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Research paper

Can upstream biofuel production increase the flow of downstream ecosystem goods and services?

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ABSTRACT

Advanced biomass feedstocks tend to provide more non-fuel ecosystem goods and services (ES) than 1st-generation alternatives. We explore the idea that payment for non-fuel ES could facilitate market penetration of advanced biofuels by closing the profitability gap. As a specific example, we discuss the Mississippi-Atchafalaya River Basin (MARB), where 1st-generation bioenergy feedstocks (e.g., corn-grain) have been integrated into the agricultural landscape. Downstream, the MARB drains to the Gulf of Mexico, where the most-valuable fishery in the US is impacted by annual formation of a large hypoxic “Dead zone.” We suggest that advanced biomass production systems in the MARB can increase and stabilize the provision of ES derived from the coastal and marine ecosystems of the Gulf-of-Mexico. Upstream, we suggest that choosing feedstocks based on their resistance or resilience to disturbance (e.g., perennials, diverse feedstocks) can increase reliability in ES provision over time. Direct feedbacks to incentivize producers of advanced feedstocks are currently lacking. Perhaps a shift from first-generation biofuels to perennial-based fuels and other advanced bioenergy systems (e.g., algal diesel, biogas from animal wastes) can be encouraged by bringing downstream environmental externalities into the market for upstream producers. In future, we can create such feedbacks through payments for ES, but significant research is needed to pave the way.

1. Introduction

This special issue is devoted to understanding how an emerging bioeconomy will influence ecosystem goods and services [1], which have been defined as ‘*flows of natural capital to human societies*’ [2]. The US has been moving toward increased reliance on renewable energy. In addition, US agencies are considering the value of natural capital and ecosystem goods and services (ES) in planning and decision-making. According to a 2015 memorandum issued by the Obama Administration [3], integration of ecosystem goods and services into government decision-making can lead to better outcomes, fewer unintended consequences, and more-efficient use of taxpayer dollars and other resources [4].

Early ecosystem services initiatives such as the Millennium Ecosystem Assessment [5], categorized ES across four categories: provisioning, regulating, supporting and cultural. Subsequent frameworks such as The Economics of Ecosystems and Biodiversity (TEEB) and The UK National Ecosystem Assessment [2,6] recognized the need: 1) to focus on final, rather than intermediate, goods and services, 2) to use ecosystem goods and services in a comparative way (i.e. use ES to compare different scenarios, for example a proposed bioenergy scenario and a reference case), and 3) to account for the fact that different beneficiaries realize different value from ecosystem goods and services. Distinguishing final ES from intermediate ES is important when adding (‘stacking’) monetary values from various ES to compare alternative scenarios. This is because summing only final ES avoids double counting of benefits [6–8]. In addition, beneficiaries have well-defined (i.e., easily quantified) preferences for final ES, but not always for intermediate ES [9].

Freshwater ecosystems are characterized by complex ES relationships where ecosystem goods and services generated in upstream watersheds (e.g. food crops, bioenergy feedstock), can cause distant effects in downstream river networks and coastal estuaries. Hypoxia caused by the excessive use of fertilizer is a problem in coastal estuaries of the US and around the world [10], and can impact coastal economies through fisheries, property values, and tourism. A well-known example is the Mississippi and Atchafalaya River Basin (MARB), where agriculture contributes to hypoxia in the

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Gulf of Mexico [11] (Section 2). The MARB supports the majority of biofuel production in the US and has the opportunity to either exacerbate or reduce hypoxia.

This Short Communication discusses how expanding the production of perennial biofuel feedstocks using good agricultural practices upstream, and adoption of other advanced feedstocks, could influence the provision of final ecosystem goods and services from downstream coastal and marine ecosystems. We use biofuel feedstock production in the MARB as a case study to demonstrate how integrating new feedstocks into the agroecosystems and/or changing the management of current feedstocks might reduce nutrient loadings and enhance the provisioning of ecosystem goods and services downstream in the Gulf of Mexico (Section 2 and 3). Section 4 outlines how the provision of regulating ecosystem services can enable greater market penetration of advanced biofuels and Section 5 discusses how the disturbance-adapted life histories of perennial feedstocks can reduce the risk (variability) in regulating ES that they provide.

2. Linking intensive agriculture in the MARB with hypoxia in the Gulf of Mexico

If the MARB is the breadbasket of the US, the Gulf of Mexico is its fish basket. The MARB is the largest river system in North America, draining one-fifth of the landmass of the conterminous US (Fig. 1). Upstream, the MARB contains a significant fraction of the US's highly-productive agricultural land. In addition to wheat and other grains, upstream watersheds supply most of the corn and soybean used for animal feed. Downstream, the Gulf is the most productive fishery in the US [12], helping to support growing domestic and international demand for fish [13].

Hypoxia in the Gulf became an annual summertime event in the 1970s [14], and over the past four decades, nutrient loadings from MARB croplands have tripled the size of the hypoxic area in the Gulf [15,16]. Because nutrients stimulate algal growth, moderate nutrient enrichment enhances food supply for higher trophic levels that are harvested for seafood. However, when nutrient loadings are too high, they have adverse effects on fisheries. As algal blooms decompose, they deplete oxygen supplies, suffocating animals at higher trophic levels. Low-oxygen conditions stimulate phosphorus release from sediments that promote further blooms, and shunt energy into the microbial loop to decompose [17] without building populations that contribute to fisheries.

Because of hypoxia, benthic prey in the northern Gulf declined by 9.3 million tons km^{-2} y^{-1}, reducing the food base for higher trophic levels (i.e., fisheries) [18]. One-quarter of the Louisiana shelf that supports high densities of brown shrimp *Farfantepenaeus aztecus* [14] becomes uninhabitable during summer. Mobile fauna such as shrimp aggregate near the boundaries of the 'Dead zone' to escape hypoxia, where they are more susceptible to being caught [19].

The economic signals of hypoxia are challenging to detect because of strong integration with (i.e., compensation by) global markets. Recently, however, a study detected an increase in the price of large brown shrimp, which are not available from Asian markets, as a result of hypoxia [20]. In another US estuary (the Neuse River, NC), annual harvests of brown shrimp were reduced by 12.9% between 1999 and 2005 due to hypoxia [21].

The U.S. Environmental Protection Agency (EPA) Gulf Hypoxia Taskforce aims to shrink the Gulf 'Dead zone' to less than 5000 km^2 by 2035. An interim target is to reduce nutrient loadings from the MARB by 20% by 2025. Individual states are now contributing to these reduction targets by promoting better upstream agricultural nutrient management practices.

3. How can upstream biomass production benefit fisheries in the Gulf of Mexico?

Intensively managed corn and soybean agriculture is a primary cause of the Gulf of Mexico's hypoxia problem. Concerns have been raised about the effects of expanding corn production to meet the additional demand for corn-grain ethanol [22] beyond that for

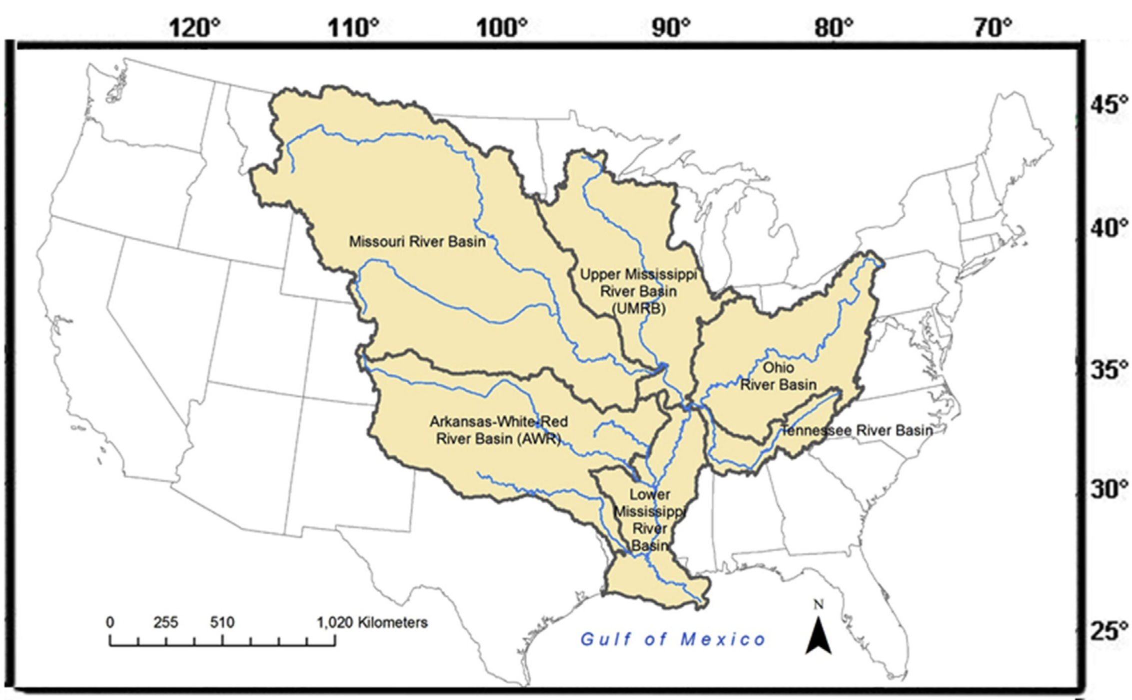

Fig. 1. The Mississippi-Atchafalaya River Basin, USA, which drains to the Gulf of Mexico. Map created by Dr. Latha Baskaran (ORNL).