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Structural Conditions in Poultry Production and the Socioecological Drivers of Marine Pollution

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ABSTRACT We examine socioecological drivers of nutrient overloading and eutrophication in the Chesapeake Bay associated with poultry production on the Delmarva Peninsula. We use a social metabolic analysis—rooted in a political-economy perspective—that highlights the interchange of matter and energy and the inextricable links within and between social and ecological systems, illuminating the social structural processes contributing to ecological changes. The concentration and consolidation of poultry production through integration, which involves contract farming, and geographic concentration of operations, have been associated with intensified and increased scale of chicken (broiler) production. These processes have had significant effects on waste accumulation, maintenance, and disposal, and this industry has become one of the major contributors of nutrient overloading in the Chesapeake Bay. This study, therefore, specifies social processes that are driving environmental changes between land and sea. KEYWORDS food systems; water pollution; metabolic rift; vertical and horizontal integration; animal production

Anthropogenic environmental changes in aquatic systems are matters of ongoing and increasing concern. Natural scientists stress that pollution, climate change, overfishing, and ocean acidification are transforming ecological conditions and threatening the sustainability of marine ecosystems (Earle 2009; Harvell 2019; Pauly 2019; Roberts 2013). In this article, we examine the structural changes and socioecological drivers that influence nutrient loading, or what amounts to nutrient *overloading* in the Chesapeake Bay, on the eastern coast of the United States.

Nutrient pollution is a "widespread and serious" ecological problem (Weis 2015:xvi). Rivers, streams, lakes, estuaries (bays), and ocean systems have been inundated with nutrient runoff, which has had far-reaching effects on both terrestrial and aquatic

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ecosystems. The excess loading of nutrients into waterways sets off cascading ecological modifications. Combined with other anthropogenic environmental changes, such as climate change, this pollution can cause significant ecological and social problems.

Using a social metabolic approach, this study seeks to better understand how specific socio-structural processes associated with economic development contribute to nutrient overloading in the Chesapeake Bay. Agri-food production, as the largest emitter of nutrients into water systems, plays a central role in eutrophication. We inquire into specific socioecological conditions and practices in food production that result in marine ecological changes in the Chesapeake Bay region, including the creation of distinct ecological rifts, and consider the reciprocal consequences for social systems. While there are numerous studies on agri-food production in sociology, including some that highlight environmental concerns, this research empirically analyzes its associated drivers of water pollution from a novel theoretical framework, offering an integrated examination of changes in socioecological relations. In regard to social metabolic research, it incorporates a more extensive consideration of specific political-economic processes and structural conditions that influence the social metabolism and environmental changes.

THEORY AND METHODS

Social Metabolism

Social metabolic analysis has been used to analyze global environmental change. As an open-ended, materialist-dialectical approach, it incorporates biophysical factors and ecological processes—such as the life cycles of species, food webs, and energy and nutrient transfers—into social analysis (Angus 2018; Foster 2000; Kaup 2020; Longo 2012; Longo, Clausen, and Clark 2015; Napoletano et al. 2019). It offers a socioecological approach that assesses how humans interact with and are affected by ecosystems, and provides the means to study how specific social drivers and organizations influence environmental change and/or create ecological problems. As such, it generates critical insights regarding sustainability.

The concept of "metabolism" is increasingly used in social science research on the environment (González de Molina and Toledo 2014). In some work in urban geography, it is often used in a metaphorical manner, and commonly in an abstract, euphuistic style that we find limits its accessibility, particularly for interdisciplinary audiences. Most importantly, this approach has different analytical motivations and metatheoretical foundations from the social metabolic perspective applied in this study. A central difference, aside from but linked to the explicit focus on cities, is that, in its most recent applications, the former tends to be rooted in posthumanist conceptual elaborations, including notions of "assemblages," "hybrids," and "cyborgs," that recast cities and urbanization processes as "socio-natural things" (Swyngedouw 2006). The latter, which we use, is grounded in the historical-materialist tradition. It actively examines the dialectical mediation between society and nature as an open process, which involves studying and understanding contradictions (Napoletano et al. 2019).

Industrial ecology is another approach that incorporates metabolism into its analysis (Fischer-Kowalski and Hüttler 1999). Work in this realm largely documents the quantitative environmental flows of energy and materials within the operations of industrial production. Importantly, this scholarship offers material flow accounting and product lifecycle assessments (Ayres and Ayres 2002). There are clear overlaps between industrial ecology and social metabolic analysis; but the latter tradition offers a more comprehensive political-economic analysis. It is also better situated to investigate the qualitative dimensions and socioecological interconnections that are the focus of this study (see Fischer-Kowalski 1998; Fischer-Kowalski and Hüttler 1999; González de Molina and Toledo 2014 for historical discussion of the use of the metabolism concept).

Our work is rooted in the social metabolic approach, within environmental sociology, that examines ecological rifts. It is a critical political-economic perspective that emerges directly out of Karl Marx's historical-materialist analysis, in which the socioeconomic system is embedded within the larger biophysical world, to study the interchanges of matter and energy within and between human society and the environment (Burkett 1999; Foster 1999). Thus, it examines the social metabolism in relation to "the universal metabolism of nature" (Marx and Engels 1975, vol. 30:54–66; see also Marx 1976:283). The social metabolism is organized by the historically specific mode of production, including, necessarily, the structure of labor relations. As a result, each mode of production creates a distinct social metabolic order that mediates the interactions (Mészáros 1995). The universal metabolism of nature consists of specific cycles, processes, and conditions that produce and regenerate ecological conditions (Foster 2013). When the social metabolism transgresses against the universal metabolism of nature, ecological rifts (or ruptures) emerge, creating distinct environmental problems (Foster 1999).

In developing his metabolic analysis, Marx (1976, 1991) integrated it into his critique of political economy, focusing extensively on the development of capitalist agriculture. He assessed how social processes of production, distribution, and consumption were developed and organized in relation to the soil nutrient cycle. He explained that, during the enclosure movement, peasants were driven from the land and forced to seek employment in the cities. As agricultural production was geared to capitalist commodity production, more intensive practices were used in the fields to increase yields. Trees were often cleared, imposing a type of uniformity on the land, and industrial power was used to make operations more efficient (Morton 1859). The growth imperative associated with the metabolic order of capital increasingly dominated decisions, as efforts were made to enlarge the scale of operations. Marx (1976) argued that as this system was applied to agriculture, the social metabolism progressively created an ecological rift in the soil nutrient cycle. For example, food and fiber were shipped to distant markets in cities. The nutrients in these items were not returned to the countryside. This led to the exhaustion of soil, while the nutrients in food became waste that accumulated in cities, often polluting waterways (Angus 2018; Clark and Longo 2018).

The social metabolic order of capital, predicated on constant growth, commodification, and accumulation, drives structural changes that shape production operations. For example, the centralization and concentration of capital allows firms to reorganize production systems and use new technologies to increase the scale and efficiency of operations, as well as to reduce labor costs (Auerbach and Clark 2018). These firms tend to pursue vertical and horizontal integration to gain control over purchasing and marketing power in a sector. In Marx's (1976) analysis, these basic processes and developments create the potential for numerous ecological rifts in the interchanges of matter and energy between human society and the larger biophysical world. Capitalist commodity production tends to increase the demand for resources to maintain and expand operations, and thus generate more waste and pollution (Foster 1994; Schnaiberg 1980).

We analyze structural changes and socioecological processes associated with the modern social metabolic order in relation to the poultry industry in the Delmarva Peninsula. In doing this, we advance social metabolic scholarship by devoting additional attention to the political-economic and structural conditions that influence the social metabolism and by examining land–sea linkages. We highlight how the modern agri-food system resides at the center of ecological concerns in the Chesapeake Bay. Using a social metabolic approach, rooted in the ecological rift tradition, we aim to better specify key organizational conditions, particularly the political-economic, associated with chicken meat production that contribute to environmental transformations that can compromise the sustainability of marine ecosystems. Thus, this study highlights the complex interchanges between terrestrial and marine systems, advancing marine sociology (Longo and Clark 2016).

Historical Case Study: Poultry and the Chesapeake Bay

We present a historical case study of the poultry industry on the Delmarva Peninsula to analyze socioecological processes linked to the Chesapeake Bay. Poultry production, in general, includes chickens, turkeys, and ducks. In this study, we focus on chickens produced for meat (broilers), as these are the most common animal reared for food in this region. This agri-food industry is also a significant contributor to the social and ecological conditions of interest (Hancock and Algozzine 2006).

Given the benefits and necessity of examining interconnected social processes and environmental changes, we use multiple sources of data. They include reports from nongovernmental organizations, state and federal agencies, and industry groups, and news articles on the subject, especially environmental conditions in the Chesapeake Bay and industry development in the Delmarva region. Importantly—and in line with the social metabolic approach outlined above—we draw on published research, detailing the biophysical context and dynamics associated with specific environmental changes. We deductively synthesize these data to illuminate the land–sea interconnections, as part of identifying key sociostructural drivers of nutrient overloading and ecological change in the Chesapeake Bay. This historical analysis provides an in-depth assessment of specific socioecological transformations and the social processes and mechanisms that are central components in these transformations (Mahoney and Rueschemeyer 2003). The case study approach investigates contextual conditions and uses several sources of data (Yin 2009). It enables deep description and detail less easily achievable in other types of studies (Mahoney and Rueschemeyer 2003).

FIGURE 1. The Delmarva Peninsula and the Chesapeake Bay
Source: Google Maps (2020).

The Chesapeake Bay is the largest estuary in the contiguous United States, bordering both Maryland and Virginia. The watershed that empties into the Chesapeake Bay extends from New York, through Pennsylvania, West Virginia, and Delaware, covering over 63,000 square miles (Figure 1). As an estuary, the Chesapeake Bay is a mix of salt and fresh water. Estuaries are particularly important for aquatic organisms, given that they serve as nurseries for marine species (such as the Chesapeake's famous blue crabs and oysters) and many species inhabit the bay or visit it during migration, including marine mammals.

The Chesapeake Bay has long been known as an area teeming with life, which plays a critical role in marine biodiversity on the Atlantic Coast of the United States. It is a very large and also relatively shallow estuary, making it productive but also vulnerable to the effects of changes in land use (Kemp et al. 2005; Rick et al. 2016). The quantity and quality of the water from the numerous rivers and streams that feed into the estuary influence the state of many species and affect how biologically productive this system is. The estuary also provides several marine services for human populations, including access to protein. Since inhabiting the larger watershed, humans have interacted with and affected this estuary, but in recent decades this marine system has drastically changed, in large part due to the organization of terrestrial food production in the region (Harding et al. 2016; Kemp et al. 2005). These transformations have affected both aquatic organisms and humans.

ANALYSIS

Nutrient Loading and Environmental Concerns: Land–Sea Linkages

"Nutrient loading" refers to the quantity of nutrients that enter an ecosystem during a specified period. Biogeochemical, metabolic processes cycle nutrients throughout ecosystems. Nutrients are essential for life; they must be present for plant and animal growth and development (Magdoff 2011). Nutrients enter waterways from a variety of sources, including atmospheric interchange, the weathering of rocks and soils, and other natural sources. Following the Second World War, agriculture, industrial development, and urbanization became major sources of nutrients in aquatic systems (Ator and Denver 2015; Weis 2015).

Excessive concentrations of nutrients in water systems become pollutants and lead to a series of changes in ecosystems, increasing the potential for ecological rifts. For example, nutrient pollution alters trophic structures, affects plant life, and changes the composition of fish and invertebrate communities through a range of ecological mechanisms (Ator and Denver 2015; National Research Council Staff et al. 2000). Nutrient overloading from nitrates and phosphates results in eutrophication, or hypertrophication—the overgrowth of organic matter—creating algal blooms, which degrade water quality (Glibert et al. 2005; Hagy et al. 2004). As algal blooms die and decompose, dissolved oxygen is consumed, which can create hypoxia (low oxygen levels) or even anoxia (the absence of oxygen), stressing aquatic organisms. Extreme growth of algal blooms and the associated decomposition can produce "dead zones," or areas of little or no aquatic life (Smith, Tilman, and Nekola 1999). During the latter half of the twentieth century, hypoxic conditions in the Chesapeake Bay increased at an accelerated rate, with significant growth of dead zones since the 1980s (Hagy et al. 2004; Weis 2015).

Nutrient overloading also contributes to the growth of harmful algal blooms (Glibert et al. 2005). These are often called "red tides," as some appear as massive red-colored ocean currents. The algae in these blooms produce small amounts of substances that are toxic to many organisms (Allen 2011). This has resulted in large fish kills and the death of seabirds and mammals, including manatees, sea lions, and dolphins (Flewelling et al. 2005; Scholin et al. 2000). Humans are also affected, through the consumption of fish and shellfish that have been tainted with toxics produced from these blooms and through exposure when swimming or by breathing aerosol from wave activity (Allen 2011). As with dead zones, the frequency, duration, and intensity of harmful algal blooms have increased throughout the world in recent decades (Glibert et al. 2005; Hallegraeff 1993).

All of the problems caused by nutrient overloading are exacerbated by other aspects of anthropogenic environmental change, such as overfishing, ocean acidification, and climate change, with complex interacting outcomes (Rabalais et al. 2009). For example, oyster and crab harvesting, which have been a mainstay for many in the region, are in decline in the Chesapeake Bay due to a confluence of factors (Miller et al. 2011; Rick et al. 2016). The dead zones caused by nutrient pollution kill oysters and crabs. Ecosystem transformations caused by climate change are also harming oyster and crab populations, and overfishing has been a problem (Miller et al. 2011; Najjar et al. 2000; Rick et al. 2016). Oysters are important consumers of algae, and their decline magnifies the problems associated with nutrient overloading.

Thus, nutrient pollution and its cascading consequences change the structure of species populations that enter and inhabit the bay. Energy that used to be transferred to upper-trophic-level species is instead diverted to lower levels. And the consequences ripple back from the sea to the land. As marine scientists Díaz et al. (2009:1767) noted, “a conservative global estimate of biomass lost to coastal dead zones annually is over 9,000,000 metric tons wet weight of organisms. This is a lot of potential food for higher trophic levels, including humans, basically eaten by microbes.” These changes can undermine the integrity of the larger complex ecosystem.

Agriculture, Poultry Production, and Nutrient Overloading in the Chesapeake Bay

The industrialization of food production has increased the scale of agri-food operations and intensified the use of capital-intensive technologies in agriculture, such as fertilizers, to maintain and increase the growth of plant life (Mancus 2007). This has included the development of concentrated animal feeding operations, which generate substantial quantities of waste (Gunderson 2011). Runoff from farms and animal agriculture operations, as well as from urban and suburban landscapes, has dramatically increased the quantity of macronutrients, such as nitrogen, phosphorous, and potassium, in waterways.

For centuries, land use has been largely agricultural in the Delmarva region. However, the effects of agricultural production on the Chesapeake Bay have dramatically increased in recent decades (Harding et al. 2016). In 2017, agricultural operations in the watershed were responsible for the largest share of nitrogen, phosphorous, and sediment pollution in the Chesapeake Bay, including an estimated 42 percent of all nitrogen and 55 percent of all phosphorus (ChesapeakeStat 2018). According to the U.S. Geological Survey, the concentration of these nutrients on the Peninsula has been increasing steadily over the past several decades, due to intensification of both crop and livestock production (Ator and Denver 2015). In particular, the Eastern Shore of the Chesapeake, along the

Delmarva Peninsula, produces an outsized proportion of the nutrient inputs to the bay in comparison to the rest of the watershed. Most of the nitrogen contribution in this area is from fertilizers and manure (Ator and Denver 2015). Poultry production has been a principal contributor to these outcomes.

There is a direct link between poultry house concentration in the Delmarva region and the amount of nutrient pollution in the watershed of the Chesapeake Bay (Amato et al. 2020). Over the last several decades, broiler production has experienced significant growth, and its operations have spread throughout the watershed. A by-product of broiler production is nutrient-rich manure, high in nitrogen and phosphorous. Thus, this industry has become a major polluter of the bay (Harding et al. 2013; Pew Charitable Trusts 2013). The Environmental Integrity Project, a nongovernmental organization investigating environmental problems, estimates that the poultry industry (from all states in the watershed) adds about 24 million pounds of nitrogen to the Chesapeake Bay every year. This is more than the amount of nitrogen from all of the urban and suburban stormwater runoff in Virginia and Maryland combined (Pelton, Lamm, and Russ 2020). The nutrient overloading and the ecological changes of the Chesapeake Bay associated with poultry production are rooted largely in structural changes in the sector and food production systems more broadly.

Political-Economic Trends: Industrialization, Growth, and Integration

The production and consumption of poultry products has soared in recent decades in the United States and globally (Gerber, Opio, and Steinfeld 2007). Major production facilities have been expanded, and the production process has been transformed to maximize efficiencies and profits (Williams 1998). Technological and organizational changes have been implemented to allow the scale and pace of production to increase at unprecedented rates (Delmarva Poultry Industry 2018). These changes, which intensify the social metabolism, are the result not only of general industrial expansion but also of growth in combination with particular structural processes, such as sectoral integration.

Since the Second World War, the entire agri-food system in the United States has been gradually restructured, one commodity sector after another. While different sectors have taken distinct paths, the structural outcomes have been similar: market domination of each sector by a few large firms (Heffernan 2000; Heffernan and Hendrickson 2002; Hendrickson et al. 2001). In the Chesapeake Bay states, for example, the number of all farms (crops and/or livestock) is about one-third what it was in the 1950s (Chesapeake Bay Foundation 2005). These farms tend to be larger and more intensive in their operations. By the twenty-first century, 8 percent of the farms in this region produced 75 percent of all agriculture sales, due to ongoing processes of farm concentration and the economic benefits of large-scale production.

Vertical integration occurs when firms acquire or merge with other firms along the sequence of production or commodity chain. Examples include when fertilizer and chemical companies purchase seed companies, or when feed producers expand into the poultry processing stage. Horizontal integration, meanwhile, occurs as firms buy out or merge with their competitors. This results in firms increasing their size and control within a particular stage of the production system, such as pork slaughter or soybean processing (Heffernan 1998; Howard 2016). These firms gain greater control over the market within a specific commodity sector, resulting in sectors being dominated by a few big firms.

The broader structural drive for integration is associated with the need to increase the firms' share of the food market, revenues, and profits. These structural dynamics have often resulted in oligopolistic market conditions in various food sectors (Heffernan 2000). Under such conditions, sectors are often shaped by the dictates of a few firms, reducing competition and increasing the power, both economic and political, of particular actors. This has become the case throughout the food system, such as with seeds and agri-chemicals, hog production, retail and supermarkets, and poultry (Howard 2016). The tendency to merge, converge, and concentrate creates structural imperatives in the economic system that widely influence the processes, organization, and management of production (Baran and Sweezy 1966).

In the agri-food sector, the poultry industry has been a leader in implementing major structural transformations and is "considered a role model for the industrialization of agriculture," especially in broiler production (Vukina 2001:29). It was early to use large-scale industrial organization, following a factory-like system of production, and control over animal lives from egg to plate (Constance 2008). In the first half of the twentieth century, technological developments aided by government programs and subsidies (such those associated with the Second World War) provided the foundation for the industrial growth of the broiler sector in the United States (Constance 2008; Genoways 2014; Harrison 2013).

In broiler production, extensive vertical and horizontal integration have both taken place. In the mid-1950s, large grain and feed companies began to integrate into broiler production, partly to ensure markets for their products (Goodwin 2005). By the mid-1960s, 90 percent of broilers came from vertically integrated corporations (National Chicken Council 2020). The firms that established themselves as leaders in the poultry sector then pursued horizontal integration (Hendrickson et al. 2001).

Integration was driven in part by increasingly tense price competition at the wholesale and retail levels. The extensive consolidation and concentration in the poultry sector has been an important factor in making chicken meat highly affordable and widely available (especially through fast-food chains), which fed greater demand and further expansion (Goodwin 2005). The broiler industry is now one of the most horizontally concentrated agricultural industries in the United States, with processors functioning as the "coordinators of the industry" because a large proportion of value is added at this stage and there is potential for significant economies of scale (Vukina 2001:29). As horizontal integration neared its apex, firms continued to acquire other parts of the value chain (e.g., various production, outlet, and marketing channels) to increase economic efficiencies and retain more of the profits. The economies of scale that have been identified in poultry slaughter and processing, for example, have led to a near disappearance of small plants (Ollinger, MacDonald, and Madison 2005). About

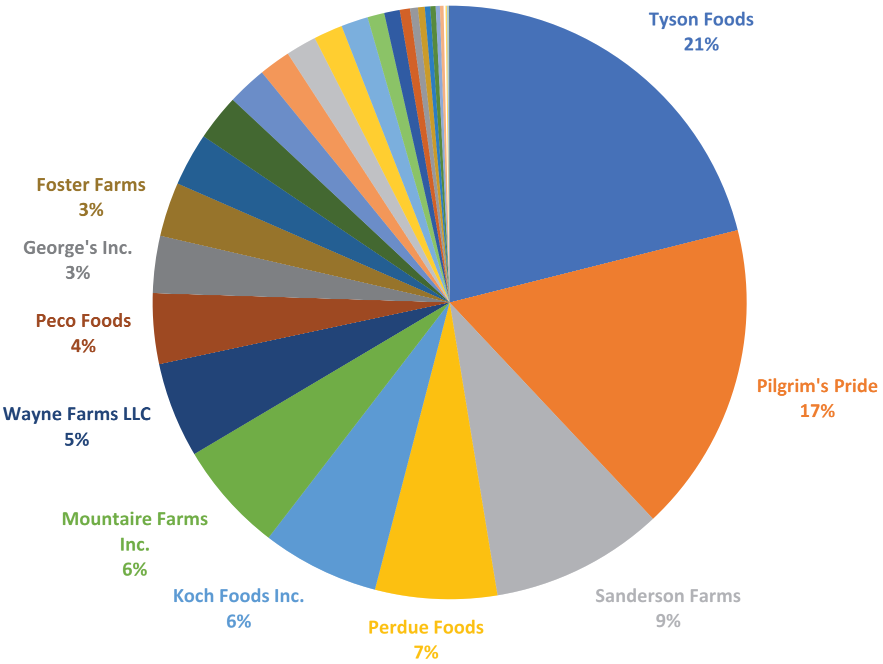

FIGURE 2. Weekly average production (million lbs. of "ready to cook" chicken meat) from the 31 "top broiler companies" in the United States in 2019. Over half of the total meat produced comes from the largest four companies (Tyson Foods, Pilgrim's Pride, Sanderson Farms, and Perdue Foods). Ten companies produce over 80 percent. While this is not an exhaustive list of U.S. poultry companies, the amount produced by smaller companies is negligible in comparison.
Source: WATT (2020).

20 firms (integrators) control virtually the entire U.S. chicken meat output. In 2019, the top eight companies controlled over 75 percent—and Tyson Foods, the largest, over 21 percent (Figure 2).

The poultry industry is almost completely vertically integrated. The vast majority of production occurs in integrated firms that also own and control feedmills, breeding flocks and hatcheries, transportation, and processing (Figure 3). The exception is the finishing stage, the keeping and feeding of birds until they reach slaughter weight. This has largely remained in the hands of so-called independent growers, which are bound by contracts with specific firms. The integrator companies supply chicks, feed, medications, and advisory services, while the growers provide land, housing facilities, utilities (such as electricity and water), and labor. Growers are also responsible for most operating expenses, such as manure disposal, cleanup, repairs, and disposal of dead birds (Silbergeld 2016; Vukina 2001). According to the National Chicken Council (2020), 90 percent of all chicken raised for human consumption in the United States is produced using contracted labor, while most of the remainder is produced by company-owned farms, and less than 1 percent by individual growers. Modern broiler contracts are typically short-term, covering only one flock of birds, with no guarantee of any particular number of flocks per

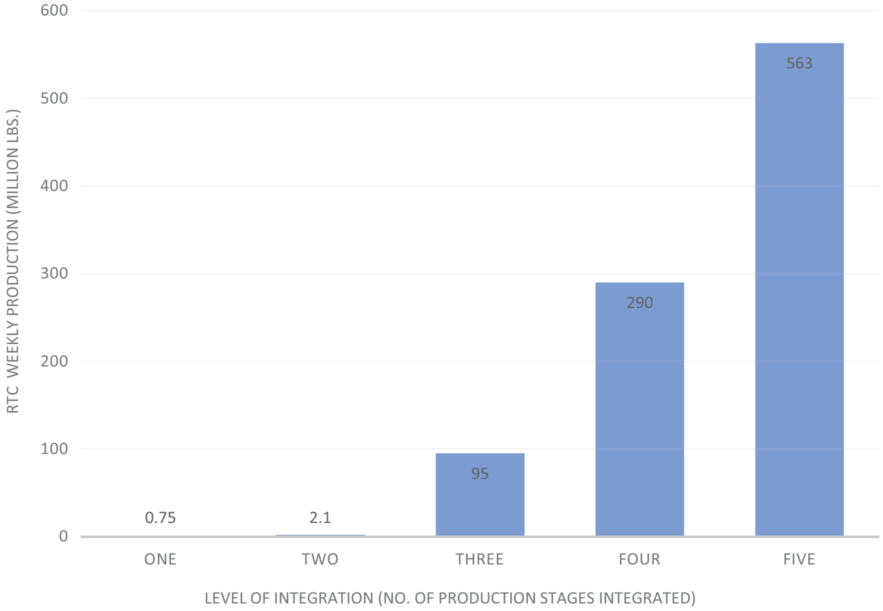

FIGURE 3. U.S. weekly average "ready to cook" (RTC) by level of integration, 2019. Poultry production (weekly averages) from the 31 largest poultry companies, grouped according to how many stages of the value chain they control. The five stages, as defined by industry journal *WATT Poultry USA*, are hatcheries, feed mills, slaughter facilities, further processing facilities, and cook plants. Only one company listed (Shenandoah Valley Organic LLC) is solely involved in slaughter; the vast majority of chicken meat is produced by companies that have integrated four or all five stages of production.
Source: Adapted from WATT (2020).

year. Growers work according to a "tournament" system, receiving financial rewards or penalties depending on how they perform in relation to other growers (Vukina and Leegomonchai 2006).

Given all these trends, poultry production tends to be concentrated, both at the firm level and geographically (Figure 4). According to USDA researcher James MacDonald (2008:3), the geographic concentration of broiler production stems from "economies of scale . . . which encourage the growth of large facilities, and from the reductions in transportation costs for chicks, feed, and birds that can be achieved by locating processing plants, hatcheries, feed mills, and grow-out farms near one another." These structural conditions and processes have shaped poultry production on the Delmarva Peninsula.

In 2017, the Delmarva region produced more than 600 million chickens, more than twice the rate in the 1960s (Delmarva Poultry Industry 2018). Sussex County, Delaware, produces over 200 million chickens a year, more than any other county in the country (Sussex County 2018). The location is not arbitrary. The mid-Atlantic region has a long history of poultry production, and there are numerous large processors and shippers there (Figure 4). For example, Norfolk, Virginia, is one of the largest ports for the export of poultry products (USDA 2013).

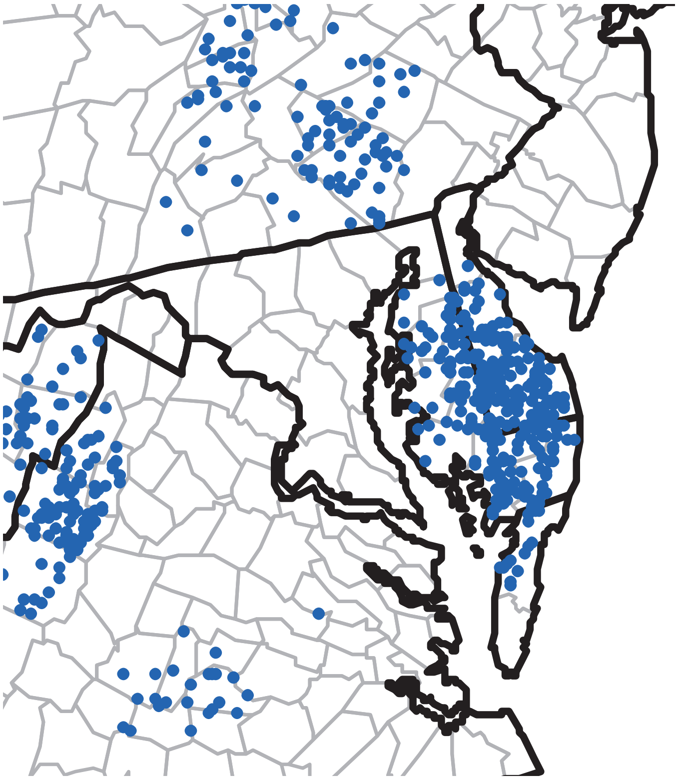

FIGURE 4. Delmarva Peninsula poultry production. Grey lines indicate counties; dots indicate poultry facilities.
Source: USDA (2020).

On the Delmarva Peninsula, there are five large poultry integrator firms (Perdue, Tyson, Allen Harim, Amick Farms, and Mountaire Farms) and over 1,300 contract growers. The leading poultry producer (integrator company) is Perdue Farms, followed by Mountaire Farms. These companies have a major presence in the Chesapeake Bay region, such as owning numerous distribution centers and processing plants. As in other sectors in agri-food production, integration in the poultry sector drives the concentration and consolidation of production. Technological and organizational changes are applied to lower the costs of production, expand output, promote increased consumption, and increase revenues. These major changes, which also intensify the production process and increase resource demands and wastes, can only be pursued by large firms, which have the needed capital. Thus, companies like Perdue dominate the structure and practices of broiler production in the Delmarva region.

Integration, Labor, and Environmental Change

The concentration and intensification of poultry production is reflected in specific structural changes and dynamics in the sector. For example, the number of chicken producers and chicken houses on the Delmarva Peninsula has fallen in recent years, but production has increased as growers build larger and more economically efficient chicken

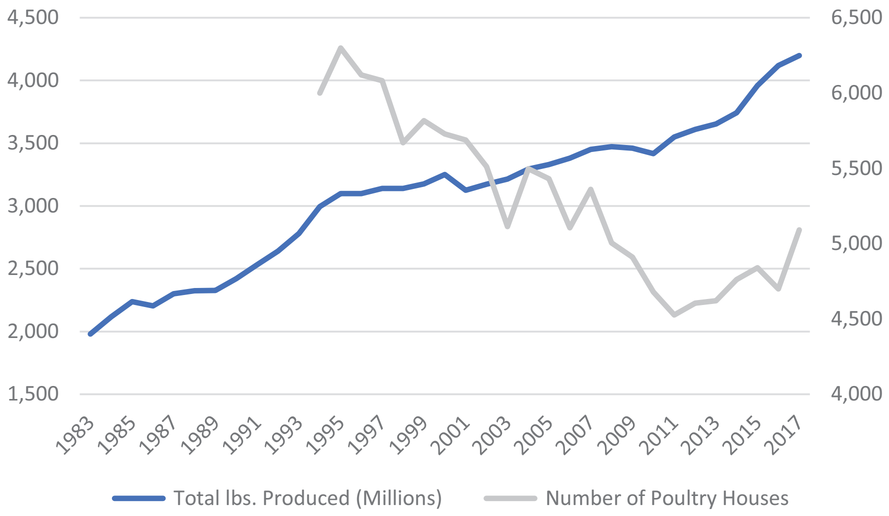

FIGURE 5. Pounds of broilers produced (1983–2017) and number of poultry houses (1994–2017) on the Delmarva Peninsula
Source: Delmarva Poultry Industry (2018).

houses. This trend arises from economic conditions that limit the financial viability of small- and medium-scale producers (Heffernan and Hendrickson 2002; Molnar, Hoban, and Brant 2002). In the past 20 years, there has been a 34 percent increase in the total weight of chickens produced in the region. In 2017, this amounted to 4.2 billion pounds of chicken (Delmarva Poultry Industry 2018). During the same 20 years, the number of chicken houses fell by 12 percent (Figure 5), and the number of growers declined by more than 50 percent (Figure 6). Since 1970, the capacity of houses on the peninsula has grown by 70 percent (Delmarva Poultry Industry 2018). Thus, the size and capacity of chicken houses has grown, while the number of farms and growers has dropped. All the while, production totals and sales of poultry in the United States and worldwide are increasing.

The concentrated animal operations in the Chesapeake Bay watershed produce millions of tons of manure. Throughout the entire watershed, the bay receives billions of pounds of nitrogen and tens of millions of pounds of phosphorous annually (Ator, Brakebill, and Blomquist 2011). The poultry industry in the whole watershed produces over 185 million pounds of nitrogen and over 50 million pounds of phosphorous each year (Chesapeake Bay Foundation 2004). While production on the Delmarva Peninsula produces only a portion of this total, with its large number of facilities and its growth and intensification over the last several decades, it is a significant contributor to nutrient pollution in the Chesapeake Bay (Amato et al. 2020; Ator, Brakebill, and Blomquist 2011).

In the 1950s, when integration took hold in the poultry industry, marine scientists noted significant increases in phytoplankton and other algal growth in the Chesapeake Bay (Kemp et al. 2005). This marked a distinct ecological change, an ecological rift, as the “occurrence of bottom-water hypoxia and anoxia in the main-stem Bay is a relatively

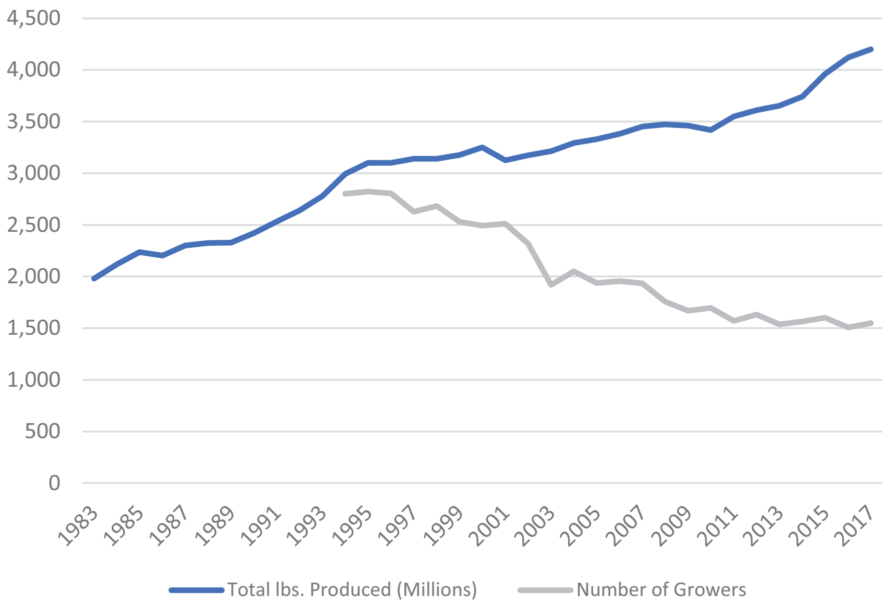

FIGURE 6. Pounds of broilers produced (1983–2017) and number of growers (1994–2017) on the Delmarva Peninsula
Source: Delmarva Poultry Industry (2018).

recent phenomenon . . . [and] indicators show that the intense and recurrent seasonal depletion of O_2 is relatively unique to the last 50 yr" (6). While the nutrient overloading of Chesapeake Bay is due to several modern socioeconomic processes, agricultural practices—including poultry production—are notable drivers of this pollution.

Many factors contribute to creating this link between structural changes in the poultry industry and the intensification of environmental effects. Here, we distinguish between three aspects or processes that have emerged in relation to and combined with vertical and horizontal integration: the scale and pace of production; geographic concentration; and contract farming. These structural conditions and dynamics are prominent factors shaping the ecological rift associated with nutrient pollution that has developed in the Chesapeake Bay.

First, there has been a dramatic increase in the scale and pace of production. During the twentieth century, major changes were made in the operations of production. Large farms and packing plants can grow and process birds by the tens of thousands in vast confined animal feeding operations. Under these conditions, chickens are constantly given specialized feed to increase their rate of growth. Broiler chickens grow to market size in about half the time it took in the 1920s, and modern chickens are about twice the size of their predecessors from a century ago (Pew Charitable Trusts 2013). In other words, modern production results in larger birds raised for market at a faster rate of growth. As production was intensified, it generated increasing quantities of accumulating waste, which contribute to nutrient overloading. This reorganization of chicken production also radically altered labor practices and farming techniques, with serious ecological, human health, and animal welfare implications.

In the Chesapeake states, the number of broilers produced increased by 6 percent from 2007 to 2017. During the same period, the amount of manure produced on broiler farms increased as much as 16 percent due to production of heavier birds (Pelton, Lamm, and Russ 2020). Given the conditions under which chickens are raised, as well as the use of antibiotics and growth hormones, this waste is both rich in nutrients and contaminated with various pollutants. There are also numerous reported incidences of waste dumping from large poultry operations. For example, according to the Toxics Release Inventory, Perdue facilities dumped over 31 million pounds of toxic waste into U.S. waterways between 2010 and 2014 (Rumpler 2016). More recently, the company was fined close to USD 85,000 for discharging polluted water from a Delaware plant. Tyson is an even bigger offender. Their own 2015 sustainability report indicates that between 2013 and 2015 their facilities exceeded water pollution limits over 300 times, received 80 notifications of violations, and were fined over USD 4.6 million, of which USD 3.95 million was a penalty for multiple releases of anhydrous ammonia (Rumpler 2016). While these fines may seem large, they are minor compared to the annual revenues of these firms: approximately USD 7 billion for Perdue and over USD 40 billion for Tyson Foods (*Forbes* 2020a, 2020b).

Second, these increasingly large-scale and fast-paced production processes tend to be geographically concentrated. With integrated value chains and concentration into larger processing plants, all aspects of broiler production—such as growing of feed and finishing of animals, all of which involve metabolic processes and interchanges—tend to become concentrated in specific regions, as the industry continually works to maximize capital efficiencies. Before, animal farming was on a smaller scale, dispersed across the landscape, and integrated with crop production, which reduced the polluting consequences of manure; but modern meat production is dramatically different. With today's concentrated animal feeding operations, "vast amounts of nutrient and bacteria-laden manure—sometimes in volumes that approach the sewage production of small cities"—are produced, stored, and in many cases disposed on much smaller areas of land (Rumpler 2016:12; see also Driscoll and Edwards 2019). This geographic concentration of waste from broiler production raises the risk of pollution of water and air (MacDonald 2008).

The manure produced from chicken houses is typically stored in open lagoons before being spread as fertilizer. These lagoons produce an array of environmental and human health concerns due to gas emissions and overflow. The overapplication of manure is also common, resulting in further nutrient runoff into waterways (Rumpler 2016). According to Scott Ator and Judith Denver (2015:27), hydrologists with the U.S. Geological Survey, "applications of nitrogen and phosphorus from these sources [broiler operations] to croplands on the Eastern Shore have exceeded crop needs since at least the 1980s." This problem is not limited to the Delmarva Peninsula, as it occurs throughout the Chesapeake watershed. For example, in Pennsylvania, the agricultural sector, which includes many poultry plants, is responsible for 26 percent of the nitrogen and 16 percent of the phosphorus entering the Chesapeake Bay. Much of the waste stays within the same county, contributing to nutrient pollution in the larger watershed (Russ et al. 2017).

The metabolic relationship between humans and the larger environment has appreciably shifted with the development of concentrated large-scale animal agriculture and the use of synthetic fertilizers as inputs to support food production. Historically, and still in many parts of the world, manure is a renewable and effective resource used to enrich soils with needed nutrients. But the structural changes associated with animal production, separating it from crop production, as part of the intensive operations noted above, have often turned it into a form of pollution, dumped on land and discharged into waterways (de Wit et al. 1997; Pew Environment Group 2011). Economists (e.g., Sheriff 2005) explain this as a problem associated with the low opportunity costs of overapplication due to excess availability of manure. Indeed, on very large farms, it may make economic sense, due to weight and transportation costs, to apply all the manure on a nearby field and to purchase synthetic fertilizer for the remainder. In the Chesapeake Bay watershed, most of the manure is applied on less than 10 percent of the agricultural land, which is near livestock housing areas such as those on the Delmarva Peninsula (Kleinman et al. 2012). Poultry litter (manure, bedding, feathers, and spilled feed) is particularly bulky, making disposal a major challenge for the industry (MacDonald 2014). Unsurprisingly, the price of litter is especially low in places where a large amount is produced in relation to the total cropland, such as in Delaware and Maryland.

The excessive availability of manure from geographically concentrated animal agriculture has encouraged the overapplication of manure, as a means to dispose of waste. This in turn has created high levels of runoff, unabated by weak regulatory efforts (Molnar, Hoban, and Brant 2002; Russ et al. 2017). Phosphorous is a special problem in this regard. Chicken litter tends to contain phosphorous and nitrogen in similar ratios, while crops require far less of the former. As a result, over many years of overapplication of chicken manure on the Delmarva Peninsula, there has been a buildup of soil phosphorous and runoff of this nutrient into the Chesapeake Bay watershed (Pew Environmental Group 2011). Further contributing to the nutrient overloading process are the large exhaust fans on chicken houses, which blow ammonia-rich air into the surroundings. This ammonia harms the health of people living nearby, and it eventually breaks down into nitrogen, adding to the nutrient pollution of the Chesapeake Bay, on a scale larger than is currently assumed by the Environmental Protection Agency (Pelton, Lamm, and Russ 2020).

Third, as noted, the vast majority of broilers today are raised by contracted growers who supply land, building, equipment, and labor to grow the animals to market size. At the end of the contract, the company picks up its chickens and leaves the grower to deal with the waste, including manure and dead birds. This arrangement, where so-called independent growers are solely responsible for the difficult task of litter disposal, is another important driver of ecological problems in the Chesapeake Bay region and other areas where intensive poultry production is concentrated (Molnar, Hoban, and Brant 2002). According to agricultural legal scholar Neil Hamilton (2001:29), "a surprising number of contracts are silent on the issue of the disposal of litter and manure left in the houses after a grow-out cycle, with the contract containing no reference either to the litter or the grower's responsibility for removing it." Food & Water Watch (2015:2) notes that poultry growers are "financially and legally responsible for the manure disposal," which also includes securing the necessary environmental permits. The potentially high cost of the environmental damage that large animal confinement facilities can cause is

> not contemplated or calculated in the price producers agree to in their production contracts. Typically, most contract producers are unable to pay for the costs of cleanup or environmental damages. . . . Most production contracts characterize the producer as an independent contractor and place the risk of liability for environmental damage squarely on the producer. (Stokes 2006:7; see also Ashwood, Diamond, and Thu 2014)

The industry thus effectively displaces responsibility, adding to the negative externalities of its operations. While it refers to growers as "independent," they are extremely dependent on the particular company with which they have a contract. Most growers "operate in highly concentrated markets for their services, with few integrators in any given region" (MacDonald 2014:iv). In 2011, more than half of the growers had only one or two integrators in their area. They are also financially vulnerable. They have to make significant capital investments in chicken housing, with most new facilities financed by debt, making it difficult for growers to shift to other activities after entering the broiler industry (MacDonald 2014; Pew Environment Group 2011). It is also common for integrators to demand that growers make further significant investments in various upgrades to secure contracts, which are typically short-term (Food & Water Watch 2015).

Often, investments in chicken housing also have to meet strict company-specific requirements (Molnar, Hoban, and Brant 2002; Vukina and Leegomonchai 2006). Growers can only shift to another company if one is geographically close enough and actively recruiting, which is often not the case. And finally, contracts may be difficult to understand due to their complexity (MacDonald 2014). This situation is associated with two outcomes, which have been persistent sources of tension in the industry: limited ability for growers to negotiate their contracts (for example, to more equally share the burden of litter disposal); and small economic margins for growers, which prevents their adequately dealing with issues like manure management (Hamilton 2001; Molnar, Hoban, and Brant 2002). For example, in 2011, in the United States, over 30 percent of small growers (those with one or two chicken houses) had negative net farm income, as did 17 percent of the largest producers (those with more than six chicken houses) (MacDonald 2014). Under these conditions, management of litter is determined much more by economic considerations and the structural dynamics of the poultry industry than by environmental concerns. The result is a series of social conditions and processes that lead to nutrient overloading and an array of detrimental ecological changes in the Chesapeake Bay watershed.

DISCUSSION

In the Chesapeake Bay region, geographically concentrated, large-scale production of chickens as a commodity is significantly contributing to nutrient pollution of waterways, causing detrimental changes in the marine ecosystem, such as dead zones, algal blooms, and loss of biodiversity. Much of the research on nutrient loading in the Chesapeake Bay emerges from the natural sciences or state and federal agencies, such as the Department of Agriculture. The reports and studies clearly identify agricultural production as a central aspect of the problems associated with nutrient pollution. However, the problem is often represented as an inevitability (i.e., an unintended consequence of feeding growing populations and growing demands), a technological problem (such as the improper use of existing technologies and/or the need for technological innovations), or a regulatory problem (e.g., lack of enforcement of regulations, like the Clean Water Act). While pointing to the principal role of agriculture is clearly correct, there is much more to consider from a social metabolic perspective, such as the historical-structural specificity of socioecological problems in the watershed and Chesapeake Bay.

Our study suggests it is not simply agriculture, in a general sense, that produces these problems. The *metabolic rift* approach highlights the importance of specific historical developments in the form, organization, and associated practices of agri-food production that drive socioecological change. The modern social metabolic order generates a particular set of organizational principles, production and consumption tendencies, and inclinations toward certain purposes and goals, which mediate socioecological developments. Importantly, under current socioeconomic conditions, food production, such as animal production for food, is centrally geared toward producing food commodities. Too often this aspect is taken for granted in studies on nutrient loading and agriculture. Commodification of the agri-food system is a significant overarching social mechanism that structures the form and manner of production and consumption of food. In this, there is a distinct social logic and context that shapes food production systems, with definite effects on the social metabolism.

This agri-food system is constituted in large part by commodification of inputs and outputs, where there are powerful and coercive social forces associated with capital accumulation, the economic growth imperative, and the concentration and consolidation of capital. These predispositions practically emphasize the primacy of earnings over other social or ecological matters (Longo, Clausen, and Clark 2015). Modern animal agri-food systems, in this case poultry, require factory-like production practices and highly rationalized processing and distribution to optimally advance capital efficiency and growth to meet the economic demands of integrator firms (Constance and Heffernan 1991; Freshour 2019; Gisolfi 2017). The breadth and scale of production are centrally driven by what is beneficial for a small number of producers with disproportionate power over the system, which results from the centralization and concentration in the sector. The concentrated growth of production—with a primary emphasis on economic efficiency—is typical of a social metabolic order that has, at its core, imperatives propelled by commodification. In this, the commodification of human labor also acts as an essential organizational principle of production and consumption. The labor process, including management and the application of technologies, is shaped and constrained by the same priorities, like all other commodity systems (Freshour 2019; Heffernan 2000).

The concentration of production and use of larger contracted farms has allowed the poultry industry to increase the scale of operations, pursue economic efficiency in the broiler production system, control the grow-out rate of the birds, reduce prices for chicken products, promote expanded consumption, and, in the end, grow revenues and profits. An important component of this system is contract farming, which has been a boon for the major integrator enterprises in the poultry industry. This transformation of poultry production in the United States has left growers subject to the dictates of major poultry firms, and they generally carry a heavy debt to serve the integrator firms (Gisolfi 2017; Molnar, Hoban, and Brant 2002). If growers do not have other sources of income, they are likely to fall among the working poor (Pew Charitable Trusts 2013).

Integrator companies have accrued significant economic and thus political power, especially in regions with high concentrations of poultry production. The firms have considerable influence on the regulatory processes (both environmental and labor) that are meant to oversee their activities (Molnar, Hoban, and Brant 2002). The growers, with their heterogeneous interests and inadequate organization, have little bargaining power, resulting in regulation (or lack thereof) that tends to favor integrator firms (Vukina and Leegomonchai 2006). This includes agricultural waste management.

First, the regulations in several states surrounding the Chesapeake Bay have numerous loopholes, weak requirements, and lax enforcement (Fry 2012; Russ et al. 2017). There is a "vast body of evidence" for the need for strong regulations on waste management to prevent widespread nutrient pollution, but the "immense political power" of the agricultural industry has prevented such actions (Fry 2012:ii). Second, the historical development and structural changes in the system of poultry production have allowed integrator firms to avoid taking on the cost of growing out the animals and distanced them from the responsibility for effectively dealing with the wastes from production (Gustin 2018). Instead, growers must contend with these issues, often under financial strain. Given the overabundance of animal waste, it has little economic value. The increasing scale and intensity of poultry production, and the geographic concentration of the operations, lead to a growing accumulation of waste in relatively small terrestrial spaces. In the Delmarva region, one of the sites that has seen dramatic expansion of poultry production, a significant outcome of these conditions is the pollution of streams and rivers that feed the Chesapeake Bay. As we have described, nutrient pollution contributes to significant changes in the marine ecosystem, such as algal blooms, dead zones, altered energy transfers within the food web, and a loss of biodiversity.

The watershed and the bay act as conduits for the flow of energy and nutrient exchange between social and ecological systems. These processes are being transformed as a result of the cascading consequences of nutrient overloading, together with other ongoing anthropogenic environmental changes. While there are additional contributors to pollution and nutrient overloading in the bay, we find that the historical and structural changes in poultry production are directly linked to metabolic rifts in marine ecosystems. The political-economic organization of poultry production on the Delmarva Peninsula has played a significant role in transforming the metabolic relationships between the land and sea.

CONCLUSION

Through analyzing the structural changes and socioecological processes, with a focus on the political-economic factors that have influenced the development and social metabolism associated with the poultry industry, this article has highlighted specific socioecological drivers of marine pollution in the Chesapeake Bay. Given the largely structural nature of these drivers, our findings can be expected to be partly generalizable to other places where industrial animal agriculture is concentrated. However, we also point to specific aspects of both poultry production and the biophysical dynamics of the study region, which shape the causal dynamics and socioecological outcomes in several important ways. We have identified certain structural changes and social dynamics of poultry production that contribute to environmental concerns, particularly those linking land and sea. By creating the conditions in which individuals and firms operate, these processes have shaped the particular social metabolic relationships that have changed marine ecosystems in the Chesapeake Bay through generating land–sea rifts.

Vertical and horizontal integration have played an essential role in the centralization and concentration of capital in the poultry industry on the Delmarva Peninsula. A few integrator firms dominate the market and exert considerable political-economic influence. They determine how production is organized, prioritizing capital efficiencies and growth. This has expanded both the scale and the pace of production, intensifying the resources used and the waste generated in the creation of food commodities. At the same time, poultry operations are geographically concentrated, often in poorer rural regions where people have fewer employment options, whether it is growers or workers in processing plants. While often burdened with debt from building and operating enormous chicken houses, growers shoulder the responsibility of disposing of the massive amounts of waste from so many birds concentrated in one area. These structural changes and social processes have dramatic and far-reaching ecological consequences.

As the social metabolic approach highlights, it is crucial to consider the political-economic dynamics and structural conditions that influence socioecological relationships and exchanges. In doing so, this study points to the need to fundamentally transform the structure and organization of agri-food production to address sustainability and equity concerns. This involves decentralizing and diversifying production of poultry to avoid waste problems that are amplified by concentrated production; eliminating the exploitation associated with contract farming; and implementing standards that advance the restoration of the Chesapeake Bay ecosystem and sustainability in this region and beyond. Further, this research suggests that, broadly speaking, the decommodification of food and human labor would likely have beneficial socioecological effects in the region and for ecosystems like the Chesapeake Bay.

Due to the structural nature of the social forces, addressing the aforementioned problems requires more than technological fixes like installing filters on farms, or imposing regulations to limit the number of farms, or reducing farm size. Rural social development and rural economic opportunities that provide viable options for people to work and flourish are needed. While regulation can be beneficial and is necessary, such actions must be part of restructuring the rural political economy in general. In the agri-food system, this should be done in a way that transitions growers and workers into sustainable forms of food production and ensures a just transition, one that considers the impacts on workers' livelihoods, social equity, and ecological systems.

Perhaps the array of social and ecological problems associated with modern industrial poultry production will spur mobilization for the needed changes (Harnesk and Isgren 2021). There are numerous grievances and concerns regarding injustice in the industry. For example, workers in chicken processing plants face extreme forms of exploitation. The work itself is organized in a way that increases injuries and shortens workers' lives (Freshour 2020). In 2020, this was associated with significant outbreaks of COVID-19 in these plants on the Delmarva Peninsula. Animal cruelty is an ongoing concern in industrial animal production. Growers are often economically vulnerable. Nutrient pollution is negatively affecting fishers, recreationalists, and citizens in general. As Michael Carolan (2020:26) explains, a nuanced political-economic analysis of rural and environmental justice issues is needed, to avoid false dichotomies that "pit a historically marginalized group against another that might look privileged but that is not"—where the latter includes farm families stuck in inequitable contractual arrangements, large debt burdens, and polluted communities. The possibility of bridging such varying interests was demonstrated by the "brief but compelling" experience of the labor-community coalition known as the Delmarva Poultry Justice Alliance in the late 1990s and early 2000s (Bussel 2003). Using a social metabolic approach, this study contributes to elucidating political-economic processes and structural conditions that can connect these various socioecological concerns. It illuminates fundamental conditions and dynamics that must be addressed to pursue the development of more sustainable food systems. ■ ■

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