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Interannual changes in seafloor surficial geology at an artificial reef site on the inner continental shelf

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ABSTRACT

The influence of reef structures on seafloor surface sediments has implications for marine spatial planning and coastal development, including use of the coastal zone for offshore wind energy. We present results of interannual changes in seafloor surficial geology at the Redbird artificial reef site, located on the continental shelf offshore of Delaware Bay. The Redbird reef is composed of NYC subway cars, barges, tugboats, and other sunken objects. Since objects were added sporadically between 1996 and 2009, the survey area acts as a natural laboratory to study the evolution of the surrounding seafloor at a structural reef habitat through time. Annual side-scan surveys from 2008 through 2011, and one bathymetric survey in 2010 provide information about surface geology and morphology. Local wave and current data for this time period were analyzed to determine the main morphological agents. Automated backscatter segmentation show that three bottom types dominate and that these large-scale (>10 m) surface sediment patterns persist from year to year. Grab samples reveal that the bottom types are silty sand with clay and sandy gravel. Clear sediment and biological patterns emerged revealing the influence of the objects on the seafloor. Comet-shaped moats of sandy gravel surround single objects and grow to form large-scale coalesced patches around groups of objects. Alignment of sediment patches suggests the periodic hydrodynamic influence of seasonal storms. The abundance and diversity of organisms increases with decreasing clay/silt content. Evidence of scour includes the removal of fine sediments, the formation of moats 1–30 m in diameter and 0.5–1 m deep around the reef objects, and the >1 m settling of objects into the seafloor. Data suggest subway cars reached equilibrium with the environment in 6–7 years, but that larger objects or clusters of objects take a longer time to equilibrate and have farther-reaching effects. Knowledge of local wave and current climate and stratigraphy could inform decisions of object clustering and orientation to decrease scour impacts.

1. Introduction

Large, permanent, structures including offshore wind towers, oil platforms, breakwaters, bridge pilings, and artificial reefs are becoming more common on the inner continental shelf. Structures placed in dynamic coastal waters will affect local hydrodynamics, thus altering surficial sediments and bedforms, and benthic communities. Seafloor structures and communities are affected by the stability of sediments as well. In a time when the dynamic coastal zone is seen as an ideal location for offshore energy structures (wind, fossil fuels) it is important that coastal managers consider the evolution of the seafloor in the vicinity of objects when planning such projects.

Marine scour is the localized removal of sediment around an object by waves and currents (Whitehouse, 1998). Previous studies have identified different scour mechanisms and features around shipwrecks, large rocks, or engineered structures (e.g. Richardson, 1968; Caston, 1979; Werner et al., 1980; McNinch et al., 2001; Quinn, 2006). Scour may lead to a change in grain size distribution caused by sediment sorting and change the topography of the bed by introducing scour pits, scour ridges, or ripples and sand waves. Important factors affecting scour processes include the orientation, shape, and size of the object, water depth, seafloor and subsurface geology, and prevailing hydrodynamic and sediment dynamics, as summarized by Quinn (2006).

Past published studies did not monitor the progression of geomorphic change caused by large objects on the seafloor, rather they have focused on end member situations (initial onset of scour or fully developed features). In this study we use annual side-scan sonar

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surveys, a phase-measuring bathymetric sonar (PMBS) survey and select ground-truth samples and images to evaluate the geomorphic evolution of the seafloor. Side-scan sonar allows efficient coverage of large areas and captures the changes in sediment texture and location/scale of bed forms. For this reason many other scour studies rely on side-scan sonars (Caston, 1979; Quinn, 2006; Trembanis et al., 2011). In addition, the PMBS collects collocated bathymetric and backscatter data, which enables the measurement morphologic features and the evaluation of the associated sediment characteristics. Since objects have been periodically added to the reef between 1996 and 2009, we have the ability to use distinct objects surveyed the same year as unique temporal windows into the scour dynamics at the site. Unlike other studies, the planned emplacement of objects at the reef site allows us to track the evolution of the seafloor at objects placed 1–11 years prior to a given survey. The reef site is also a controlled environment in the sense that trawling or dredging of the area is prohibited; so geomorphic changes are entirely attributable to natural processes and the placement of reef objects.

Another aspect of the impacts of large objects on the seafloor not well represented in the literature, but important in marine spatial planning, is an understanding of the affects of object density, namely multiple objects in close proximity to each other. The reef site has singular objects (tug boats, barges, ballasted tires, military track vehicles) and clusters of objects (Redbird subway cars), which allow us to examine the additive affects of objects on the seafloor. Developing an understanding of how large objects change the seafloor over time is critical to planning and managing the development of the inner continental shelf.

2. Regional setting

The Redbird artificial reef site (Fig. 1) is located on the inner continental shelf 16.5 nautical miles from Indian River Inlet, Delaware, at 28 m depth (DNREC, 2009–2010), and is adjacent to the planned offshore energy (wind turbine farm) development (NRG Bluewater Wind, 2010). The reef, also called Site 11, was created by the Delaware Department of Natural Resources and Environmental Control (DNREC) starting in 1996 when the first 26 Redbird cars were placed at the site. Additional objects were periodically added to the reef through 2009 (DNREC, 2011–2012). The reef consists of former NYC subway cars, military and nonmilitary vessels, including tugboats and barges, ballasted tire units and other metal military vehicles, covering a 1.3 square nautical mile area (DNREC, 2011–2012). The subway cars were placed in circular clusters, with a diameter of 150–250 m. The most recent placement of 44 cars in March 2009 brought the total number of cars at the site to 934 (DNREC, 2009). All cars have a carbon–steel frame, but only older cars have a carbon-steel skin, while more recent cars have stainless skins. Stainless skins corrode leaving only the frame. Larger vessels, such as the 90′ Delilah tug (1999), 160′ Navy barge YC 1479 (2000), 90′ commercial tug Margie Ann (2007), 97′ Margaret tug (2007), 55′ William C. Snow tug (2008), 110′ Fells Point tug (2008), 95′ Cittie Point tug (2008), and 74′ push boat Sandy Point (2010) were placed at the site sporadically. The site was created to increase local biodiversity, attract fish for recreational fisheries, and generate interest among sport divers (DNREC, 2011–2012). We use the Redbird site as a natural laboratory for studying the magnitude and evolution of effects of large objects on the sea floor, and as an analogue for the impacts of other structures, such as wind towers, on the sea floor.

The semi-diurnal (M2) tide is the dominant force controlling surface currents in the region (Muscarella et al., 2011). The bidirectional currents flowing NE–SW (major axis: 160/340°) (Münchow et al., 1992) over the site are the largest daily hydrodynamic influence. However, in general periodic storms have the largest influence on sediment transport on the continental shelf

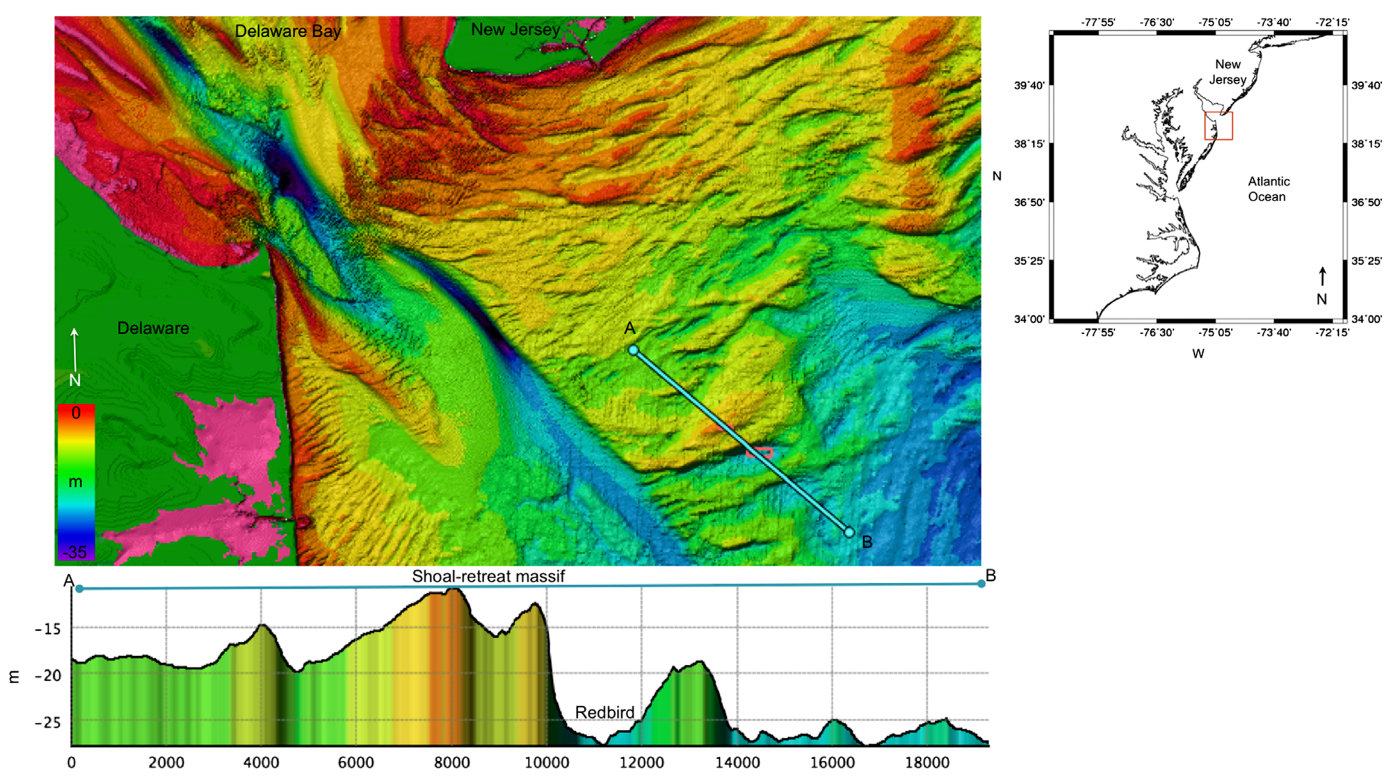

Fig. 1. Location map of the mid-Atlantic shelf and bathymetric DEM of the Redbird artificial reef site (NOAA Coastal Relief Model 90-m gridded bathymetry). A profile across the region shows shoal-retreat massif bathymetry (vertical exaggeration = 200).