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Effects of an oil spill on benthic community production and respiration on subtropical intertidal sandflats

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ABSTRACT

This study determined effects of an oil spill on subtropical benthic community production and respiration by monitoring CO_2 fluxes in benthic chambers on intertidal sandflats during emersion before and after an accidental spill. The oil spill decreased sediment chlorophyll *a* concentrations, altered benthic macrofaunal community, and affected ecological functioning by suppressing or even stopping microalgal production, increasing bacterial respiration, and causing a shift from an autotrophic system to a heterotrophic system. Effects of the oil spill on the macrofauna were more severe than on benthic microalgae, and affected sedentary infauna more than motile epifauna. Despite the oil spill's impact on the benthic community and carbon metabolism, the affected area appeared to return to normal in about 23 days. Our results suggest that the prompt response of benthic metabolism to exposure to petroleum hydrocarbons can serve as a useful indicator of the impact of an oil spill.

1. Introduction

Coastal ecosystems are generally highly productive (Lin et al., 2001) and serve important ecological functions (Laffoley and Grimsditch, 2009) that represent valuable ecosystem services and contribute to human welfare (Costanza et al., 1997). However, these valuable ecosystems are threatened by pollution such as oil spills, heavy metals, and wastewater (e.g. Boudouresque et al., 2009). Oil spills' effects on coastal organisms are primarily caused by exposure to petroleum hydrocarbons (Baker, 1970; Kingston, 1992; Megharaj et al., 2000). Most oil spills are from shipwrecks, oil wells, oil refinery explosions, and other spills (Teal and Howarth, 1984). For example, in 1978, the supertanker *Amoco Cadiz* grounded on rocks, and 223,000 metric tons of light crude oil were lost to the western English Channel, 28% of which was washed into the intertidal zone (Gundlach et al., 1983). The largest marine oil spill in world history occurred in 2010 in the Gulf of Mexico, where about 4.9 million barrels of light crude oil were discharged during a blowout of the Deepwater Horizon drilling rig (Kostka et al., 2011). Although cleanup efforts were aggressive, much oil was transported to the shoreline and trapped in the sediment. Because marine oil spills are a regular occurrence, understanding their environmental impact is of great importance.

Although microbial degradation (Leahy and Colwell, 1990) and photodecomposition (Plata et al., 2008) may shorten the duration that oil remains in sediment, oil trapped in sediment nonetheless decreased meiofauna density (Boucher, 1980), total density and biomass (Kalke et al., 1982) and diversity (Teal and Howarth, 1984; Kingston, 1992) of benthic fauna, as well as reducing macrofauna feeding activity (Farke et al., 1985), and altering the macrofaunal community (Junoy et al., 2005; den Hartog and Jacobs, 1980; Gómez Gesteira and Dauvin, 2000). Concentrated hydrocarbon in oil spills may suppress photosynthesis of phytoplankton (Karydis, 1979; Kush, 1981) and salt marsh plants (Smith et al., 1981), however low concentrations may actually stimulate photosynthesis in certain phytoplankton species (Dustan et al., 1975; Gordon and Prouse, 1973; Karydis, 1979). The large oil spills of the 1991 Gulf War had also affected subtidal benthic metabolism (Burns et al., 1993). Data on meiofauna, macrofauna, phytoplankton, and salt marsh plants are available, but to date there has been little research on the effect of oil spills on intertidal benthic metabolism and benthic microalgae.

The Kaomei Wetland (24°18'N, 120°32'E) is a subtropical coastal wetland in central Taiwan (Fig. 1). *In situ* benthic community production and respiration have been measured monthly since 2008 by monitoring CO_2 fluxes in benthic chambers on intertidal sandflats during emersion (Lee et al., 2011). Clear seasonal and spatial patterns in maximum gross community production (GCP) and community respiration (CR) were evident, with higher values in summer and fall and lower values in winter and spring. Lee

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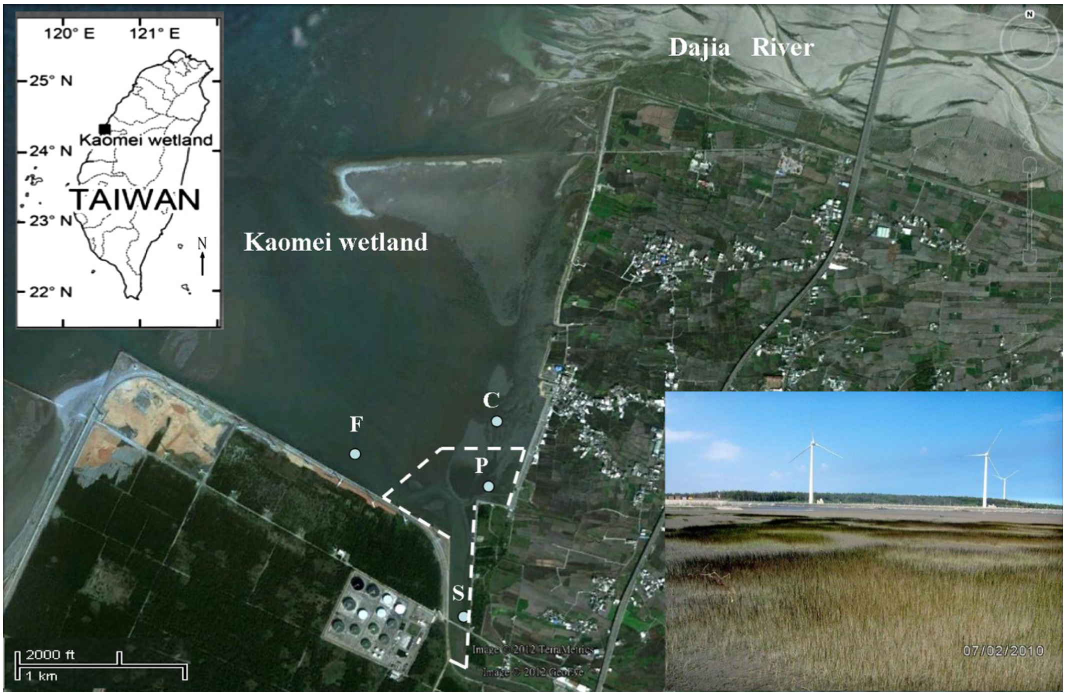

Fig. 1. Location of the study sites at the Kaomei Wetland, central Taiwan, showing the oil spill location (S), the Polluted study site (P), the Control study site (C), and the Long-term monitoring site (F). The polluted area is indicated by a dot and a photograph taken at site P. Map credit: Google Earth.

et al. (2011) further discovered that maximum GCP is positively correlated with sediment grain size and negatively correlated with higher silt and clay content. CR has a strong positive correlation with sediment chlorophyll *a* concentration and macrofaunal biomass values. Estimated annual net community production (NCP) on emersed sandflats is 2.87 g C m^{-2} $year^{-1}$, indicating an autotrophic system. However, the subtropical intertidal system is heterotrophic at night or during immersion, and thus heterotrophic as a whole.

On the night of 29 June 2010, about 8 metric tons of fuel oil was accidentally dumped into the Kaomei Wetland, and much of this oil was trapped on the intertidal sandflats. This event provided an opportunity to determine the effects of an accidental oil spill on the benthic community in a subtropical coastal wetland. This study characterized changes in the abundance, production, and respiration of this benthic community before and after the oil spill. We hypothesized that the oil spill would suppress the abundance and production of the benthic community and cause this autotrophic system during emersion to shift to a heterotrophic system.

2. Materials and methods

2.1. Study site

The Kaomei Wetland, south of the Tachia River estuary, is a 701-ha area, 3.5 km long and 1.8 km wide. Because of its high biodiversity, the wetland has been designated a wildlife reserve. This wetland consists mainly of coarse sandflats (341 ha) with small areas of salt marsh (22.3 ha) and seagrass beds (7.9 ha). Tides are semidiurnal with a range of 3–4 m. During the study period, the air temperature averaged 29.2 °C in July and 29.3 °C in August.

Heavy fuel oil was accidentally spilled on the night of 29 June 2010 in the Qingshui drainage ditch (Fig. 1, S, the Spill site) in the southern part of Kaomei Wetland. The tide quickly spread about 8 metric tons of the oil over about 300 ha of the reserve. The hydrocarbons in the lightly weathered oils in the sediment were mostly *n*-alkanes and polycyclic aromatic hydrocarbons (PAHs) with a small proportion of branched alkanes (Chinese Petroleum Corporation, 2010). In the spill area, *n*-alkanes in the range from *n*-C_{14} to *n*-C_{35}, maximizing at *n*-C_{23}, were present. The aromatic fraction was dominated by the alkylated phenanthrene and dibenzothiophene (sulfur-containing aromatic) series.

We selected a monitoring site inside the polluted area, which we labeled Polluted. About 400 m outside the polluted area, we selected a site as a spatial Control, hereafter referred to as Control. Our Long-term monitoring site was 1 km away from the Polluted site, labeled hereafter as Long-term, provided a temporal Control. Data on benthic metabolism were available before the oil spill only at the Long-term and Control sites, as these had been monitored since 2008 (Lee et al., 2011). Effects of the oil spill were determined by comparing the measurements made at the Control and Polluted sites. On Day 8, however, the heavy fuel oil had been dispersed from the Polluted to the Control site by the tides. Therefore, measurements made at the Control site during the same months in 2009, a year before the oil spill, were used as a benchmark for determining the changes at the Control and Polluted sites in 2010. For temporal comparison, measurements were also made at the Long-term site to identify the changes in 2010 by comparison to its levels in 2009. Sediments collected from the Polluted and Control sites consisted of silt with an average grain size of 0.22 ± 0.01 mm. Sediments collected from the Long-term site were of coarse sand with an average grain size of 0.66 ± 0.07 mm (Lee et al., 2011).

2.2. In situ benthic metabolism

We measured CO_2 fluxes at the air-sediment interface during emersion at low tide using benthic chambers (Lee et al., 2011) that were modified from those described by Migné et al. (2002). A chamber was 30 cm in diameter and had a semicircular upper transparent acrylic cover fitted onto a stainless steel ring. The steel ring was pushed into the sediment to a depth of 10 cm to enclose a