elements, described below:

- **Injury determination,** in which the Trustees evaluate whether the *Deepwater Horizon* incident injured natural resources or impaired their services (15 CFR § 990.51).
- **Injury quantification,** in which the Trustees quantify the degree and the spatial and temporal extent of those injuries and service losses (15 CFR § 990.52).

### 4.1.2.1 Injury Determination

#### 4.1.2.1.1 The Components of an Injury Determination

Figure 4.1-1 illustrates the three components of an injury determination.

- **Pathway evaluation.** The Trustees evaluated whether a pathway could be established from the discharge to the exposed natural resource [15 CFR § 990.51(b)]. As defined in the OPA regulations, pathways may include (but are not limited to) "the sequence of events by which the discharged oil was transported from the incident and either came into direct physical contact with a natural resource, or caused an indirect injury" [15 CFR § 990.51(d)].
- **Exposure assessment.** As part of their injury determination, the Trustees evaluated whether the injured natural resource had been exposed to the discharged oil (directly or indirectly) [15 CFR § 990.51(b), (d)]. Section 4.2 summarizes the widespread exposure of natural resources in the northern Gulf of Mexico to oil and provides an overview of the pathways by which discharged oil was transported in the environment, resulting in those exposures.
- **Injury evaluation.** The Trustees evaluated injuries caused by exposure to oil, as well as injuries that resulted from actions taken to respond to the *Deepwater Horizon* incident. For these "response" injuries, the Trustees must determine whether the injury or impairment of a natural resource service occurred as a result of the incident [15 CFR § 990.51(e)]. Section 4.3 describes

the toxic effects of the oil that the northern Gulf of Mexico resources were exposed to, and Sections 4.4 to 4.10 describe resource-specific pathways, exposure, and injury.

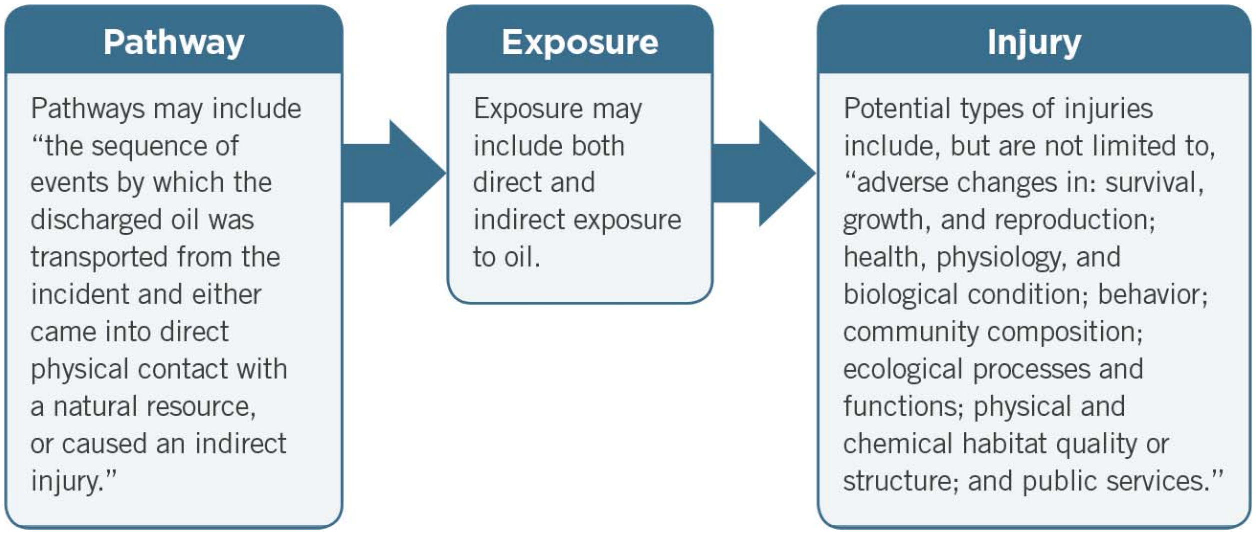



**Figure 4.1-1.** Pathway evaluation, exposure assessment, and evaluation of whether injuries occurred are the fundamental elements of injury determination (15 CFR § 990.51), and OPA regulations (15 CFR § 990.51) provide specific definitions for "pathway" and "injury," as shown in this figure. Resource-specific methods of evaluating pathway, exposure, and injury are described in Sections 4.2 to 4.10 of this chapter.

OPA regulations indicate that the "Trustees must determine if injuries to natural resources and/or services have resulted from the incident" [15 CFR § 990.51(a)]. The Trustees used a variety of standard scientific approaches, appropriate to the nature of the resource and the injury in question, to make this determination.

In some instances, the relationship between the incident and injuries did not require explicit evaluation (e.g., impacts directly resulting from response actions, such as physical disturbance and removal of beach sands). In other cases, the Trustees determined that the incident caused injuries by **establishing pathway and exposure**. For example, Section 4.4 demonstrates a clear relationship between the exposure of marsh vegetation to *Deepwater Horizon* oil and a series of consequential injuries, including death of marsh plants.

In Sections 4.2 to 4.10, the Trustees present information and conclusions related to:

- **Exposure** of the resource to *Deepwater Horizon* oil.
- **Injury determination**, in which the adverse effects of that exposure are evaluated and described.
- **Injury quantification**, in which injuries are quantified, where feasible, in terms of their degree, and spatial and temporal extent.

For other resources, the Trustees determined injuries based on **field studies** that compared locations exposed to oil with unoiled reference areas. For example, the Trustees documented a series of injuries to bottlenose dolphins in oiled areas that were not observed in unoiled reference locations. For observational injury determinations, the Trustees considered several common evaluative factors, including:

- The presence of known or likely exposure pathways, either direct or indirect.
- The spatial pattern of observed injury and relationship to the oil exposure, either direct or indirect, including comparisons with unoiled (or less oiled) reference areas.
- The timing of observed adverse changes in relation to the timing of the oil exposure.
- Statistical relationships in the data.
- Whether the cause-effect relationship is consistent with known processes in ecology, biology, and/or toxicology.
- Evaluation of possible alternative causes, where appropriate.

#### 4.1.2.2 Injury Quantification

Injury quantification involves quantifying the degree and spatial/temporal extent of the injury relative to **baseline conditions**—i.e., the condition of the natural resource or services that would have existed had the incident not occurred (15 CFR § 990.30). As described in Sections 4.4 to 4.10, the Trustees use various techniques to evaluate baseline conditions: comparison to historical data, evaluation of time trends, comparison with reference areas or conditions, calculation of incremental losses through counts of collected injured organisms (e.g., number of dead birds), and quantitative models based on oil exposure.

Following OPA regulations (15 CFR § 990.52), the Trustees quantified injuries in terms of the degree and spatial and temporal extent of the resource injury or the amount of services lost as a result of the incident. To estimate the temporal extent of injury, the Trustees considered several factors, including:

- Time trend data, where available.
- Life history data for injured organisms.
- Relevant scientific information from prior oil spills.
- Natural recovery times.
- Important physical/chemical processes.

The Trustees also used numerical models in calculating the amount of injury caused by oil exposure. For example, the Trustees' quantification of injuries to water column resources (such as fish and invertebrates) relied in part on the use of numerical models to calculate the total fish mortality based on their exposure to toxic concentrations of *Deepwater Horizon* oil. The Trustees quantified certain injuries by reference to other relevant indicators, rather than relying on resource-specific injury data.

### 4.1.3 The Trustees' Ecosystem Approach to Injury Assessment

#### 4.1.3.1 The Basis for the Trustees' Ecosystem Approach

As discussed in other chapters of this document, the scale of the *Deepwater Horizon* spill was unprecedented in terms of geographic extent, duration, and the complex array of ecosystem zones and habitats affected:

- **Geographic extent.** As detailed in Section 4.2, 3.19 million barrels of oil were released into the Gulf of Mexico over nearly 3 months. This resulted in a surface slick that cumulatively covered over 43,300 square miles of the ocean surface, an area roughly equivalent to the size of Virginia, and oiled more than 1,300 miles of shoreline habitats (see Section 4.2).

- **Response effort.** The spill necessitated a similarly unprecedented extensive and diverse response effort, including application of nearly 2 million gallons of dispersants, burning of surface oils, application of more than 9 million feet (more than 1,700 miles) of absorbent boom in offshore and nearshore environments, releases of fresh water in Louisiana, and oil removal from shorelines at different levels of intensity and destructiveness (Figure 4.1-2) (see Chapter 2). Over 600 million pounds of oily waste material were collected and transported to disposal facilities. The volume of this waste could have filled approximately 80 football fields 3 feet deep (EPA 2011).

***Source**: U.S. Coast Guard photo by Petty Officer 3rd Class Stephen Lehmann (top left), Mabile and Allen (2010) (top right), (Zengel & Michel 2013) (lower left), NOAA/Scott Zengel photo (lower right).*

**Figure 4.1-2.** Response activities. Top left: Aircraft applying dispersant. Top right: In-situ oil burns conducted on June 18, 2010. Lower left: Example of boom stranded in the marsh, Bay Jimmy, LA, June 2010. Lower right: Workers manually raking oiled marsh vegetation in Barataria Bay, LA, October 2010.

- **Ecological scope.** The ecological scope of this incident was also unprecedented, with oiling occurring in the deep ocean a mile below the surface and in offshore "blue-water" habitats, *Sargassum* habitats, coral habitats, and nearshore and shoreline habitats (see Section 4.2).

In designing their injury assessment approach, the Trustees considered the practical realities resulting from this enormous scope:

- The spatial extent, type, degree, and duration of oiling were vast, both geographically and in terms of the complex set of habitats affected, from the deep sea to the coastline.
- The geographic scale, extent, and diversity of response activities, which had also impacted Gulf resources, was huge.
- The number of species, resources, and services potentially injured was vast.
- Evaluation of all potentially injured natural resources in all potentially oiled locations was cost-prohibitive and scientifically impractical.

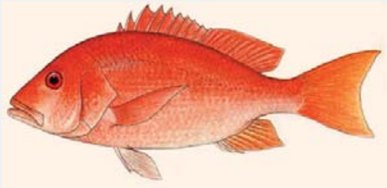
For these reasons, the Trustees determined that it was not feasible to study every species or habitat potentially affected by the incident in all locations exposed to oil or response activities. Instead, they employed an ecosystem approach to the assessment by evaluating injuries to a suite of representative habitats, communities, and species, as well as select human services, ecological processes, and ecological linkages. The Trustees used the information collected to develop scientifically informed conclusions not only about injury to the resources, processes, and locations studied, but also, by scientific inference (Section 4.1.5.3), about injury to resources, ecological processes, and locations that they could not directly assess.

The oil discharged into the environment is a complex mixture containing thousands of individual chemical compounds (Section 4.2). Once in the environment, those chemical compounds, in turn, may change as they are subject to natural processes such as mixing with air and water, microbial degradation, and exposure to sunlight. As described in Sections 4.2 and 4.3, the Trustees' injury assessment considered, to the extent feasible, this suite of chemical and physical environmental stressors, including the effects of oil and response actions individually and collectively.

## The Trustees Used Information from the Representative Resources, Processes, and Locations They Studied to Reach Broader Ecosystem Conclusions

Due to the unprecedented scale of the *Deepwater Horizon* incident, the Trustees evaluated injuries to *representative* habitats, communities, and species, and to *representative* ecological processes and linkages. They applied scientific inference to the results to develop broader conclusions about injury to northern Gulf of Mexico resources they could not directly study during the assessment. For example:

- In the water column resources assessment (Section 4.4), the Trustees used representative species such as red snapper, sea trout, and mahi-mahi to evaluate injuries to the large variety of fish species in the Gulf.



- In the nearshore marine ecosystem assessment (Section 4.6), the Trustees used species such as brown shrimp, red drum, and oysters to represent the many different fauna that rely on the edges of coastal salt marshes.

- To assess injury to coastal marshes, which support several important ecosystem processes (see Chapter 3), the Trustees considered one of these processes (the role of healthy marsh habitat in stabilizing the marsh and slowing coastal erosion rates) as representative of other ecological processes that marshes support.



### 4.1.3.2 Biological Scales of the Trustees' Injury Assessment

Injury assessments can be conducted at different scales of biological organization:

- **Organisms** can be evaluated at scales ranging from cellular processes that underlie physiological fitness, to the health or survival of individual organisms, to the status of sub-populations or populations of species.

- **Species** can be evaluated individually or in terms of the sometimes complex multi-species communities on which they rely. Communities of organisms are supported by habitats and ecological landscapes.

OPA regulations do not specify what scale(s) or organization to use in an injury assessment [see 15 CFR § 990.51(c)]. Rather, the OPA regulations leave the consideration and selection of injuries to include in the assessment to the discretion and expertise of the Trustees. As an ecosystem-level assessment, the Trustees' injury assessment evaluated injuries across a range of components and functions of Gulf of Mexico ecosystems. Thus, the Trustees' injury assessment was conducted at multiple scales of organization, including the cellular, individual, species, community, and habitat levels. In addition, the Trustees' assessment considered organism life history requirements and reproductive biology by evaluating injuries to embryonic and juvenile organisms and adult organisms. Using this approach, the

Trustees can interpret conclusions they derive from the injury assessment broadly over different scales of biological organization.

### 4.1.4 Injury Assessment Timeline and Stages

Figure 4.1-3 shows a generalized timeline for the Trustees' injury assessment process, from 2010 to 2015. This process involved several stages, described below. Throughout, the Trustees pursued an *iterative* injury assessment process. In other words, on a continual basis, they have used the data and results from work already performed to inform design and planning of subsequent assessment efforts.

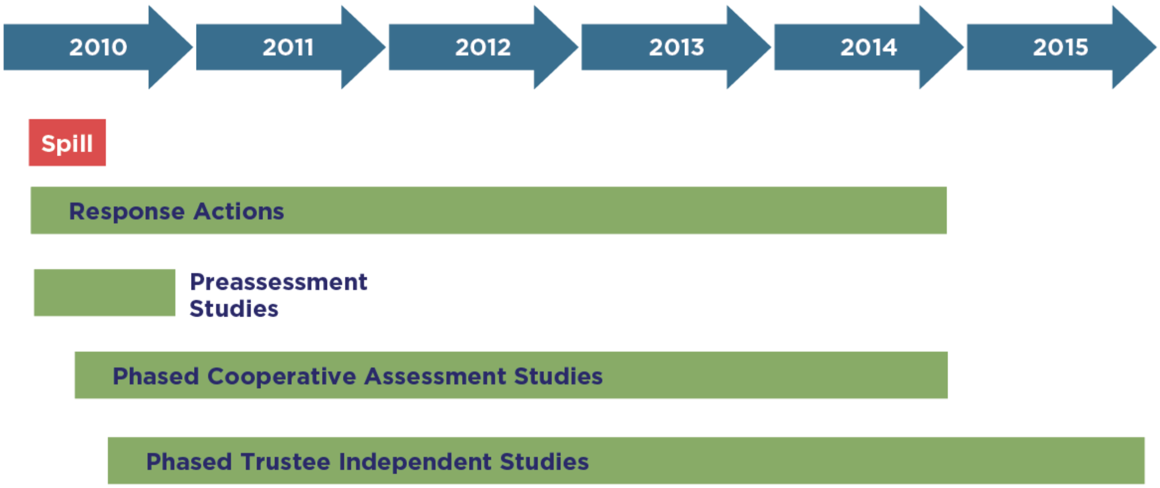



**Figure 4.1-3.** Generalized timeline for the Trustees' iterative, phased assessment process.

#### 4.1.4.1 Immediate Data Collection

The Trustees' injury assessment started as soon as news of the spill was received. Working together with oil spill response efforts, the Trustees mobilized teams of scientists to rapidly evaluate the potential for injury, taking into account modeled and observed oil trajectories along the ocean surface, their experience at other oil spills, and their fundamental understanding of the natural resources of the northern Gulf of Mexico.

#### 4.1.4.2 Data from Response Efforts

Immediately following the spill, response efforts were initiated by numerous government agencies, overseen by the U.S. Coast Guard (USCG 2011). BP participated actively throughout the response, working collaboratively with the U.S. Coast Guard and other response agencies as required by OPA.

Although not formally part of the injury assessment, response efforts collected considerable amounts of data to inform and support cleanup decisions. These data include environmental samples, extensive shoreline observations to identify oiled locations, collections of live oiled organisms (with subsequent efforts at rehabilitation), and identification and collection of dead animals. The Trustees judged that certain response data, though collected for another purpose, had value for the injury assessment; they relied on response data, where appropriate, in their injury assessment.

#### 4.1.4.3 Preassessment Studies

Shortly following the spill, the Trustees initiated a series of preassessment studies designed to provide initial information to inform Trustee decisions about potential injury assessment studies.[2] The Trustees relied on these results in the NRDA and interpreted them in conjunction with subsequent data collection efforts.

#### 4.1.4.4 Cooperative Assessment Studies

Following the preassessment phase, the Trustees and BP initiated a series of cooperative assessment studies, pursuant to a Memorandum of Understanding between the Trustees and BP,[3] designed to broadly evaluate the potential for injuries to a variety of natural resources over a wide geographic area. The cooperative nature of these studies was generally limited to the collection of certain data and not the analysis of data or interpretation of the results. In many instances, cooperative studies were performed in a phased manner, often over several years.

#### 4.1.4.5 Independent Assessment Studies

In addition to cooperative assessment studies, the Trustees conducted a series of independent assessment studies that focused on discrete issues of concern to the Trustees. Independent assessment studies included human use studies, toxicity testing studies, and other resource-specific studies and evaluations. The Trustees also analyzed and evaluated data independently from BP.

### 4.1.5 Injury Assessment Methods

#### 4.1.5.1 Assessment Procedures

OPA regulations identify different assessment procedures for use in an injury assessment, including field studies, laboratory studies, model-based approaches, and literature-based approaches (15 CFR § 990.27). The Trustees used combinations of all four approaches. As described in Sections 4.1.5.1.1 and 4.1.5.1.2, they used:

- **Field studies** to measure environmental exposure to oil, evaluate biological responses, and quantify lost human uses.
- **Laboratory studies** to evaluate the toxicological responses of organisms to *Deepwater Horizon* oil under controlled conditions.
- **Scientific literature** to supplement their injury assessment.
- **Model-based approaches** to quantify exposure and injuries to resources where direct measurement was infeasible given the scope of the incident. For example, numerical modeling was employed to quantify injuries to nearshore resources based on exposure to toxic concentrations of oil, and to quantify injuries to marsh fauna such as flounder and shrimp.

[2] See work plans available at *http://www.doi.gov/restoration/Gulf-Coast-Oil-Spill-Work-Plans.cfm* and *http://www.gulfspillrestoration.noaa.gov/oil-spill/gulf-spill-data/*.
[3] See work plans available at *http://www.la-dwh.com* and *http://www.gulfspillrestoration.noaa.gov/oil-spill/gulf-spill-data/*.

#### 4.1.5.1.1 Use of Field, Laboratory, and Literature Information

The Trustees used field studies when, in their judgment, such studies would yield valuable and usable observational data to inform the injury assessment. They used laboratory studies to evaluate the toxicological responses of different organisms to oil and dispersant under controlled conditions. They also relied on published literature to support the injury assessment, including previously published studies about how oil affected natural resources, as well as academic research conducted outside the NRDA but related to the oil spill and/or to the Gulf's natural resources. The Trustees also considered independent data collected by BP.

#### 4.1.5.1.2 Use of Numerical Models

When field studies were judged infeasible or impractical (e.g., when sampling was impractical or sufficient samples could not be collected to support robust conclusions), the Trustees used alternative assessment approaches, such as numerical modeling, to determine and quantify injuries based on known data or environmental processes.

Widely utilized in environmental science fields, numerical models simulate or calculate quantitative relationships between environmental variables based on understood and hypothesized conditions. The Trustees used numerical models as part of their assessment because, as discussed earlier, they could not measure oil concentrations everywhere in the northern Gulf of Mexico or directly study the impact of the incident on the vast number of potentially affected species and habitats. For example, as described in Section 4.4 (Water Column), because the Trustees could not study the response of every potentially affected fish species (and life stage) to oil exposure, they developed numerical models to quantify injuries to fish based on:

- Toxicological dose-response relationships derived from controlled laboratory studies.
- The estimated abundance of fish from available survey data.
- Modeled concentrations of oil in water developed from understood physical-chemical relationships.

When developing such models, the Trustees used empirical data from the Gulf (when available), well-understood environmental processes, and standard approaches in the field of environmental modeling.

### 4.1.5.2 Use of Scientific Inference

As noted earlier, the scale of the *Deepwater Horizon* incident precluded studying all individual components of the affected ecosystem, in all locations affected, over the full time period of potential effects. Instead, the Trustees' injury assessment focused on representative habitats, communities, species, processes, and linkages. To assess injuries not directly studied, The Trustees applied scientific inference to the study results to make informed conclusions about resources and locations that could not practically be assessed.

Scientific inference is the process of using data, observations, and knowledge to make reasonable conclusions about things that may not have been directly observed. For example, the Trustees may use observations and data they obtained showing that oil in sufficient amounts can smother wetland plants to infer that similar plants they did not study, when similarly oiled, would also be smothered. Similarly, existing knowledge can support reasonable scientific inferences. For example, if prior published studies have shown that certain species of organisms depend on marsh plants, scientists can reasonably infer that loss of those marsh plants in the Gulf would harm those dependent organisms. Section 4.1.3 provides more details on the types of scientific inference used by Trustees.

#### 4.1.5.3 Trustees' Approach to Addressing Uncertainty

In scientific studies, scientists use uncertainty as a measure of how well they know something. For example, scientists may have a very good idea of the approximate number of dolphins living in Barataria Bay, Louisiana, but will use the term "uncertainty" to describe the degree to which they are not certain about the precise number of dolphins.

**Scientific Uncertainty**

In science, use of the term "uncertainty" does not mean that scientists don't know something. Rather, scientists use uncertainty to describe how precise their understanding is.

Scientific studies and findings typically involve some degree of uncertainty due to factors such as:

- Natural environmental variability.
- Variability related to sampling and measurement.
- Limited ability to collect data.
- Basic unknowns about the systems being studied.

In the case of the *Deepwater Horizon* incident, several factors introduce scientific uncertainties. For example, the ecology of the deep sea is not yet well understood, knowledge about many resources of the open ocean is limited, and scientists' ability to collect samples in and study these environments is limited. Many of the Gulf resources affected by the incident are highly mobile and difficult to observe, posing practical limitations on sampling and study. The incident's spatial scale was sufficiently large that scientists cannot survey or sample all areas that may have been injured.

These uncertainties do not mean that the Trustees have not been able to reach a series of scientifically robust and accurate conclusions. Rather, the scientific uncertainty discussed in this injury assessment provides transparency into the precision of the Trustees' numerical findings.

The Trustees employed a number of commonly used approaches to address uncertainty, including use of alternative model scenarios, presentation of injury calculations in reasonable numerical ranges to reflect uncertainty, statistical analysis of uncertainties through sensitivity and randomization analyses, and calculation of confidence intervals and error rates (NRC 2004).

In evaluating scientific uncertainties, the Trustees weighed information against two different possible errors:

- **Type I error:** a conclusion that injury had occurred when, in fact, there was no injury.
- **Type II error:** a conclusion that injury had not occurred, when in reality an injury had occurred.

In the case of the *Deepwater Horizon* incident, a Type I error would lead to overestimating restoration needs, whereas a Type II error would lead to underestimation, resulting in insufficient restoration.

Scientists often use statistical analysis (see Section 4.1.5.4) to describe the level of uncertainty. In the environmental sciences, use of statistical analysis frequently minimizes Type I errors, particularly in variable natural environments.

The Trustees considered both Type I and II errors during injury assessment and restoration planning.

The purpose of this Final PDARP/PEIS is to determine the need for and decide on restoration. Not all uncertainty must be fully resolved to meet these objectives. Even with more time and resources for scientific study, substantial uncertainty would remain. While further study could somewhat decrease uncertainty, the Trustees do not expect that the degree of increased certainty would change their selection of the preferred alternative presented in Chapter 5 of this Final PDARP/PEIS.

The extensive scientific data and conclusions set out in this Final PDARP/PEIS can address most of the questions the Trustees face regarding the nature and extent of injuries and the need for required restoration actions. However, to make all the determinations required to fulfill their trust responsibilities, the Trustees must exercise informed judgment in light of expert opinion to address remaining uncertainties and unresolvable data gaps. The result, reflected in this document, is a series of critical decisions based on a combination of the best available scientific information, agency expertise, and extensive experience gained from other cases.



#### 4.1.5.4 Statistical Analysis

The Trustees and their principal investigators selected a variety of statistical approaches for the injury assessment based on the type of data collected, the nature of the study and study design, and the specific questions to be addressed in analyzing the data. Examples include:

- **Regression analysis.** This involves analyzing the numerical relationship between a dependent ("response") variable and one or more independent ("driver") variables. With regression analysis, the Trustees can calculate how changes in a driver variable will result in changes to a response variable (e.g., how increases in oil concentrations are related to increases in an organism's mortality rates).

- **Tests comparing mean (i.e., average) values of two or more groups.** These include t-tests (to compare means of two groups) and analysis of variance (ANOVA, to compare means of multiple groups). The Trustees used these methods to determine whether the average condition of a variable differed between groups (e.g., to compare average vegetation health at oiled and unoiled sites).

- **Tests comparing attributes of individual organisms against reference values.** The Trustees used these types of tests to determine if the value of a parameter associated with a particular organism, or locality, was typical or atypical relative to a known standard value (or range of values) for that parameter. For example, physiological data collected from an individual organism (such as a hematocrit level measured in a sample of bird blood) may be compared with a reference interval developed from hematocrit levels measured in unaffected birds to determine whether the condition of the sampled organism is impaired.

- **Geostatistical modeling techniques, such as kriging.** These are used to evaluate spatial patterns in data. A kriging model uses information about attributes of sampled locations (e.g., oil concentrations in shoreline sediments) to describe how those attributes are similar or different across a landscape. A kriging model may be used to infer conditions in unsampled locations based on the spatial patterns found among sampled locations.

### Trustees' Approach to Determining Statistical Significance

For this injury assessment, the Trustees did not adopt a single universal threshold value for statistical significance. Rather, the investigating scientists interpreted the data as they judged appropriate, considering factors such as the resource investigated, type of data collected, statistical power of a test to detect a difference, and the associated possibility of making a Type II error (i.e., concluding there is no effect when there actually is one—see Section 4.1.5.3, above). Two techniques used by investigators to determine significance are the use of p-values and confidence intervals.

**P-values and the null hypothesis.** An output of some statistical tests, the "p-value" refers to the probability that patterns in sample data occurred through random chance alone, rather than as a result of an actual effect being evaluated. Calculations to determine p-values are based on clearly defined statistical models, such as the widely used "null hypothesis." A typical null hypothesis might be that the mean value of a parameter of interest in each of two populations is identical. Because of variability in a study, the difference in the mean values determined from *samples* collected from two populations is likely to be non-zero even if the difference in *actual* population means is in fact zero. The probability of finding a particular degree of difference between sample means, if the null hypothesis is true, is defined as the p-value. Briefly, if the differences in sample means are "large enough," the results are interpreted as evidence *against* the null hypothesis. Small p-values are interpreted as evidence that the null hypothesis is unlikely to be true (i.e., there is a small probability that the null hypothesis is true).

**Confidence intervals.** In the injury assessment, the Trustees used another type of statistic: the "confidence interval." A confidence interval is derived from sample data and may be used to qualify the mean value of sample data as a reflection of the true, but unknown, population mean. For example, a 95 percent confidence interval around a sample mean denotes that there is a 95 percent probability that the true population mean lies within that interval.

#### 4.1.5.5 Overarching Injury Quantification Factors

The Trustees' approaches to quantifying injuries varied by resource type and according to the specifics of the scientific study. Details are provided in subsequent sections of this chapter. Two principles, described below, impacted quantification design. The Trustees did not conduct population-level assessments, and they placed limited reliance on counts of animals killed by the incident.

As a general matter, the Trustees did not quantify effects in terms of changes in population size or status. There are a number of reasons why the Trustees concluded that seeking to quantify population-level changes would be of little scientific value for the assessment.

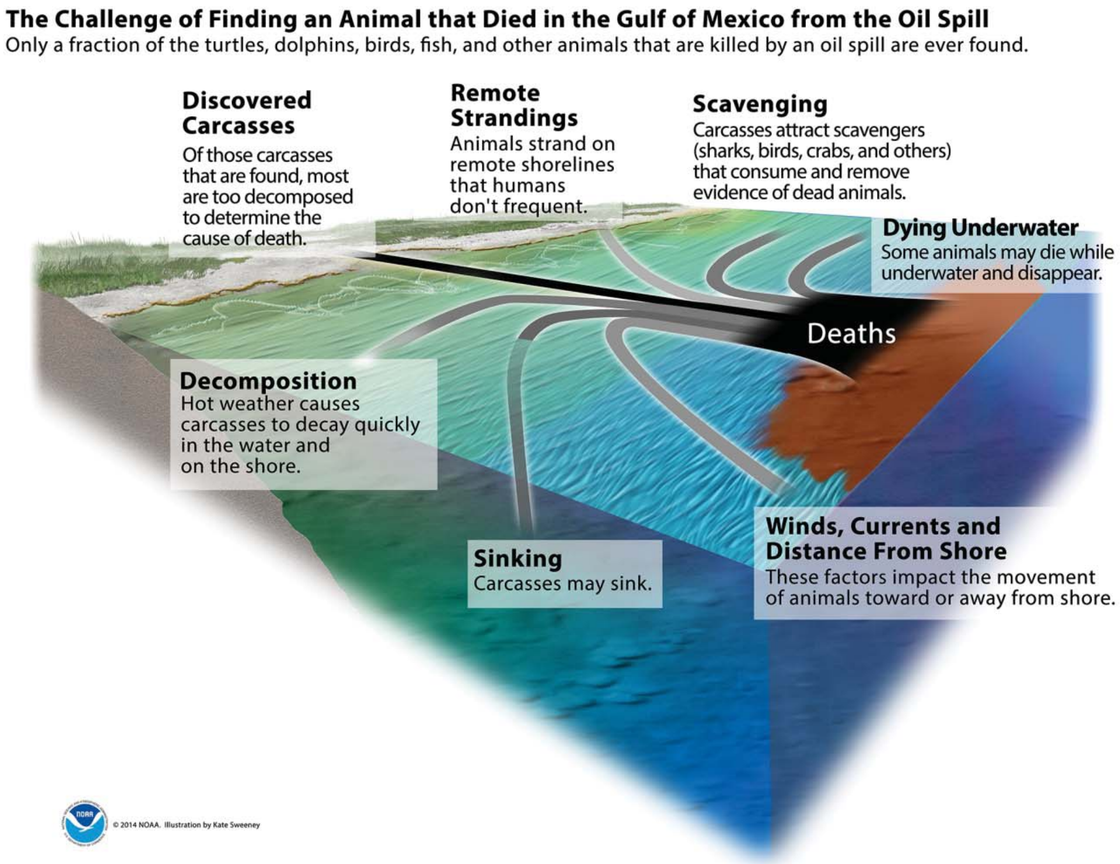
> "[P]opulation-level effects are inherently difficult to assess because of high variability, migrations and multiple factors affecting the populations."
>
> Boesch (2014)

The Gulf of Mexico covers a very large area that includes a U.S. shoreline length exceeding that from Florida through Maine, as well as a vast ocean area and volume. Organisms move freely within this system and between the Gulf, the Caribbean Sea, and the Atlantic Ocean. Given the natural changes and variability, assessing population-level impacts within such a huge area where organisms move freely is impractical. The sheer number of samples that would be required for a population-level assessment renders such approaches unrealistic and potentially misleading. As noted by Boesch (2014), analyses of such broad regional trends are incapable of quantifying impacts on resources within the geographic areas exposed to substantial oiling.

In their injury quantification for some resources, Trustees relied on collection and counts of animals killed by the spill. However, due to difficulties associated with observing and collecting carcasses of killed animals over such a vast geographic and temporal scale, such counts drastically underestimate injury. The Trustees therefore developed methods and models that accounted for these challenges to develop a representative quantification of actual loss.

As illustrated in Figure 4.1-4, carcass collection studies are greatly limited by a number of different factors, including:

- Animals that die often are consumed by predators or sink before being observed.
- Animals that die offshore may not be observed unless they are pushed by winds/waves to shoreline areas where observation likelihoods may be greater.
- The Gulf's warm weather causes rapid decomposition of carcasses, rendering them impossible to observe.
- Carcasses that do make it to shorelines may end up in locations such as marshes that are remote or otherwise difficult to sample. For example, Louisiana's intertidal marshes are extremely difficult to survey.
- Small organisms, such as juvenile fish and crustaceans, are virtually impossible to observe, even when studies are designed to survey them.




***Source:*** *Kate Sweeney for NOAA.*

**Figure 4.1-4.** Quantifying injuries based on observed dead animal carcasses is extremely difficult and leads to drastic underestimates of injury.



## 4.1.6 Trustees' Data Management Process and Systems

### 4.1.6.1 Types of Data Collected

Over the course of the injury assessment, the Trustees collected information to document the quantity and location of oil in the environment, as well as the ways in which the oil affected natural resources:

- **Field data.** Data collected in the field included photographs; global positioning system (GPS) data on locations and movements; videos; instrument data; physical samples of water, air, tissue, and sediment; direct observations (e.g., plant stem length, type of marsh vegetation); carcasses of thousands of dead and dying birds; telemetry information from fish, turtles, and marine

> The injury assessment relied on data collected by Trustees as part of NRDA studies, as well as data and information collected by other researchers and agencies. Each NRDA study was conducted under a work plan, which is available for public review. These work plans can be found at the NOAA Gulf Spill Restoration site: *http://www.gulfspillrestoration.noaa.gov/oil-spill/gulf-spill-data/*.

mammals; and remote-sensing information. Field data collection involved roughly 20,000 trips and generated over 100,000 samples of water, tissue, oil, and sediment, and over 1 million field data forms and related electronic files.

- **Chemical testing data.** Chemical testing performed on samples resulted in over 4 million laboratory result records, as well as about 1 million records of the biological and physical composition of the samples.

- **Other data.** This work also generated over 1 million additional instrument files, photographs, telemetry records, and observation records.

- **Lost human use data.** The Trustees also collected substantial amounts of data for their evaluation of lost human use.

#### 4.1.6.2 Data Management

The Trustees developed a robust set of data management protocols and systems to manage how field samples were collected and how the resulting samples were handled. These protocols and systems allowed Trustees to track collections through several distinct stages, including the data intake process, quality assurance/quality control (QA/QC) verifications (e.g., double transcription when turning written field sheets into electronic files), analysis at a laboratory, validation of analytical data by a third party, and final addition of the data to the appropriate databases.

To store data generated during the NDRA process, the Trustees developed a set of databases. Together, these databases constitute the Trustees' overall data repository, or "data warehouse," referred to as the **Data Integration, Visualization, and Reporting system (DIVER)**. DIVER is publicly accessible at *https://dwhdiver.orr.noaa.gov/*.

Data managers organize all the data elements (i.e., each sample, data point, analysis, or photograph) so that data users can systematically track and analyze the information. All elements are linked to the original information collection activity to better characterize data origin and to trace how each data element passed from one official handling stage to the next (known as "chain of custody"). In addition to field data, DIVER house information on laboratory experiments and other analyses conducted by NRDA investigators.

#### 4.1.6.3 The NRDA Data Management Process

Figure 4.1-5 shows the steps in the Trustees' data management process:

- **Work plan.** The first step generally is to develop a work plan to collect data that will answer specific questions about the incident. *Deepwater Horizon* NRDA work plans can be found at *http://www.gulfspillrestoration.noaa.gov/oil-spill/gulf-spill-data/*. Then, the Trustees generally work with the data management team to plan field events, train the sample collectors on proper data management protocols, and coordinate with sample intake teams on where and when samples will be handed over.

- **Sample collection.** Sample collection procedures are governed by scientific protocols. Upon collection, each sample is given a unique sample identification (ID) that follows the sample throughout its life cycle. Sample documentation includes the field sheets that scientists use to write down sample locations, time, environmental conditions, etc.; the chain-of-custody forms; the original photographs; GPS files; mailing labels routing the sample to the proper laboratory; and any other information associated with that particular collection.

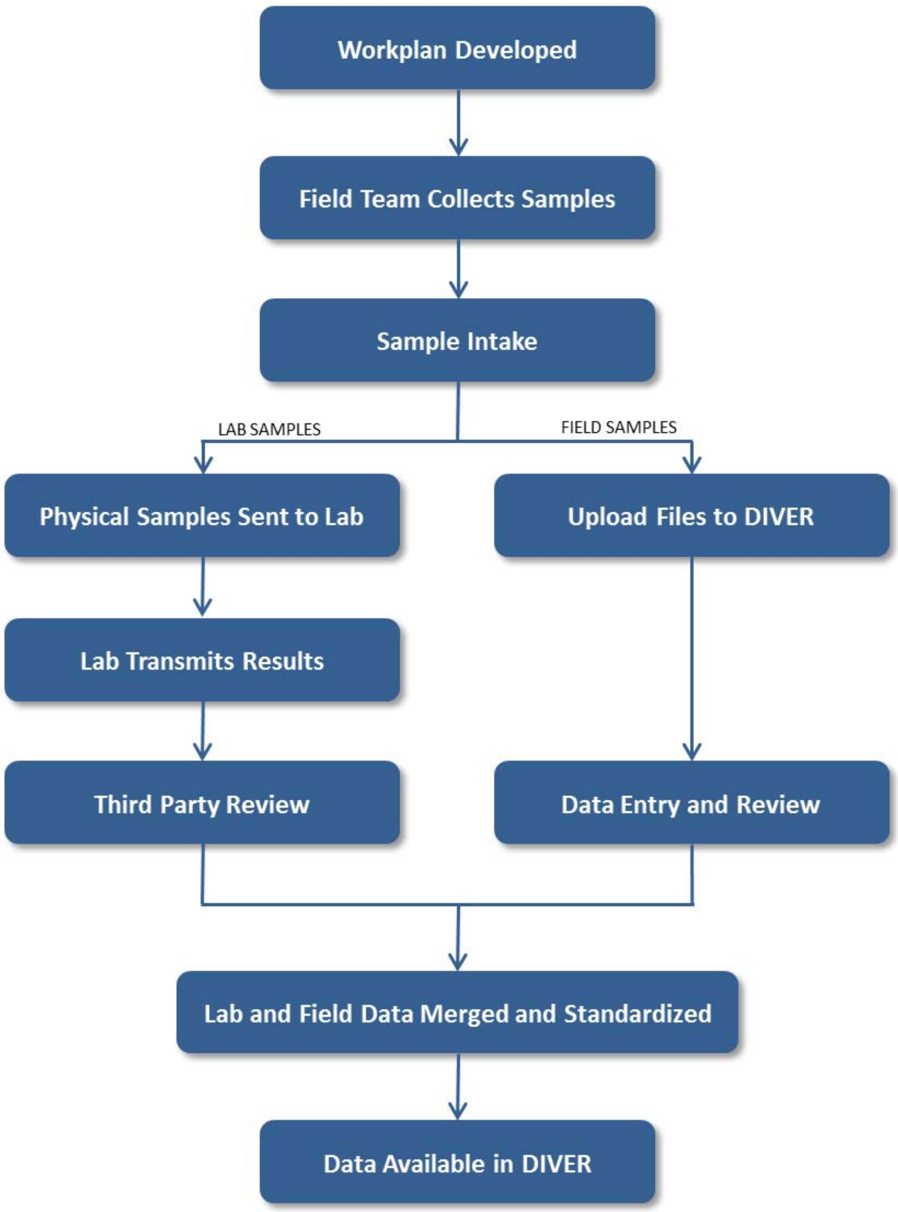



**Figure 4.1-5.** The Trustees' data management process for the *Deepwater Horizon* NRDA.

- **Sample intake.** Following collection, field researchers submit samples and associated documentation to one of several sample intake centers in the Gulf region. Sample intake teams are responsible for uploading the complete bundle of information—both electronic files and scanned paper forms—to DIVER. The sample intake and data management teams also provided

QA/QC checks to ensure that all documentation is complete and has been correctly transcribed and standardized (e.g., consistent measurement units and species names).

- **Laboratory samples.** The intake teams mail the samples to the appropriate laboratories for analysis. Laboratory researchers process samples and instruments according to procedures specified in the Analytical Quality Assurance Plan (AQAP) or work plan. All samples analyzed for contaminant chemistry (e.g., water, sediment, fish tissue, marine mammal blood samples, source oil) generally are sent to a third party to validate the laboratory results. The validators ensure that analytical equipment was calibrated correctly and that results meet performance standards. The *Deepwater Horizon* AQAP outlines all validation protocols and performance standards.

- **Field samples.** After intake, field samples are uploaded to DIVER for data entry and review.

- **Merge and standardization of laboratory and field data.** After the analytical results have been validated, they are integrated with the corresponding field data and made available within DIVER.



#### 4.1.6.4 Data Management Systems

The Trustees' data management system comprised several components, including:

- **DIVER.** As described earlier, NOAA and the data management team created DIVER to serve as a warehouse and portal for all data related to the *Deepwater Horizon* NRDA effort. DIVER is designed to address the unique data demands associated with the *Deepwater Horizon* incident. DIVER allows the user to access not only analytical chemistry results, but also original field data, work plan-specific observation data, photographs taken during sampling trips and other field research, instrument data, and information on the status of samples as they proceed through laboratory analysis. Figure 4.1-6 depicts this data integration graphically.

- **Environmental Response Management Application (ERMA®).** NOAA's ERMA® is an online mapping tool that integrates static and real-time data in a centralized, easy-to-use map to provide environmental responders and decision-makers with faster visualization of the situation and improve communication and coordination for environmental response, planning, and restoration (see *http://gomex.erma.noaa.gov/erma.html*). During major response activities, ERMA was a main way the Trustees shared data publicly.

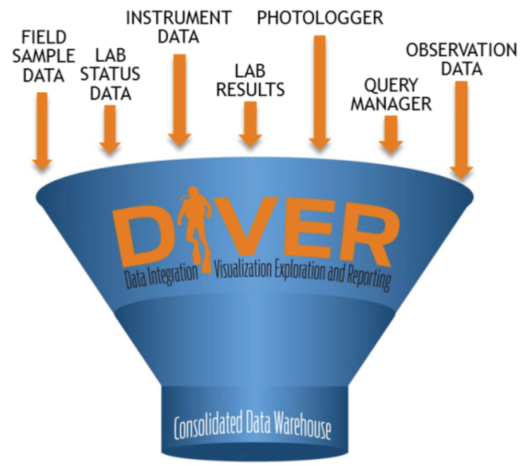



**Figure 4.1-6.** DIVER data integration.

- **Data management protocols.** Specific data management protocols were developed for distinct purposes. For example:
    - The field study of recreational uses included onsite surveys, ground counts, and oblique aerial imagery counts to count, for example, the number of individuals on a segment of beach. Sampling plans and data management protocols were developed to manage how the field and aerial data were collected, handled, and processed.
    - Toxicity tests required a tracking system to monitor and manage all phases of toxicity testing, from test development through to receipt of laboratory testing and analytical data, validation of chemistry data, QC, and analysis.

#### 4.1.6.5 Data Tracking and Integrity

While samples were being analyzed, the Trustees' data management team tracked the status of the sample (i.e., whether it was in the queue, under analysis, archived, delivered to validation, validated, or shared publicly). As case data were integrated into the system repositories, the data management team conducted quality reviews to promote consistent data suitable for application in this Final PDARP/PEIS. These quality reviews included basic standardization (e.g., correcting misspelled species names, converting to consistent units), reviews to ensure record completeness and accuracy, and coordination with work plan principal investigators to make any necessary updates.



### 4.1.7 Road Map to the Trustees' Injury Assessment

Figure 4.1-7 provides an overall road map to the Trustees' injury assessment. As the figure shows, the Trustees' injury assessment, described in subsequent sections of this chapter, is organized into four elements: exposure assessment, toxicity assessment, resource-specific injury assessment, and summary and synthesis of findings.

- **Section 4.2 (Natural Resource Exposure).** The Trustees' exposure assessment provides a summary and synthesis of all the evidence gathered and analyzed about where and how natural resources were exposed to *Deepwater Horizon* oil, as well as other contaminants (e.g., dispersants) and stressors (e.g., drilling muds). The exposure assessment chronicles how the oil and other contaminants moved and changed as they were transported through water, sediment, air, and biota, and ultimately exposed many habitats, plants, and animals in the deep sea up to and across a broad expanse of the ocean surface and along the coastlines of the northern Gulf of Mexico.

- **Section 4.3 (Toxicity).** The Trustees' toxicity assessment involved detailed evaluation of the toxic effects of *Deepwater Horizon* oil and dispersants (Figure 4.1-8) to determine what concentrations cause toxic effects. The Trustees used this information together with the exposure assessment results when they evaluated injuries to natural resources in the northern Gulf of Mexico (Sections 4.4 to 4.10).

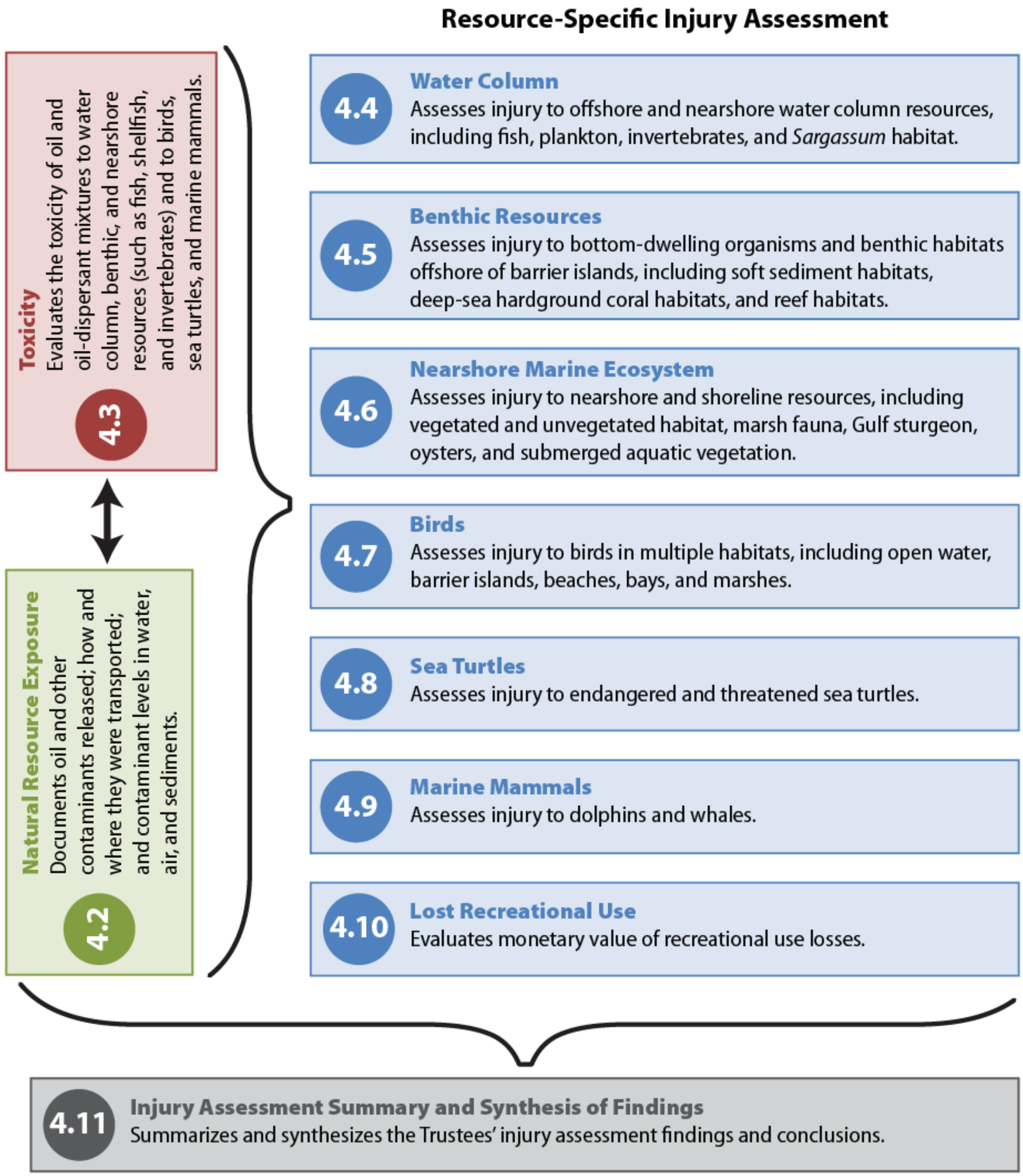



**Figure 4.1-7.** "Road map" to the Trustees' injury assessment presented in Chapter 4.

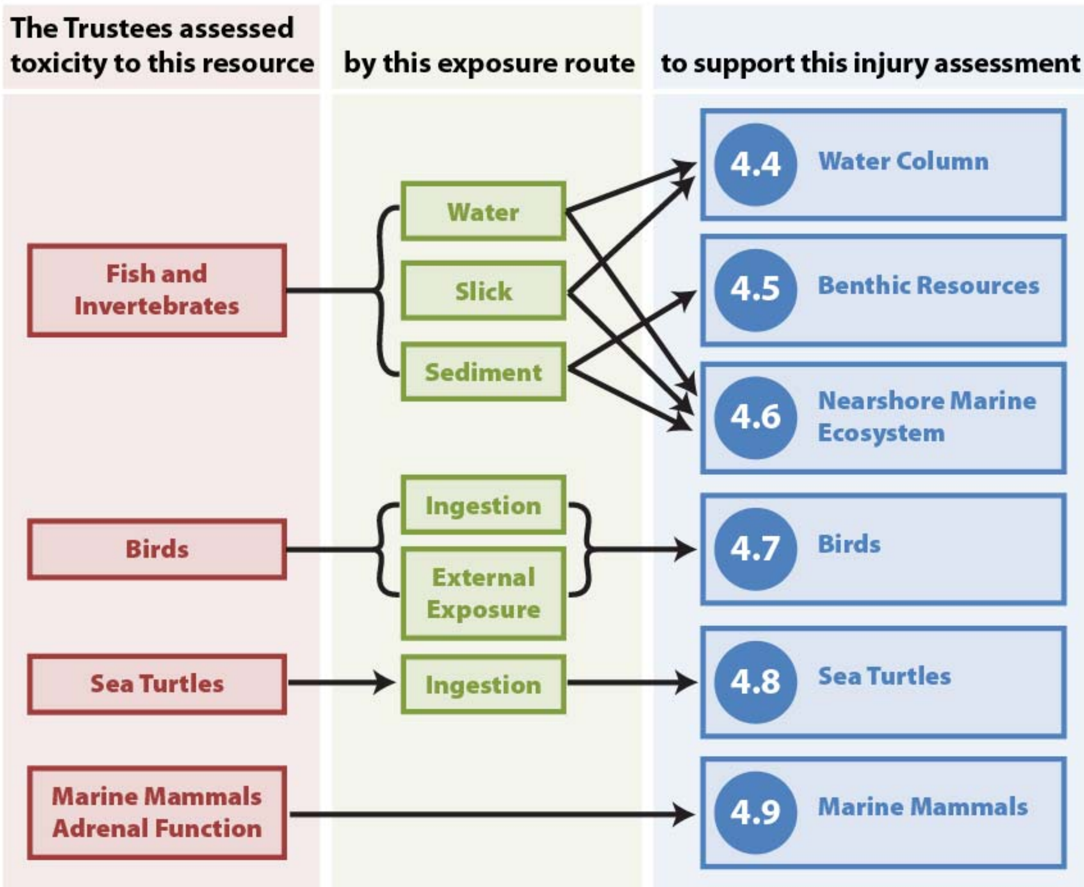



**Figure 4.1-8.** Use of toxicity information in the Trustees' injury assessment.



- **Resource-specific injury determination and quantification (Sections 4.4 to 4.10).** Approaches and results for each of seven resource categories are presented in separate sections:
  - **Section 4.4 (Water Column)** contains information on injuries to fish and invertebrates in the open water column and in nearshore waters. This resource analysis relies heavily on understanding the relationship between exposure to oil, the toxicity of the oil, and the application of numerical models.
  - **Section 4.5 (Benthic Resources)** describes a variety of soft-bottom (mud) and hard-bottom (rock and coral) habitats. Despite the challenges of working in the deep sea, this section relies largely on empirical field studies to document harm to sea bottom habitats and organisms.
  - **Section 4.6 (Nearshore Marine Ecosystem)** addresses a wide variety of habitats and representative species, including vegetation shorelines (e.g., marsh and mangroves), sand beaches, and submerged aquatic vegetation, as well as a series of representative resources that serve primarily as indicators of marsh habitat quality. This section combines extensive field data, toxicological data, published literature, and numerical models.

- **Section 4.7 (Birds)** describes injuries to a wide variety of bird species, including pelagic sea birds, colonial nesting birds, waterbirds, and marsh birds. The assessment relies on observations of numerous dead birds, numerical extrapolations of those dead birds to estimate a range of bird mortality where possible, and toxicity tests in which birds were exposed to oil under various conditions.

- **Sections 4.8 (Sea Turtles) and 4.9 (Marine Mammals)** describe the Trustees' assessment of injury to these highly charismatic organisms, which are protected by the Endangered Species Act and the Marine Mammal Protection Act. The sea turtle assessment relied on extensive observations of oiled turtles data from NRDA field studies, stranded carcasses collected by the NMFS SEFSC Sea Turtle Stranding and Salvage Network, historical data on sea turtle populations, and the published literature to develop opinions regarding sea turtle injuries, as supplemented by veterinary assessments of captured turtles and a laboratory study of surrogate freshwater turtles. The marine mammal assessment synthesized data from NRDA field studies, stranded carcasses collected by the Southeast Marine Mammal Stranding Network, historical data on marine mammal populations, NRDA toxicity testing studies, and the published literature.

- **Section 4.10 (Lost Recreational Use)** focuses on losses of human recreational use services attributable to the incident. Losses are expressed in terms of lost recreational trip opportunities and monetary damages.

- **Summary of Injury Effects and Quantification (Section 4.11).** The final section of Chapter 4 presents the Trustees' key findings and conclusions resulting from the injury assessment.



### 4.1.8 References

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