Comparative Evaluation of Nearshore Sediment Sampling Methods Based on Field Trial in the Northern GOM

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Abstract

A comparison of traditional sediment sampling methods based upon multiple (7) evaluation criteria demonstrated variable performance for the recovery of sediments and flocculent material within the dominant sediment types found in the northern Gulf of Mexico (GOM) nearshore environments potentially impacted by the *BP Deepwater Horizon* (DWH) oil spill. The collection of sediment samples proved particularly challenging among coastal oyster beds and hard sands. For example, the Ponar and van Veen samplers required many attempts when oyster shells or debris prevented the full closure of the sampler jaws. The incomplete closure of the sampler jaws allowed the fine surface particulates and flocculent material to partially or completely wash-out of the grab samplers. Alternative methods, such as a Horizontal box grab sampler, were not able to retain the surface water that potentially contained significant portions of the fine surficial sediment and flocculent material. The Diver push corers required more time to collect replicate samples. Hammer and Piston corers proved difficult to use in wavy conditions and hard sandy sediment. The results from this study were used to standardize the sampling equipment and methods used by the NOAA NRDA DWH field teams. They demonstrated that wide-diameter Valved Push Corers offered the best recoveries of fine surface particulate and flocculent material in shallow water (approximately 0 m to 4 m deep), while Modified van Veen grab samplers performed best in deeper water (approximately 4 m to 30 m) and sediment that was too dense for the Valved Push Corer. These findings indicated that sampling teams equipped with both Valved Push Corers and Modified van Veen grab samplers would recover the maximum amount of fine particles and flocculent material using hand-held sampling devices deployed from small fishing boats capable of quickly travelling long distances and accessing sediment in water depths ranging from approximately 1 m to 30 m.

Introduction

The DWH drilling platform exploded on April 20, 2010 and released millions of gallons of crude oil from the Macondo Well (Mississippi Canyon Block 252, abbreviated Macondo oil) before the leak stopped on July 15, 2010 (Crone and Tolstoy, 2010). The distribution and character of crude oil from the Macondo well that reached nearshore environment[1] varied along the northern Gulf of Mexico (GOM). Nearshore shallow water and benthic habitats are valuable for fisheries. Characterizing the nature and extent of oil introduced into these habitats is an important step in determining exposure and potential injury resulting from the DWH Macondo oil spill.

Multiple technical working groups (TWGs) investigated the impacts of fugitive Macondo oil in the nearshore environment during the summer and fall of 2010. The TWGs developed numerous sampling work plans (SWPs) that governed the collection of thousands of multimedia samples (oil, soil, sediment,

[1] The nearshore environment is functionally defined in this report as the supratidal (above the high tide water), intertidal (between low and high tide water), and subtidal (below the low tide water) environment from which field teams collected samples in accordance with the SMPs produced by the applicable TWGs. The nearshore environment generally extends inland to the stormwater reach of GOM seawater and offshore approximately 3 nautical miles. Multiple TWGs conducted environmental investigations that involved the collection of thousands of soil, sediment, tissue, and water samples within the nearshore environment.

water, tissue and sorbent material). The sediment sampling programs used several different hand-held devices in accordance with guidance documents pertaining to the collection of sediment and benthic samples (Environment Canada, 1994; USEPA, 2001; ASTM, 2008). During this period, the field teams observed highly variable sediment types and recovery efficiencies of fine surface-sediment particles and flocculent material sometimes present at the sediment-water interface. The primary devices used during the initial investigations by the NOAA NRDA DWH and other field teams included the Ponar and van Veen grab samplers. The secondary techniques used by the NOAA NRDA DWH field teams included a Horizontal box grab sampler and Diver tube corers. No single technique worked best in all sediment types (e.g., silty mud, sand, oyster hash, organic matter, and mixtures thereof); however, some techniques worked better than others. The grab samplers were particularly effective, because they were 1) suitable for rapid deployment on a range of small vessels and 2) capable of collecting adequate sediment sample volumes for chemical testing. The core samplers produced sediment samples with minimal disturbance of flocculent material and fine surface particulates; however, diving proved logistically difficult and many replicate samples were required to achieve the targeted sample volumes. In addition, the low abundances of Macondo oil in laboratory tested sediments collected in 2010 from visibly impacted areas raised concern about the ability of nearshore sample collection methods to accurately recover the Macondo oil during the 2010 sampling period.

The purpose of this study was to systematically evaluate the performance of seven common industry-accepted sampling methods for the purpose of optimizing the sampling protocols for a wide range of sampling conditions within the study area. The study included all of the sediment sampling devices used by nearshore sampling teams in 2010, plus additional techniques that were successfully employed during sediment investigations in other locations. The data quality objectives (DQOs) focused on the recovery of fine particles and flocculent material at the sediment water interface using hand-held sampling devices deployed from small fishing boats capable of quickly travelling long distances and accessing sediment with water depths between 1 m and 30 m. The efficient recovery and retention of fine particulates and flocculent material in the upper 2 cm is significant, because these particulates likely represent recent deposited material, potentially including Macondo oil, and is one of the most biologically significant sub-tidal zones for the assessment of Macondo oil exposure.

Methods

This sampling evaluation consisted of pilot field studies using a variety of equipment at locations with a variety of sediment types. Previous sampling locations were reviewed to help identify the variety of sediment types targeted by this study and ensure that samples were not collected in locations that were previously disturbed by earlier sampling efforts (Figures 1 to 3). The pilot studies employed seven sampling techniques capable of rapid deployment on light watercraft among the dominant sediment types observed in the GOM nearshore environments. The vessels used for this effort represented the same types of vessels and equipment employed by sediment sampling teams during the initial nearshore assessment (April to December 2010). A single group of experienced field-sampling personnel conducted this study in order to maintain procedural consistency. The following evaluation discusses multiple technical and logistical criteria used to select the best site-specific sampling methods for future nearshore sediment-sampling events.

Sampling Equipment

The nearshore sediment sample collection methods (Figure 4) used in the initial response from April to October, 2010 included hand-operated sampling equipment capable of rapid deployment from small watercraft (generally 12 to 40 ft fishing boats) with no winch, lifts, moon pools, or special anchors. This evaluation included sampling methods used during the initial response and some were introduced as alternate options for this study. Each of the sampling methods evaluated in this study collected a fixed surface area of sediment and each was designed for quantitative chemical analysis use. Table 1 presents the specific dimensions of the equipment and surface sediment recovery volumes used in this study. A more detailed description of each sediment sampling method used in this study follows.

Ponar Grab Sampler

The Ponar grab sampler is a "clam-shell" device with two opposing jaws connected to scissor arms that close when the sampler is lifted off the sediment surface (Figure 4a). The sampling teams used self-tripping Ponars equipped with spring-loaded pins that release when the sampler strikes the sediment and meets sufficient sediment resistance. The jaws of the Ponar sampler overlap when closed and theoretically prevent sediment loss during sample recovery. The top of the sampler contains screens that allow water to pass through the device during the decent of the sampler. The screens assure an even vertical decent and limit the formation of a bow wave as the sampler is lowered to the bottom. Rubber flaps cover the screens when the clam-shell is closed and prevent sample loss when the device is lifted to the boat. The penetration of the sediment is largely controlled by the weight of the device and the force of the lever arms.

On the boat, the standing water is siphoned off and returned to the sampling area before the surface sediment (0-2 cm) is skimmed off, composited, homogenized, and divided into sample collection jars. Ponar samplers are well-suited for the collection of soft to moderately hard surface sediments. They are manufactured in different sizes to address project specific objectives, such as sample volume requirements and ease of use in the field. The petit Ponar samplers used in this study measured 15.2 cm x 15.2 cm x 15.2 cm (6" x 6" x 6") and sampled an area of 0.023 m^2. The Ponar samplers used by the 2010 TWG sediment sampling teams included the 6" x 6" x 6" and 9" x 9" x 9" sizes. Larger Ponars are available, but they require multiple operators and winches due to the additional size and weight.

van Veen Grab Sampler

The van Veen grab sampler is also a "clam-shell" device; however, the van Veen grab has longer-opposing lever arms that provide greater leverage and more forceful penetration of harder or more densely vegetated sediment when the sampler jaws are closed (Figure 4b). The van Veen uses a mechanical "latch" rather than a spring-loaded pin to trigger the closure of the clam shell jaws when the unit meets sufficient sediment resistance. The doors on the top of the sampler open for the removal of sediment from the surface and may have removable screens with rubber flaps. The sediment access doors for the van Veen are fixed in-place during decent, which prevents or restricts the passage of water during vertical descent, thereby potentially forming a bow wave during decent.

On the boat, the standing water is siphoned off and returned to the sampling area before the surface sediment (0-2 cm) is skimmed off, composited, homogenized, and divided into sample collection jars. The van Veen samplers are well-suited for the collection of soft, moderately hard, and vegetated surface sediments. They are manufactured in different sizes to address project specific objectives, such as sample volume requirements and ease of use in the field. The van Veen samplers used in this study and by 2010 TWG sampling teams measured 15.2 cm x 15.2 cm x 15.2 cm (6" x 6" x 6") and sampled an area of 0.023 m^2. Larger van Veen samplers are available, but they require multiple operators and winches due to the additional size and weight.

Ekman Grab Sampler

The Ekman grab sampler is a box shaped device that is lowered into the surface sediment. Two spring-loaded doors are then triggered to close using a messenger (weight) (Figure 4c). Once triggered, the spring releases and rapidly forces the doors closed after which the operator lifts the device to the surface. Unlike the Ponar and van Veen samplers, the Ekman sampler relies solely on gravity to penetrate sediments and the door closure is activated solely through the strength of the springs. The two thin overlapping lids on top open to let water pass on the descent and allow access to the top of the sediment core when returned to the surface. The Ekman sampler offers the advantage of being triggered at any specific level as determined by the operator via the messenger. In very soft sediments, the van Veen and Ponar samplers may not meet sufficient resistance to trigger at the correct depth.

On the boat, the standing water is siphoned off and returned to the sampling area before the surface sediment (0-2 cm) is skimmed off, composited, homogenized, and divided into sample collection jars. The Ekman samplers are well-suited for the collection of soft to moderately hard sediments. They are manufactured in different sizes to address project specific objectives, such as sample volume requirements and ease of use in the field. The Ekman samplers used in this study measured 15.2 cm x 15.2 cm x 15.2 cm (6" x 6" x 6") and sampled an area of 0.023 m^2. Larger Ekman samplers are available, but they require multiple operators and winches due to the additional size and weight. Ekman samplers were not generally used by the TWG field sampling teams in 2010, but have been used successfully in past LA coastal sampling programs.

Horizontal Box Grab Sampler

The Horizontal box grab sampler is a stainless-steel hinged box that slides into the sediment from one side, similar to a dredge shovel (Figure 4d). The sampler is inserted at an angle and drawn horizontally through the sediment. The lid is closed and a rectangular section of sediment is recovered. Divers can use Horizontal box samplers to collect hard sediments containing cobble, clay, dense shellfish, or surface debris. The Horizontal box samplers are custom built with fixed dimensions and are capable of collecting moderate to large surface sediment samples. The Horizontal box sampler used in this study and by TWG sampling teams in 2010 measured 20.3 cm x 15.2 cm x 10.2 cm (8" x 6" x 4") and sampled an area of 0.03 m^2. Larger units are not presently available and may prove unwieldy for divers. On the boat, the box samplers have little ability to retain water, which effectively results in the loss of the overlying water and likely flocculent material through the juncture between the main body of the sampler and the closure before it is opened.

Diver Push Corer

The Diver push corers are plastic tubes that SCUBA divers push into the sediment manually (Figure 4e). They work best in soft to moderately hard sediment. Diver push corers have difficulty in hard sediment or sediments with large shells, because the penetration depth is limited to the force exerted by the diver's hand on the top of the core. The core liners are typically made of stiff clear, non-reactive plastic (e.g., polycarbonate or butyrate). Once inserted into the sediment to a depth of approximately six inches, a polyethylene cap is placed on the top of the core. After a small hole is dug beside the corer, the diver places a second polyethylene cap on the bottom of the corer and returns to the boat with the core in its original vertical position. Alternatively, the diver may slide his/her hand under the core while it is extracted from the sediment. The volume of surface sediment is controlled by the diameter of the core. The Diver push corers used in this study and by TWG sampling teams in 2010 measured 7.62 cm diameter x 25.2 cm height (3"x10") and the area sampled is 0.005 m^2. Multiple cores are required for the production of large sample sizes. These cores can be processed in the field by removing surface water and collecting the surface sediment to 2 cm, or cores can be chilled or frozen and processed in the laboratory.

Hammer Tube Corer

A Hammer tube corer consists of a plastic liner inside a stainless steel tube, which is mounted on the end of a metal drive shaft equipped with a slide hammer (Figure 4f). The slide hammer is used to drive the corer barrel into the sediment. A core catcher at the bottom of the barrel closes to prevent sediment from flowing out of the core barrel when it is pulled from the water. The Hammer corer penetrates with greater force than does the diver core, which results in improved performance in hard sediment. While large shells and cobbles can obstruct the passage of sediment into the core barrel, the hammer allows the corer to be driven between shell hash and through organic debris. The coring samplers allow for the preservation of stratigraphic layers and the recovery of fine surface sediments. The core liners are typically made of stiff clear, non-reactive plastic (e.g., polycarbonate or butyrate). The volume of surface sediment is controlled by the diameter of the core. The Hammer core liners used in this study measured 5.08 cm diameter x 30.5 cm height (2" x 12") and the area sampled is 0.002 m^2. Hammer cores can also be 3" in diameter to sample a larger area. Multiple cores are required for the production of large sample sizes. Hammer cores were not used by TWG field sampling teams in 2010, but have been used successfully for other sediment sampling programs.

Piston Corer

A Piston corer consists of a plastic core tube liner mounted on an aluminum head, fitted with metal extension rods sized to reach from the operator to the sediment surface, similar to the Hammer corer (Figure 4g). A piston slides within the core barrel providing suction within the core tube. The position of the piston is held at a fixed height above the sediment surface by a rope that extends to the operator. The core tube is placed on the surface of the sediment, the rope fixed to a stationary object, and a hammer used to drive the corer into the sediment. The piston provides vacuum pressure to prevent sediment from flowing out of the core barrel when it is pulled from the water. As with the other coring methods, large shells and cobbles can obstruct the passage of sediment into the core barrel. As with the Hammer corer, the Piston corer allows for the preservation of stratigraphic layers and the recovery of fine surface sediments. The core liners are typically made of stiff clear, non-reactive plastic (e.g., polycarbonate or butyrate). The volume of surface sediment is controlled by diameter of the core liner. The Piston core liners used in this study measured 7.62 cm diameter x 61 cm height (3" x 24") and the area sampled is 0.005 m^2. Multiple cores are required for the production of large sample sizes. Piston cores were not used by TWG field sampling teams in 2010, but have been used successfully for other sediment sampling programs.

Sample Components

The field samples contained multiple components in varying proportions. These components included:

Sand

Sand is generally made of quartz although limestone sands occur in some more tropical areas. It is typically formed by the abrasion of larger rocks and subsequent migration by glacial and fluvial processes (Plummer et al., 2014). Environmental scientists generally describe sand as minerals that are smaller than gravel (< 4.75 mm) and larger than silt (> 0.075 mm) (ASTM D422, 2007; ASTM D2487, 2011). Sand tends to accumulate in slightly sheltered environments proximal to areas with moderate to high hydrodynamic energy, such as river bends, expansions, outlets, and the lee side of barrier islands (Bird, 2008; Charlton, 2008). Sandy sediments can be hard to penetrate and lack cohesive plasticity unless they are mixed with silts, clay, and organic matter. For this reason, some degree of force is typically applied to the sediment sampler to help penetrate a sandy bottom. In addition, a closure mechanism at the bottom of the sampler is often needed to retain sandy sediment that might otherwise flow out of the sampler.

Silt

Silt is generally composed of quartz or feldspar, abraded from larger rocks and transported by glacial, fluvial, or aeolian processes (Plummer et al., 2014). Environmental scientists generally describe silt as minerals that are smaller than sand (< 0.075 mm) and larger than clay (> 0.005 mm) (ASTM D422, 2007; ASTM D2487, 2011). Silt has a high surface area to volume ratio that allows it to adsorb larger proportions of hydrophobic contaminants (e.g., petroleum) compared to larger particles (e.g., sand and large shells) (Sun and Zang, 2009; Zhang et al., 2010; Wang et al., 2011; Gong et al., 2014). Silty sediments tend to accumulate in environments with lower hydrodynamic energy, such as river deltas, inner embayments, and lakes (Bird, 2008; Charlton, 2008). Silts are generally soft and easily penetrated by corers and grab samplers. They are also somewhat cohesive so that retention in the sediment sampler is not usually a problem.

Clay

Clay is composed of silicates shaped by the flow of dilute acids, abraded from the source rock and transported by glacial, fluvial, or aeolian processes (Plummer et al., 2014). Environmental scientists generally describe clay as minerals that are smaller than silt (< 0.005 mm) and larger than nanoparticles (> 0.001 mm) (ASTM D422, 2007; ASTM D2487, 2011). Clay has a very high surface area to volume ratio that allows it to adsorb larger proportions of hydrophobic contaminants (e.g., petroleum) compared to larger particles (e.g., silts, sand and large shells) (Sun and Zang, 2009; Zhang et al., 2010; Wang et al., 2011; Gong et al., 2014). Clayey sediments tend to accumulate in environments with lower hydrodynamic energy, such as river deltas, inner embayments, and lakes (Bird, 2008; Charlton, 2008). Clays are generally soft and easily penetrated corers and grab samplers. They are cohesive so that retention in the sediment sampler is not usually a problem.

Organic Matter

Organic matter in sediment is typically composed of living and dead plants and animals from terrigenous and aquatic environments (Whelan and Farrington, 1992). Larger organic matter is typically composed of living root matter and benthic animals while the smaller organic particulates consist of bacteria, phytoplankton, zooplankton, and decaying biomass. This organic matter frequently has a high surface area to volume ratio and hydrophobic properties that allow it to adsorb larger proportions of hydrophobic contaminants (e.g., petroleum) compared to larger mineral particles (e.g., silts, sand and large shells) (Means et al., 1980; Weber et al., 1982; Gong et al., 2014; Sorensen et al., 2014). Organic matter accumulates especially well in aquatic environments with lower hydrodynamic energy, such as river deltas, inner embayments, and lakes (Bird, 2008; Charlton, 2008). For this reason, organic matter commonly co-occurs with silts and clays and improved the cohesion of these sediment mixtures. Sediments with abundant small organic particles are generally soft and easily penetrated. They are also cohesive so retention in the sediment sampler is not usually a problem. Sediments with thick root matter can be difficult to penetrate; therefore, sediment sampling locations in areas of thick sub-aquatic vegetation are typically relocated outside of the root area.

Oyster Shell Hash

For the purposes of this analysis, oyster shell hash is defined as a mixture of oyster shells and ambient sediment. Live oysters grow among the shell fragments and the oyster hash surfaces serve as suitable substrate on which oyster larvae may settle and grow (Kilgen and Dugas, 1989). Small live oysters are commonly observed on the surface of larger shells. Large whole oysters can grow to the size of an adult human hand while the broken fragments can be as small as sand grains. The size and shapes of the oyster shells and fragments pose many challenges for the collection of sediment samples. Large and small shells commonly obstruct the closure of boat-operated grab corers (Ponar, van Veen, and Ekman). In addition, large shells can obstruct the passage of core tube samplers into the sediment bed. All sampling techniques benefit from supplemental weight or force to drive the sampler into sediment containing heavy oyster hash.

Flocculent Material

Flocculent material (floc) is a mixture of organic and mineral (silt and clay) matter capable of adsorbing hydrophobic contaminants, such as petroleum, and accumulating at the sediment-water interface (Bragg and Yang, 1993; Lee and Page, 1997; Droppo, et al., 1997; ITOPF, 2002; Neto et al., 2006). It is often found in close proximity to fine particulate matter (silt- to clay-sized) in a transitional phase between suspended solid in the water column and recently deposited particulates on the sediment surface. For this reason, flocculent material is typically collected as a sediment sample unless specialized equipment are employed, such as slurp guns. Flocculent material possesses high organic carbon and water content that imparts near-neutral buoyancy; consequently, flocculent material tends to accumulates in surface depressions and settle slowly into the sediment. Additionally, flocculent material is easily disturbed with a high potential for resuspension. As flocculent material accumulates, the older material at depth is compacted, dewatered, and incorporated into the sediment. The thickness of the flocculent material layer varies according to the particulate loading and fluid dynamics at any particular location; however, the flocculent material layer is generally concentrated within 0.5 cm to 2 cm of the sediment-water interface in many GOM nearshore environments. Before its incorporation into the sediments, flocculent material effectively floats just above the surface of the sediment where currents or physical disturbance can readily re-suspend or wash it away. The collection of flocculent material is best accomplished with sampling methods that minimally disturb the surface sediments and recover approximately 5 cm to 10 cm of overlying water, as some disturbance of the flocculent material layer will likely occur.

Overlying Water

Overlying Water is the water that resides immediately above the contiguous sediments. The overlying water is significant for this study, because the movement of the overlying water generally controls the movement of the fine surface particulates and flocculent layer (Muschenheim and Lee, 2002). The overlying water itself contains low proportions of solids compared to the flocculent material and sediment layers. Aside from its association with the flocculent layer, the overlying water is not considered a significant source of hydrophobic contaminants (e.g., petroleum) relative to the sediment particulates and flocculent material. The overlying water is typically discarded by field sampling teams after the fine particulates and flocculent material settle out.

Sediment Locations

The five substrate types (Figure 5) evaluated in this study represented the majority of substrates encountered by GOM field teams between April and October, 2010. Sand, silt, oyster hash, silty sand mixtures, and organic mud dominated the samples collected in this study. The field team collected multiple oyster hash samples, because this sediment type is heterogeneous and important to the objectives of this project. A more detailed description of each location follows.

Contact Point 028

Contact Point 028 (Figure 1) was identified by previous sampling teams as a silty mud. The sediment collected as part of this study featured four basic layers (Figure 5a). When ordered from shallow to deep, these layers included an unconsolidated flocculent layer (approximately 1-3 cm thick), an olive green silty layer (approximately 1-2 cm thick), a black silty layer with shell fragments (approximately 5 cm thick), and a mixture of black and finer dark gray silts (> 10 cm thick). This sampling location represented very soft, silty, and cohesive mud.

Tonging Reef
Tonging Reef (Figure 1) was identified as an oyster bed with thick shell hash by local shell fishermen. The sediment collected as part of this study featured two primary layers (Figure 5b). The most surficial shells were mixed with flocculent and olive green silts (approximately 1-3 cm thick). The next deeper layer contained shells mixed with dark gray silts (> 10 cm thick). This sample location represented a reef consisting of discontinuous oyster beds with varying thicknesses.

Contact Point 751
Contact Point 751 (Figure 1) was identified as a thick oyster bed and shell hash area. In 2010, a field team needed three hours to collect an acceptable sediment sample from this area using a Ponar grab sampler. According to the field team, this sample represented the difficulty of collecting sediment samples well inside a large and thick oyster reef. The sediment collected as part of this study featured two primary layers (Figure 5c). The most surficial shells were mixed with flocculent material and olive green silts (approximately 1-3 cm thick). The next deeper layer contained shells mixed with dark gray silts (> 10 cm thick). In general, the shells appeared larger and the flocculent material less abundant in Contact Point 751 compared to Tonging Reef.

CAT1
The CAT1 location (Figure 1) was a major sand bed near Cat Island. The sediment stratigraphy consisted of three primary layers (Figure 5d). The surficial flocculent layer was thin (< 1 cm thick) and colored light brown. The deeper layers consisted of well-sorted light brown sand layer (approximately 1-2 cm thick) that transitioned to well-sorted gray sand (>5 cm thick). This sediment represented hard, flowable, medium to coarse sand.

CAT2
The CAT 2 (Figure 1) location was selected in a transitional area between the outer sand beds and inner mudflats. Ponar grab samples were collected along a northerly transect from CAT1 in order to find a sampling location dominated by softer silty sand (Figure 5e). The sediment stratigraphy consisted of a surficial flocculent layer (< 1 cm thick), a well-sorted light brown sand layer (approximately 1-2 cm thick), and a mixture of gray silts and sand (>5 cm thick). This sampling location represented slightly softer and more cohesive sand.

CAT3
The CAT 3 location (Figure 1) was identified by Mr. Brian Bosch (MDEQ) as the most accessible eel grass bed in the area (Figure 5f). Unfortunately, the water depth was too shallow for the boats used in this study. No alternative location was accessible at the time of sample collection, thus this evaluation does not include submerged aquatic vegetation zones.

Bay Jimmy
The Bay Jimmy locations (Figure 2) represented organic-rich silt and clay that was similar to the upper horizons at Contact Point 028 (Figure 5a) except the organic layer was very deep and exceptionally soft.

East Bay
The East Bay locations (Figure 3) represented a mixture of organic silt, clay and sand that was similar to Cat 2 (Figure 5e).

Acceptable Sample Determination

This study adopted the sample evaluation criteria established during the sample collection efforts between April and October, 2010. The field teams needed to collect a minimum of 1,250 mL of surface sediment

(0-2 cm) in order to supply the laboratories with adequate sample volume required for physical and chemical characterization (Table 2). In general, the sample teams collected approximately 1,500 mL to 2,000 mL in order to assure sufficient sample volume when filling the sample containers.

An acceptable sample was defined as the recovery of at least 5 to 6 cm of the surface sediment with an intact surface layer. Sediment samples were considered unacceptable if the surface layer contacted the top of the sampler or exhibited obvious features of mixing (e.g., no difference between the surface and subsurface when differences were known to exist). The field teams were instructed to observe the existence of a flocculent layer on the surface of each collected sample.

During the earlier sample collection efforts between April and October, 2010, the sediment sample collection teams siphoned off the overlying water before scooping off the 0-2 cm sediment. During this study, we observed that some to most of the flocculent material moved with the overlying water and was lost when the overlying water drained out of the sampler or was removed when the overlying water was siphoned off the fixed sediment surface. For the purposes of this study, the overlying water was allowed to settle at least 15 minutes until the water fraction clarified at which point up to 1L of overlying water immediately above the sediment was collected in a separate sample container.

Evaluation Criteria

Identifying the best sampling methods for a particular site typically involves multiple, sometimes competing, technical and logistical criteria. The five substrate types in this study represent a diverse range of field conditions that necessitate a flexible and adaptive sampling approach. Recognizing that the field teams do not have perfect information about the exact sediment type or field conditions they may encounter, the evaluation criteria are intended to identify several pieces of sampling equipment that will allow the field team to respond to the varying challenges they might encounter.

This study focused on seven evaluation criteria (Table 3). Each criterion was ranked from 1 (poor) to 5 (excellent) in increments generally associated with different levels of practical significance for the sampling program. The seven evaluation criteria emphasized in this study (Table 3) follow.

<u>Number of Replicates</u>
The number of replicates was the minimum number of attempts needed to produce an adequate volume of surface sediment based on the dimensions of the sampler. The number of replicates was calculated by dividing the required volume of surface sediment (1,250 mL) by the volume of surface sediment (0-2 cm) recovered in one successful sample recovery attempt (Table 1). This calculation conservatively estimated that 10% of sediment recovered was lost or compromised during sample processing and handling.

<u>Collection Time</u>
The collection time was the estimated time needed to produce 1,250 mL of surface sediment at each sample collection location. It was calculated as the time required to successfully recover a surface sample in this study multiplied by the number of replicates described above. The average collection time of up to 10 attempts were made when the sediment was particularly complex or the sampler performance was particularly variable. The collection time estimate included the assumption that the initial assembly of the sampling equipment was complete at the time of departure.

<u>Surface Sediment Integrity</u>
The degree of surface sediment disturbance was determined by inspection of the overlying water turbidity, recovered sample stratigraphy, and comparability among other samples collected from the

same location. The surface sediment integrity rank was high when the surface stratigraphy was well resolved and low when deep mixing or extensive re-suspension occurred.

Simplicity of Setup and Deployment
Simple field techniques tended to be more practical and effective than more complicated techniques when difficult field conditions are encountered, new challenges arise, or equipment malfunctions occur. This evaluation criteria focused principally on the level of effort needed to setup the equipment and penetrate the sediment. It included the addition or subtraction of weights or hammers required to penetrate the sediment. It also included the malfunction of closure mechanisms, like boat-operated grab samplers (Ponar, van Veen, and Ekman).

Level of Effort to Recover the Sample
The level of effort to recover a sample encompassed the withdrawal of the sample from the sediment, the transfer to the boat deck, and the transfer of surface sediment into a compositing bowl. Components of this process that required extra effort included the attachment and removal of slide hammers, the removal of overlying water, and additional sampler handling procedures.

Logistical Simplicity and Training
The grab samplers were relatively simple devices that required little setup and training. The Hammer and Piston corers required a modest amount of planning, setup, and training that could be accomplished in less than one day. Diver push corers and Horizontal box grabs required specialized diver training, advanced planning for boats and equipment, and contingency planning when inclement weather threatened diver safety.

Retention of Surficial Fine Particles and Flocculent Material
The surficial fine particles and flocculent material contained sediment that was deposited recently or that was in the process of deposition. These particulates are important because recently deposited fine particulates and flocculent material exhibit high surface area to volume ratios and can contain high organic content capable of adsorbing petroleum.

Pilot Studies

The field team conducted 2 pilot studies in September and November 2010, respectively. Each pilot study consisted of 1 to 10 sample collection attempts using multiple sampling techniques in the five dominant GOM nearshore sediment types.

Field Conditions – Pass Christian, MS
The initial field trial took place around Pass Christian, MS (Figure 1) because it presented many different sediment types in and around oyster beds. The field team departed the marina every morning from September 28, 2010 to September 30, 2010. The boat captain and first mate used a GPS-equipped depth finder to locate each sampling point. The NewFields sampling team consisted of Bill Gardiner, Collin Ray, and Stephen Emsbo-Mattingly. Sampling activities were witnessed by one representative from the Mississippi Department of Environmental Quality (MDEQ) and one member of Entrix representing British Petroleum. The dive team participated in this study on September 28, 2010.

The weather was mostly sunny with temperatures between 64°F and 81°F. The winds were light on September 28 and 29 and blew less than 10 mph out of the north and north, north east. The waves were generally less than 1 ft. The winds picked up gradually on September 30, 2010 to about 15 mph from the north and the waves rose accordingly to 1-4 ft.

Field Conditions – Bay Jimmy, LA

The supplemental field trials took place in Bay Jimmy, LA (Figure 2) and East Bay, LA (Figure 3) in order to evaluate the performance of the leading sediment sampling methods in exceptionally soft, high organic mud (silt and clay) proximal to oiled shorelines. The field team departed before 8 am on November 8, 2010 and November 9, 2010 out of Joe's Landing in Jean Lafite, LA. The boat captain and first mate used a GPS-equipped depth finder to locate each sampling point. The NewFields sampling team consisted of Bill Gardiner, Collin Ray, David Puchalski, and Stephen Emsbo-Mattingly. Sampling activities were witnessed by one representative from the Louisiana Department of Environmental Quality (LADEQ) and one member of Entrix representing British Petroleum. No dive team was present, because the high amounts of suspended sediment greatly reduced water clarity and visibility.

The weather was mostly sunny with temperatures between 50°F and 70°F. The winds were light and blew less than 10 mph generally out of the east. The waves were generally less than 1 ft.

Field Conditions – East Bay, LA

Additional organic silt, clay, and sand sediment samples were collected in East Bay (Figure 3) proximal to oiled shorelines. The field team departed before 8 am on November 11, 2010 and November 12, 2010. The boat captain and first mate used a GPS-equipped depth finder to locate each sampling point. The NewFields sampling team consisted of Bill Gardiner, Collin Ray, and David Puchalski. Sampling activities were witnessed by one representative from the Louisiana Wildlife and Fisheries (LWLF) and one member of Entrix representing British Petroleum. No dive team was present, because the high amounts of suspended sediment greatly reduced water clarity.

The weather was mostly sunny with temperatures between 50°F and 70°F. The winds were light and blew less than 10 mph generally out of the east. The waves were generally less than 1 ft.

Results

The results of the pilot studies (Table 4) demonstrated the relative strengths and weaknesses of each sampling method in the dominant sediment types of the northern GOM shoreline. Figure 6 presents selected photos of observations made during this study. There was strong consensus among sampling team members during the performance evaluation regarding the performance of each method.

Silty Mud

The silty mud at Contact Point 028 was very soft, with high moisture and organic content as indicated by the thick black layer.

The van Veen sampler penetrated the sediment well and collected an acceptable sample on the first attempt. The van Veen trigger mechanism allowed the sampler to activate the jaws without over penetrating the sediment. However, overlying water that was present when the grab was first retrieved slowly drained through the bottom of the grab while processing the sample. Shells likely prevented the full closure of the clam-shell doors and a fraction of the fine surface particulates and flocculent material was lost. Despite the loss of the overlying waters, some fine surface particulates, and flocculent material, the light brown, fine surface sediments were successfully recovered and sampled.

The Ponar sampler repeatedly tripped prematurely or not at all. The Ponar requires that the sampler encounters sufficient resistance from the sediment bottom to trip the spring-loaded pin. In this case, the Ponar frequently sank too deeply into the mud and over-penetrated in the very fine silty mud. Over-penetration was indicated by fine surface sediments pushing thorough the screens at the top of the sampler. After 7 attempts an adequate sample was collected, but water drainage was observed from the bottom of the sampler, and the flocculent layer was lost.

The Ekman sampler also over-penetrated the sediment and failed to close properly due to obstructive shells. However, it collected an acceptable sample after four attempts. The overlying water drained from the four corners of the dredge; however, surface flocculent in the center of the sample remained and was successfully collected.

The Horizontal box grab sampler, collected by SCUBA divers, required two attempts, because the diver initially misjudged the penetration depth, forced the surface sediment against the top of the sampler lid, and displaced the overlying water, some fine particulates, and flocculent material out of the sampler. The box grab was easily deployed in the soft substrate and collected sufficient volume with one sample. However, the overlying water, some fine particulates, and some flocculent material drained readily form the surface of the sampler. As with the van Veen grab, the light brown oxic layers on the surface were successfully sampled in the central portions of the sampler while wash out along the edges eroded the surface sediments there.

The Diver push corer worked very well on the first attempt producing a 10" core liner filled half with sediment and half with clear overlying water. The flocculent layer was evident on the surface. Little to no settling time was required for the flocculent layer to stabilize. As the volume sampled is relative low, multiple cores were needed. In the fine sediments visibility may be an issue when collecting multiple cores and will require systematic sampling to prevent the loss of sampling equipment in the low visibility.

The Hammer and Piston corers worked well with at least 10 cm of sediment recovery including the flocculent layer. The core-catcher in the hammer core successfully retained all of the sampled sediment and overlying water. Similarly, the vacuum created by the piston effectively retained all of the sediment and overlying water. Some of the surface sediment was re-suspended during the core processing, particularly when cutting the cores. Suspended sediment was allowed to settle before the surface sediment was transferred to a sample container. The cutting of the core tube added a degree of complexity to core processing, but was accomplished relative quickly.

Overall, the van Veen sampler produced a good sample of the cohesive sediment most easily and in a timely manner (Table 4). However, all of the grab samplers lost some to all of the flocculent layer. By contrast, all of the coring methods (Diver, Hammer, and Piston) recovered the fine surface particulates and flocculent material and at least 5 cm of overlying water. The shorter length of the diver corer allowed easy removal of the overlying water and surface sediment with no core cutting or consequent sediment disturbance.

Silty Sand

The CAT2 area was a transitional area between sandy barrier islands and a silty river delta. It predominantly consisted of silty sand.

The van Veen grab sampler penetrated the sediment well and an acceptable sample was collected on the first grab. The surface sediment was intact and undisturbed and overlying water was clear, indicating a lack of disturbance of the fine surface particulates and flocculent material. The overlying water slowly drained during processing, possibly indicating a loss of the flocculent layers; however, the light brown surface sediment was present after dewatering and was successfully captured in the sample.

The Ponar sampler also penetrated well when fully weighted (approximately 8 cm depth); however, the grab either misfired or the clam-shell jaws frequently failed to close after striking the sediment. This was a common difference between the Ponar and the van Veen grab sampler. A successful sample was collected after three attempts; however, penetration depths were generally shallower than for the van Veen. Surface waters were retained when the grab was first retrieved and were clear and the surface sediment appeared to be intact.

The Ekman sampler exhibited some trouble triggering the spring-loaded doors, but finally recovered an intact sample after four attempts. The penetration depth (6 cm) was less than for the van Veen or Ponar but was sufficient for the purposes of the Gulf sampling program (upper 2 cm). Overlying water was retained in the Ekman dredge when first retrieved but poured out of the corners when the sampler was brought on board potentially causing loss of the flocculent material. Surface sediments were generally intact; however, erosion tracks were present in the surface from the overlying water draining out of the sampler.

The Piston corer successfully sampled the sediment and overlying water, however, both the piston core and hammer corers required a second anchor to hold the sampling vessel in place to create a stable sampling platform. The Hammer corer penetrated the silty sand well and the core catcher was able to retain the sediment sample. However, the core catcher scraped preferential pathways down the outside of the sediment core that allowed the overlying water, some fine surface particulates, and flocculent material to flow out of the core liner during recovery. Because the hammer core does not rely on a piston it was less affected by wave action.

The Horizontal box grab sampler recovered the contiguous sediment well and was easily deployed in the silty sand. However, overlying water was lost during handling at the surface along with some of the fine surface particulates and flocculent material.

The Diver push corer was also sampled easily and quickly at the site. It contained the surface sediment and the overlying water. Given the sandy nature of the bottom at the CAT 1 and CAT 2 sites, multiple samples could be easily collected by the diver.

Overall, the van Veen grab sampler recovered the silty sand more easily than the other grab samplers and was quickly deployed. While it may have lost some of the fine surface particulates and flocculent material during dewatering, it successfully sampled the light brown surface sediments. The Piston and Diver corers preserved the flocculent layer better than the other sampling methods.

Medium to Coarse Sand

The CAT1 location contained thick layers of flowable sand with low organic content. As for the CAT2 station, this hard substrate was penetrated fairly easily with the van Veen and Ponar samplers. The van Veen grab was quickly deployed and collected an acceptable sample on the first attempt. Surface water was clear and the surface sediment was intact. As with other stations, the overlying water slowly drained during processing and caused some loss of flocculent material; however, the flocculent material was not heavy or continuous in this area. The lighter surface sediments were successfully recovered.

The Ponar grab sampler fired readily and had adequate penetration depths when fully weighted. As with the van Veen, overlying water was clear and the surface sediment was intact. The water slowly drained during processing and may have carried some flocculent material with it.

The Ekman grab sampler required 8 attempts to recover a sample due to the misfiring of the spring-loaded doors and the need for extra weight. Once recovered, the sample volume was insufficient and would have required additional deployments. The drainage of the overlying water carried some flocculent material with it.

The Piston and Hammer corers became difficult to use at the CAT1 location due to the stiffening wind and growing waves. The Piston core liner bent and fractured during penetration which compromised the ability of the piston to retain the sediments with mild suction; consequently, no sample was recovered. No additional attempts were made because of the limited number of core liners available at the time of sample collection. Based on historic sampling experience using the Piston corer, it does collect from sand-dominated substrates; however, loss from the bottom of the core during retrieval can be problematic.

The Hammer corer rods bent during sampling and the sand flowed out of the core barrel despite the presence of a core catcher. No sample was retrieved using this sampler. The consistent flushing of sediment past the core catcher indicated poor suitability of this method in coarse sand.

The Diver corer and Horizontal box grab sampler produced successful samples in the first attempt. The Diver corer preserved a thin flocculent layer while the Horizontal box grab sampler likely lost some of the fine surface particulates and flocculent material when the overlying water drained out of the sampler.

Overall, the van Veen sampler recovered the sandy sediment easily. However, it also likely lost most of the flocculent material when the overlying water drained out of the sampler. It was able to successfully sample fine sands at the surface. The Diver push corer preserved the flocculent layer better than the other sampling methods.

Shell Hash

The dense shell hash at the Tonging Reef and Contact Point 751 posed a range of challenges for all of the sampling methods. When sampling as part of the Oyster TWG, the clam-shell grab samplers frequently experienced washout when live oyster clusters or small oyster shell fragments prevented the full closure of the clam-shell doors. The field teams were required to move the sampler location and boats repeatedly until a successful sample was recovered.

The van Veen grab recovered two acceptable sediment samples in 10 attempts. Oyster shell or whole oysters commonly prevented the jaws from closing. The sample was pulled from the water with clear water draining from the sampler. Some fines and heavy shell hash remained in the sampler once placed on the deck. The Ponar and Ekman did not collect an acceptable sample in 10 attempts even when weights were attached to the latter two devices.

The Diver corer and Horizontal box grab samples were collected rapidly and without difficulty. In both cases, the diver visually located a suitable sampling location in the form of a discontinuity in the oyster bed that contained a higher proportion of sediment and lower density of shell hash. The overlying water drained out the sides of the Horizontal grab sampler. The overlying water in the Diver push core was fairly clear and revealed the presence of flocculent material and olive green silt mixed with the surface shell hash in the Tonging Reef sample. The Contact Point 751 sample contained abundant shell hash mixed with lower proportions of fine particulates. The Diver corer was collected with the least disturbance of the fine particles in the surface sediments compared to the other sampling methods. The Hammer corer (2" diameter) failed to recover any sediment sample and the rod connecting the slide hammer to the core barrel bent slightly during penetration. The Piston corer (3" diameter) effectively penetrated the shell hash, possibly due to its large diameter. After settling, the overlying water was siphoned off, the core liner cut, and the surface sediment removed.

Overall, the van Veen sampler recovered the shell hash better than the other boat-operated grab samplers (Ponar and Ekman) at Tonging Reef. However, none of the clam-shell samplers (Ponar and van Veen) performed well at Contact Point 751 due to the high oyster shell density that frequently obstructed the clam-shell doors. As small amounts of fine particles were observed in all of the sediment samples at the Contact Point 751 location, the loss of the overlying water using the Horizontal box grab sampler was not deemed significant; therefore, the Horizontal box corer was the preferred technique for collecting the shell hash largely based on the speed of sample recovery. Nevertheless, the Diver and Piston corers both recovered suitable samples containing more surficial fines than all of the grab samplers.

Thick Organic Mud

Bay Jimmy, LA exhibited exceptionally soft sediments with high organic mud that primarily contained silts and clays. The overlying water contained suspended sediments that prevented visual inspection below a couple of inches. The primary problem with the collection of sediments in Bay Jimmy was the prevention of over-penetration.

The sampling team measured the water depth with a lead line. Ten attempts were made to collect an acceptable sediment sample with the Ponar sampler. All of these attempts resulted in over-penetration in which sediment was forced through the screens on the top of the sampling device. Two attempts with the van Veen grab over-penetrated the sediment, but eight succeeded with careful handling of the trigger mechanism. The Ekman sampler worked every time in the shallow waters of Bay Jimmy (<5 ft). The piston core worked well with the manual piston mechanism. The piston core was also reconfigured in the field with a ball valve that allowed water to pass through the core chamber during penetration, but sealed tightly when the sediment core was gently withdrawn from the sediment. The thickness of the flocculent layer in the piston core was used to determine that the grab samplers accurately recovered flocculent material as well.

Overall, the Piston Corer and Ekman sampler collected the Bay Jimmy sediments best. However, the Ekman sampler used in this study was equipped with a fixed length pole (~5 ft) with the messenger release built into the pole. Additional pole lengths were not available; consequently, the Ekman sampler was limited to water depths of approximately 4 to 5 ft. The van Veen sampler worked well when carefully triggered. The Ponar sampler was not able to collect a good sample in high organic mud.

Fine to Medium Sands

East Bay, LA exhibited fine to very fine sand materials with slightly higher organic content at depth. The sampling team measured the water depth with a lead line. The van Veen grab sampler consistently recovered shallow sediments, with minimal water washout without false tripping. The Ponar penetrated deeper in most locations, seemingly due to the greater weight of the unit, however water loss was noted in 3 sample attempts. The Ekman could only be used in 1 location, where water depth was approximately 4.75 feet. The Ekman provided an acceptable sample; however, the Ekman could only penetrate approximately 10 cm into the sandy substrate.

The piston core with a check valve control worked very well in all locations. The check valve allowed the technician to directly push the core into the sediment without securing the piston core line and required substantially less on-board handling to recover the sample. The piston core worked well in all locations, allowing manual recovering of cores up to 28-inches long and recovering the flocculent layer, when present. Inspection of the cores identified zones in the deeper water without a flocculent zone in three (3) samples. The field team speculated the flocculent zone in these areas was scraped or displaced by the action of the commercial shrimp boats in the area.

The van Veen and Piston Core samplers performed the best in these sediments, while the Ponar worked well. The pole-mounted Eckman performed well in shallow waters; however, a longer pole would be required for sampling in this area.

Physical and Chemical Testing

The field team collected and retained 31 surface sediment and 12 overlying water samples during this study. The sediments were placed on frozen archive and the overlying water samples were analyzed for total suspended solids (TSS). Grain size distributions, total organic content (TOC), and hydrocarbon analytes were not measured, because these determinations were planned for nearby samples. As a reminder, the objective of these pilot studies was an evaluation of the sample collection methods in different substrate types. The archived sediment was used for experiments with alternative hydrocarbon screening techniques.

Discussion

The field trials demonstrated that site-specific factors largely influenced the performance of the different types of equipment for sediment sampling in the Gulf of Mexico. These factors are discussed below.

Sediment Types

The commonly employed clam-shell samplers (van Veen, Ponar, and Ekman) were well-suited for general use in a wide range of sediment types. The samplers worked well unweighted in the softer sediments (i.e., silty mud, silty sand, fine to medium sand, and thick organic mud). Supplemental weights were needed for optimal penetration of hard sediments (i.e., coarser sands and shell hash). The van Veen outperformed the Ponar and Ekman samplers because the former's manual triggering mechanism was less prone to misfires and the sampler jaws were less prone to incomplete closure. The diver-operated Horizontal box grab sampler had little to no difficulty penetrating and collecting both soft and hard sediments; however, this method failed to recover most to all of the overlying water and associated particulates.

The core tube samplers worked well in the soft cohesive sediments (i.e., silty mud, silty sand, and thick organic mud), as well as the sandy sediments (i.e., fine, medium, and coarse sands). The Diver corer worked best in the hard sand and oyster beds because the diver was able to visually avoid large obstructions (e.g., shells and shell hash) and apply the necessary force for penetration to the targeted depth. The Piston corer worked well in the oyster beds laden with shell hash, but the liner bent when the sampling vessel drifted off station in the stiffening wind and increasing waves. This problem could have been rectified easily by using a different liner, had it been available during the study. The stainless steel Hammer corer rod bent during the penetration of the hard sand and oyster shell hash and was not generally recommended for this program.

The soft cohesive sediments (i.e., silty mud, silty sand, and thick organic mud) were more easily sampled than harder coarse sands and shell hash. The field team reported that the sediments off the coast of Louisiana were softer than those off the coast of Mississippi. The supplemental sample collection in Louisiana demonstrated that the Ekman, van Veen, and Piston cores were all capable of collecting acceptable samples in turbid waters less than 5 ft deep. The van Veen and Piston cores were capable of collecting acceptable samples in turbid water greater than 5 ft deep.

Flocculent Recovery

The recovery of surficial flocculent and fine particulates features centrally in selection of sediment sampling strategies. These surficial particulates can contain recently deposited oil with significant potential for contaminant exposure; however, they are difficult to recover with conventional nearshore sampling techniques. For example, the ability of the clam-shell methods to recover flocculent material and fine particulates varied when the overlying water drained from the sampler. The Diver and Piston corers recovered the flocculent and fine particulates well. The Diver corers worked particularly well, because the diver visually avoided large obstructions (e.g., shells) and placed the samplers gently on the sediment surface in order to assure the collection of the flocculent layer. The Piston corer accomplished the same results more slowly than the Diver core, because the operator could not visually relocate the corer away from obstacles. The disadvantage of these coring techniques was the additional time required to collect and process multiple replicates for the production of the targeted sample volume. For this reason, it is recommended that the target sample size for sediments be minimized, when possible. In summary, the sampling equipment exhibited different proficiencies for collecting representative nearshore sediment samples and the differences became more extreme when attempting to recover the surficial flocculent material and fine particulates.

Visibility

The primary advantage of diver collected samples was the ability to quickly locate a suitable sediment sampling area with minimal interference from obstacles, such as oyster shells and vegetative root mats. The sampler techniques operated from the boat deck were effectively blind and required many more sample collection attempts to find an acceptable location. In short, visibility greatly improved the performance of the diver collected samples in the lightly turbid waters around Pass Christian, MS. The diver visibility advantage may not represent the conditions in the more turbid waters of the Louisiana coastline, other river deltas, and coastal estuaries. In more turbid areas, divers would typically locate the sampling area by touch, which could disturb the surface sediments and compromise the sample integrity. Consequently, Diver-operated samplers are not recommended for waters with little to no visibility.

Weather Effects

Weather influenced the performance of the sampling methods. Single-operator sampling methods associated with the clam-shell devices worked best when the wind and waves increased. More complex dual-operator procedures associated with the Hammer and Piston corers became significantly more difficult and the frequency of equipment damage increased in higher wind and waves. Although waves did not significantly exceed 4 ft during the study, wind and waves at or above this level in the past reportedly delayed and cancelled sampling events with divers between April and October, 2010. Contingency planning and the vulnerability of the sampling schedule to cancellations increases significantly when sampling methods rely on more complex techniques (e.g., divers).

Field Sampling Equipment and Method Improvements

In response to the findings of the pilot studies in September and November 2010, NOAA standardized the sampling equipment and procedures used by NOAA NRDA DWH field teams after 2010. The pilot tests described herein and interviews with many NOAA sampling team members identified numerous sampler design and procedural enhancements that were implemented after the 2010 sampling season. These enhancements improved 1) the recovery fine surface sediments and flocculent material, 2) the collection of hard or shelly sediments, 3) the use of sampling equipment by single operators on small fishing vessels, and 4) the equipment reparability. A description of the sampling enhancements used after the NOAA NRDA DWH 2010 field season follows.

Primary NOAA NRDA Sediment Sampler: Valved Push Core

The Valved Push Core sampler is based on the piston core design with enhancements for single operators in a range of surface water conditions and sediment types (Figure 7a). This coring device is customized for flexibility, light weight, larger sediment volume recovery, enhanced durability in exposed marine sampling environments, and ease of repair. The head is machined from aluminum. The lower head is sized to fit inside 3" diameter disposable tubes made from clear polycarbonate or butyrate. An expansion collar can be added to accommodate 4" diameter tubes, if larger sample sizes are required. A one-way valve conveys water through the tube during insertion, which minimizes the bow wave effect. The valve seals during recovery, which creates a vacuum capable of retaining the sediment with minimal disturbance. The upper head is threaded for bull-float extension poles capable of reaching sediment in water depths between 0 m and 4 m. A brass adapter can be used to replace the bull-float poles with ½" standard galvanized pipe, if needed. The quick-release hose clamps allow for rapid tube assembly and removal. The valve materials are constructed from commonly available PVC fittings if any replacement or repair is needed.

Secondary NOAA NRDA Sediment Sampler: Modified van Veen
The Modified van Veen grab sampler can be used in place of the Valved Push Core when one or more of the following situations occur: 1) the water depth exceeds 4 m, 2) the sediment is hard or extremely unconsolidated, or 3) a large sample size is required. This small and lightweight grab sampler recovers a cube of surface sediment measuring approximately 6" length, 6" width, and 6" depth (Figure 7b). The compound contour of the scoop ensures that the full sampling area is represented throughout the biologically active zone. The smaller-sized clam-shell and lighter chain decreases weight for easier manual operation by a single operator in a small fishing vessel. The longer lever arms provide increased leverage for penetrating hard sediment. The overlapping jaws help clear obstructions (rocks, debris, and shells) during closure. The jaws are precisely aligned to seal more tightly, minimize drainage, and maximize recovery of fine surface particulates and flocculent material. The screened doors allow water flow during decent, which reduces the bow wave effect. The rubber covers on the screen doors prevent sediment disturbance during retrieval. The doors can be opened for easy access when processing the sediment samples onboard. The pelican hook latch provides a secure trigger mechanism, preventing misfires during deployment.

Procedural Enhancements
The sample collection personnel received extensive training with the Valved Push Core and Modified van Veen grab samplers before the collection of field samples based on the pilot study results. This training demonstrated improved recovery of fine particulates and flocculent material for the samples collected after 2010. The representative nature of nearshore sediment samples collected with traditional Ponar, van Veen and Eckman samplers, like those collected during the 2010 NOAA sampling effort, is less certain. As part of this training, field teams were instructed to confirm that every sample satisfied several criteria. These criteria included:

1) Recovery of at least 5-6 cm of sediment depth,
2) Minimal disturbance of the surface sediment (0-2 cm),
3) Clear or ambient turbidity in the overlying water with settling permitted, and
4) No sediment leakage from the sampler during recovery or processing.

While not all sediment samples contained flocculent material, its observation at the sediment water interface helped confirm the acceptable sample integrity using the Valved Push Core and Modified van Veen techniques. A sediment sample was recollected if the field team observed drainage of the overlying water through preferential pathways (e.g. rat-hole drainage).

Conclusion

An evaluation of sediment collection equipment and methods demonstrated a potential negative and variable bias in the recovery of fine surface sediments and flocculent material by grab samplers used during the initial DWH nearshore assessment conducted between April and October 2010. This negative bias raised concern about the representativeness of the analytical chemistry results associated with sediment collected using traditional grab samplers in the GOM study area in 2010. Pilot studies conducted in September and November 2010 evaluated the performance of seven sediment samplers under typical nearshore sampling conditions and sediment types. These pilot studies demonstrated that core samplers capable of providing passive vacuums and van Veen grab samplers recovered fine surface particulates and flocculent material from the GOM nearshore study area with the least degree of disturbance. Enhancements to these samplers, the field sampling protocols, and field personnel training enabled field teams to minimize the negative sampling bias after the 2010 NOAA NRDA DWH sampling season. The Valved Push Core worked well in shallow water and the Modified van Veen worked well in deeper water, hard sands, and shell-hashed sediments.

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Table 1. Equipment Dimensions and Surface Sediment Recovery Volumes (mL).

Sample Collection Method	Dimensions (cm)	Surface Area (cm^2)	Maximum Surface (0-2 cm) Sediment Volume (cm^3 = mL)	Estimated Loss During Handling	Estimated Surface Sediment Volume Per Attempt (mL)
van Veen	15.2 x 15.2 x 15.2	232	465	10%	418
Ponar	15.2 x 15.2 x 15.2	232	465	10%	418
Eckman	15.2 x 15.2 x 15.2	232	465	10%	418
Horizontal Box	20.3 x 15.2 x 10.2	310	619	10%	557
Diver Core	Diameter 7.62	45.6	91	10%	82
Hammer Core	Diameter 5.08	20.3	41	10%	36
Piston Core	Diameter 7.62	45.6	91	10%	82

Table 2. Sediment Sample Testing Methods and Collection Volume (mL) Requirements.

Test	Reference Method	Sample Size			Collected (mL)
		Minimum	Ideal	Maximum	
Grain Size	ASTM 422-63	100	200	500	500
TPH/THC	EPA 8015	50	75	150	187.5
PAH	EPA 8270				
Biomarkers	EPA 8270				
TOC	EPA 9060	0.5	2	5	
Archive					562.5
Total		**150.5**	**277**	**655**	**1250**

Table 3. Evaluation Criteria.

Scoring Criteria	Poor		Fair		Excellent
Assume Good Weather Unless Specified Otherwise	●	●	●	●	●
Estimated Number of Replicates To Recover 1,200 mL Sediment	>10	6-10	4-6	2-3	1
Estimated Number of Minutes To Recover 1,200 mL Sediment	>60	45-60	30-45	15-30	1-15
Surface Sediment Integrity	Deep Mixing or No Recovery	0-4+ cm Near Surface Mixing Possible	Mixing Restricted to 0-2 cm	0-2 cm Minimal Disturbance	0-2 cm Well Preserved
Apparatus Assembly and Deployment	Very Difficult	Excessive Malfunction	Premature Triggering	Minor Adjustments Needed - Weights, Rods, Hammer, etc	Little to No Adjustments Out of the Box
Level of Effort to Recover Sample	Very Difficult	Equipment Damage	Difficult in 1-2 ft Waves	Two People	One Person
Planning, Training, and Logistical Simplicity	Periodic Cancellation or Delay Likely	Extra Coordination and Confrimation Required	Advanced Planning and Training Recommended	Custom Equipment or Training Needed	Little Training Using Standard Rental Equipment
Estimated Fine Particle Retention	Fines Lost or No Recovery	Poor Recovery	Some Recovered	Minor Losses	Good Recovery

Table 4. Summary of Sampling Method Performance.

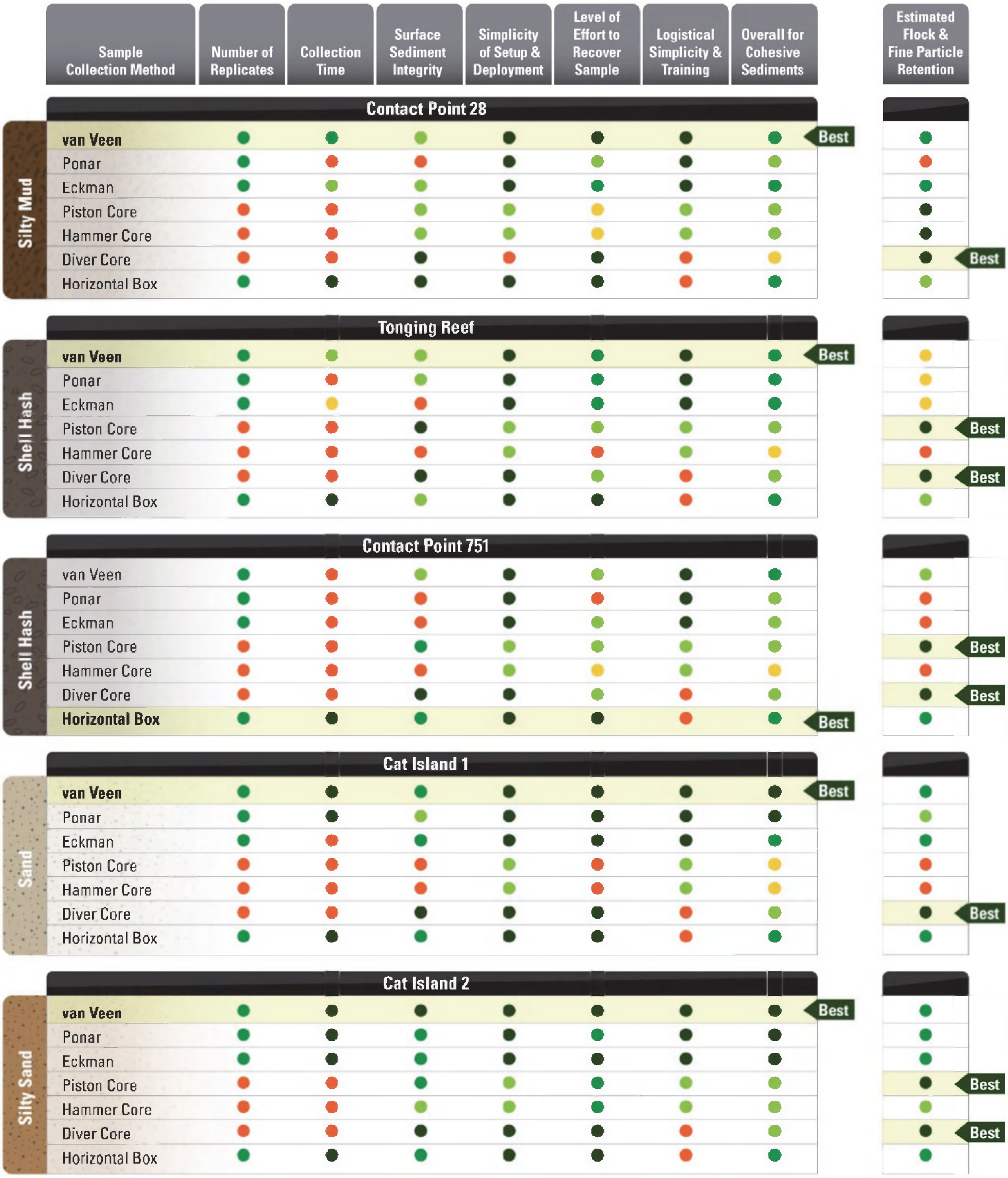


Table 4. Summary of Sampling Method Performance (continued).

Sediment	Sample Collection Method	Number of Replicates	Collection Time	Surface Sediment Integrity	Simplicity of Setup & Deployment	Level of Effort to Recover Sample	Logistical Simplicity & Training	Overall for Cohesive Sediments		Estimated Flock & Fine Particle Retention	
Bay Jimmy											
Organic Mud	**van Veen**	● (dark green)	● (green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	Best	● (green)	
Organic Mud	Ponar	● (red)	● (red)	● (yellow)	● (dark green)	● (green)	● (dark green)	● (light green)		● (yellow)	
Organic Mud	Eckman	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (green)	● (dark green)	Best	● (green)	
Organic Mud	Piston Core	● (light green)	● (green)	● (dark green)	● (light green)	● (green)	● (light green)	● (green)		● (dark green)	Best
East Bay											
Organic Mud/Sand	**van Veen**	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	Best	● (green)	
Organic Mud/Sand	Ponar	● (red)	● (red)	● (yellow)	● (dark green)	● (green)	● (dark green)	● (light green)		● (yellow)	
Organic Mud/Sand	Eckman	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (dark green)	● (green)	● (dark green)		● (green)	
Organic Mud/Sand	Piston Core	● (light green)	● (green)	● (dark green)	● (light green)	● (green)	● (light green)	● (green)		● (dark green)	Best

Figure 1. Sample Collection Locations in Pass Christian, MS.

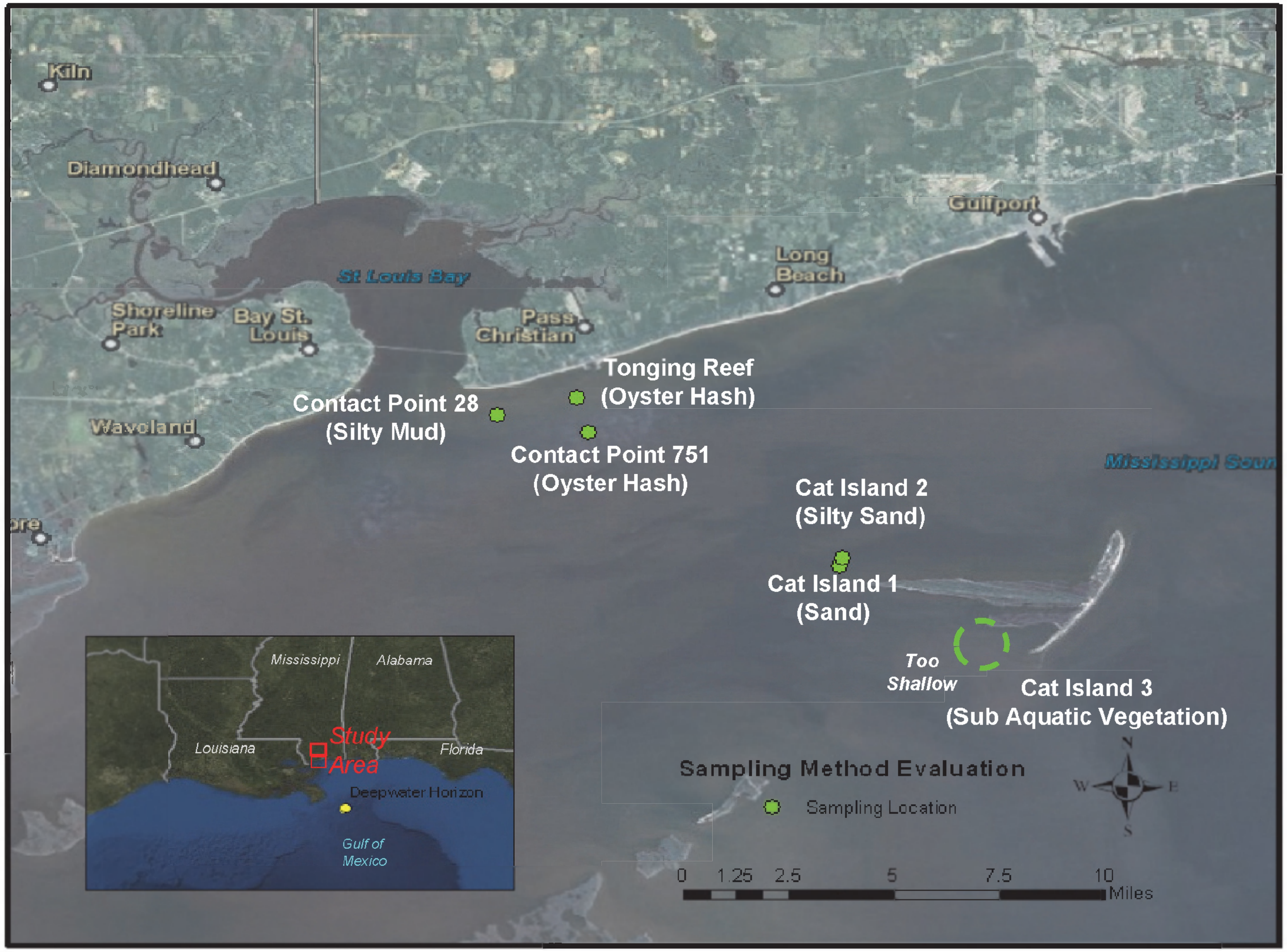


Figure 2. Sample Collection Locations in Bay Jimmy, LA .

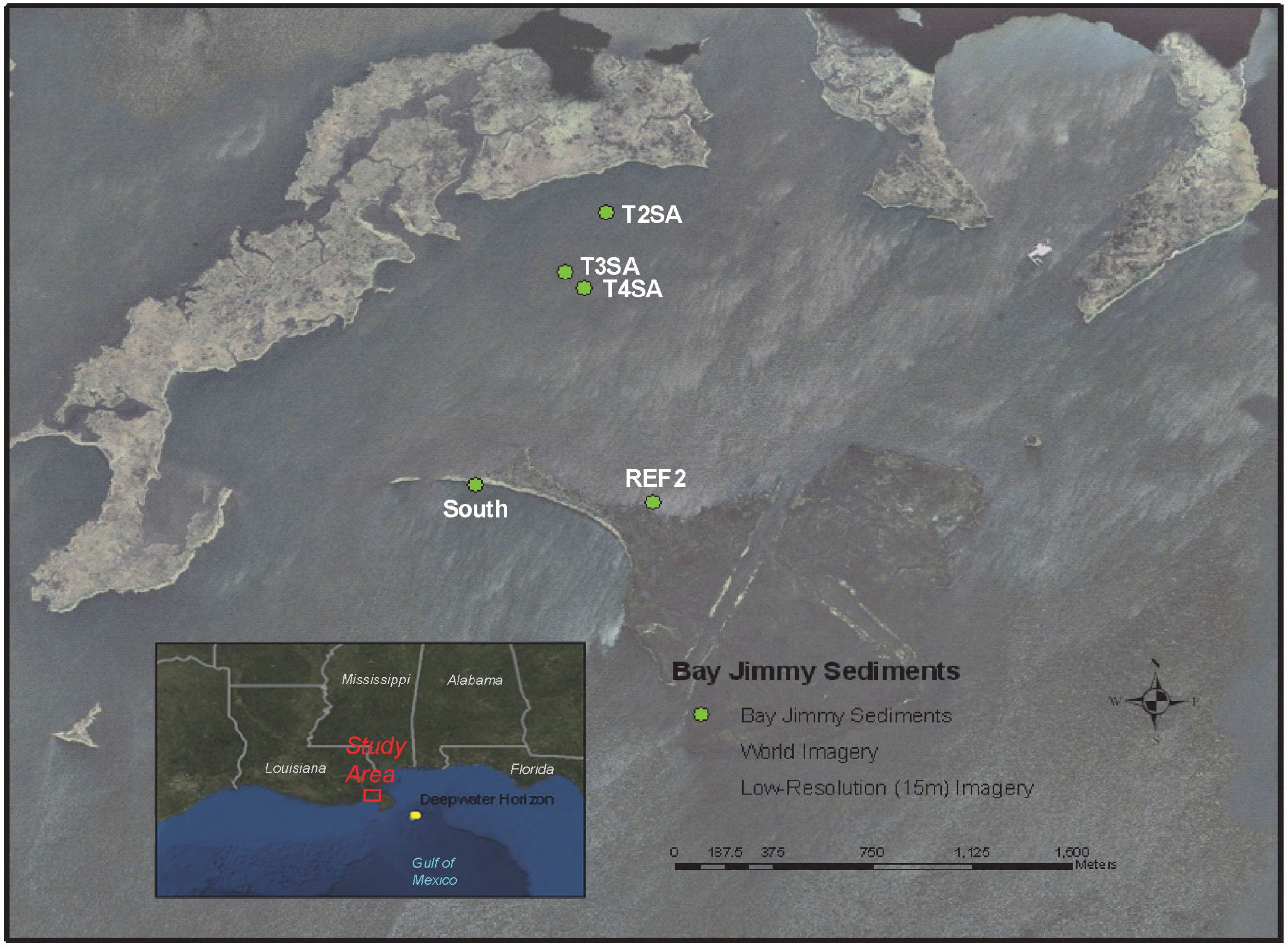


Figure 3. Sample Collection Locations in East Bay, LA .

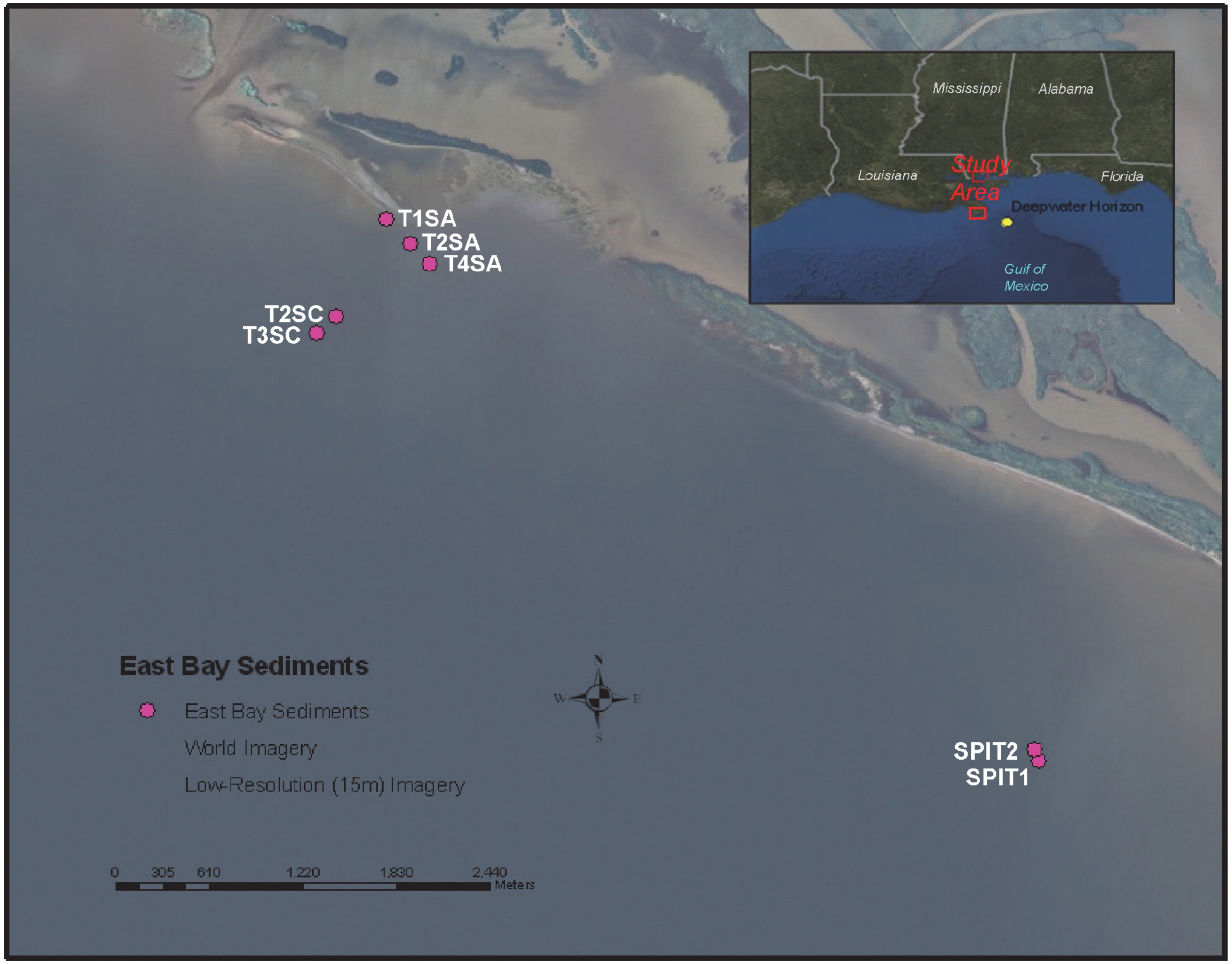
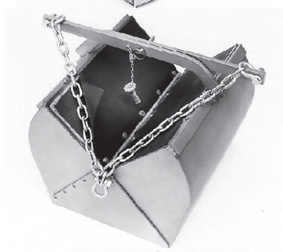


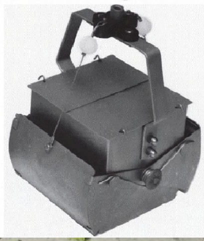
Figure 4. Sediment Sampling Techniques.

a. Ponar
Soft to moderately hard sediment
Sampled from boat
Spring-loaded release after sediment impact
Penetration governed by devise weight
No diver required
Moderate to large surface sediment volume

b. van Veen
Soft to moderately hard sediment
Sampled from boat
Manual release
Penetration governed by devise weight
No diver required
Moderate to large surface sediment volume



c. Ekman
Soft to moderately hard sediment
Sampled from boat
Messenger release of spring-loaded jaws
Penetration governed by devise weight
No diver required
Moderate to large surface sediment volume



d. Horizontal Box Grab
Hard sediment
Sampled by diver
Manual release
Penetration governed by diver
Moderate to large surface sediment volume

e. Diver Push Corer
Soft to moderately hard sediment
Sampled by diver
Penetration governed by diver
Corer diameter limits large objects
Low to moderate surface sediment volume

f. Hammer Corer
Soft to hard sediment
Sampled from boat
Penetration governed by hammer weight
Corer diameter limits large objects
Low to moderate surface sediment volume

g. Piston Corer
Soft to hard sediment
Sampled from boat
Penetration governed by hammer weight
Corer diameter limits large objects
Low to moderate surface sediment volume

Figure 5. Sediment Stratigraphy and Surface Conditions.

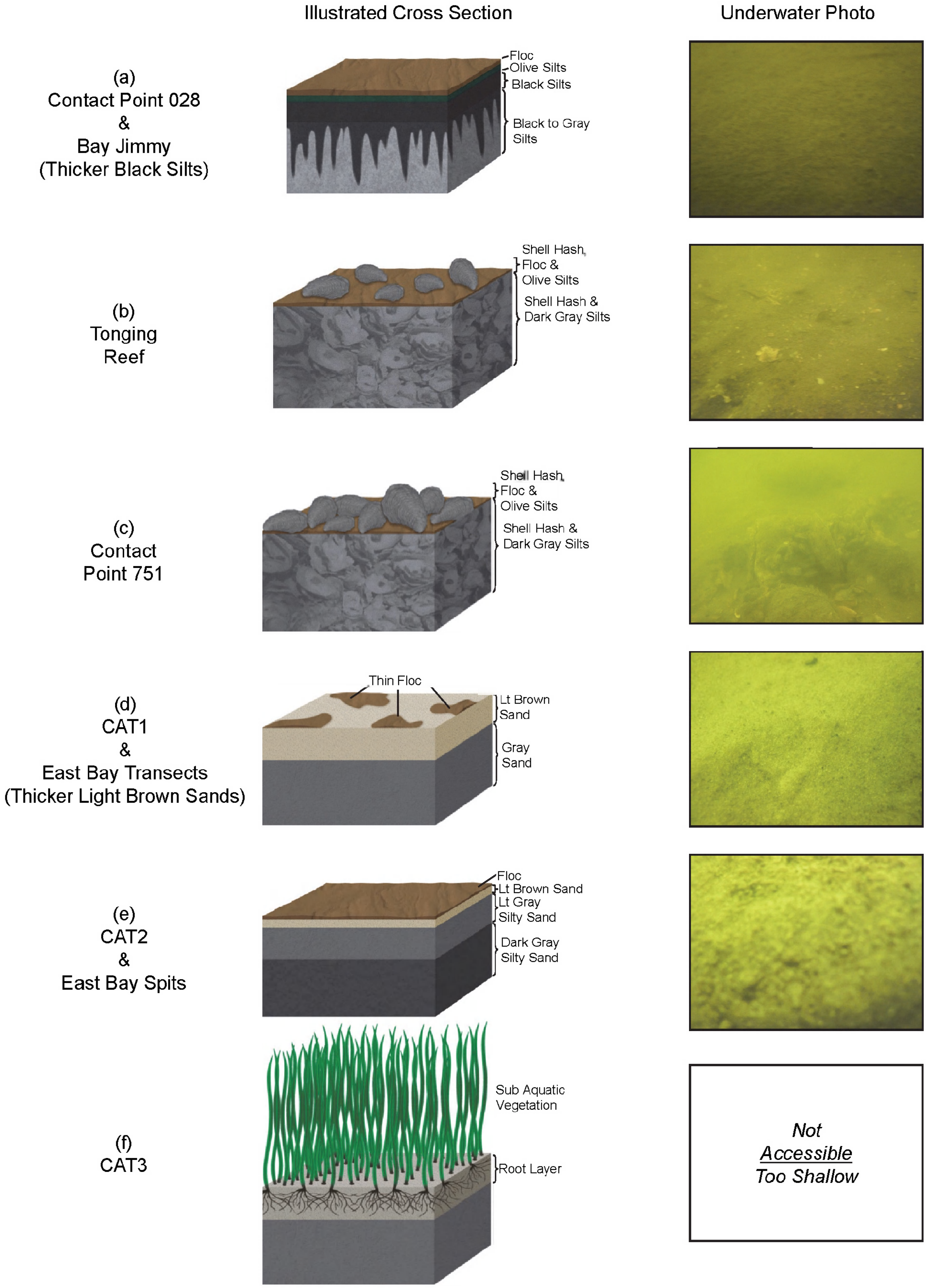


Figure 6. Selected Field Observations.

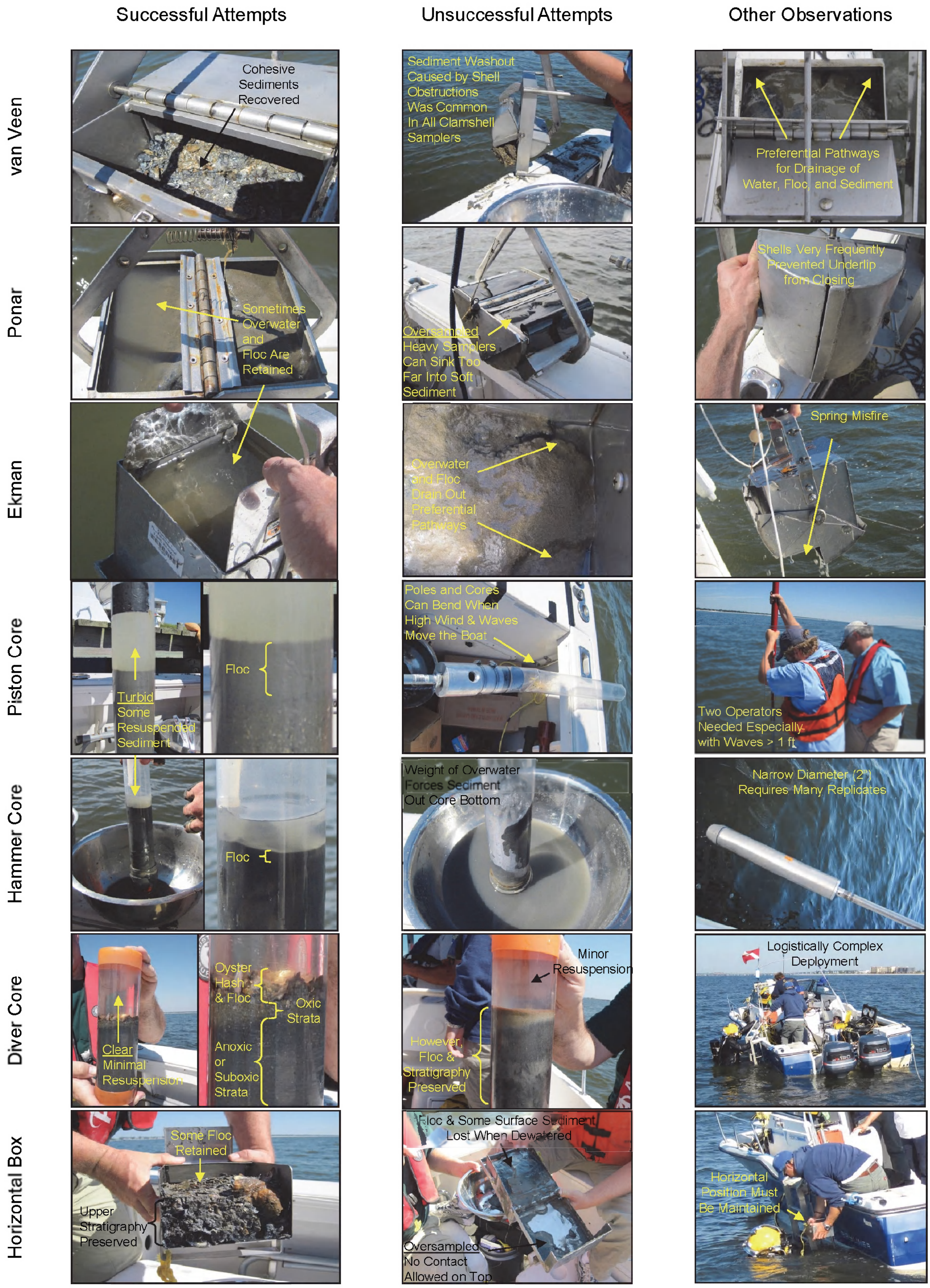


Figure 7. NOAA DWH Sediment Samplers Used After 2010.

a. Primary NOAA NRDA Sampler: Valved Push Core.

The components include (1) an aluminum head sized for 3" diameter disposable tubes, (2) an expansion collar for 4" diameter tubes, (3) a one-way valve, (4) bull-float extension poles, and (5) quick-release hose clamps.

Figure 7. NOAA DWH Sediment Samplers Used After 2010.

b. Secondary NOAA NRDA Sampler: Modified van Veen Grab Sampler.
The components include (1) stainless steel body with straight side walls, (2) extended level arms and light weight chain, (3) precisely aligned overlapping yaws, (4) screened doors, (5) rubber flaps, and (6) pelican hook latch.