Introduction

Regional economic assessments (REAs) are useful tools for policy makers to understand how various industries, or changes in those industries and the policies governing them, might affect the regional economy. Quite often in the United States (U.S.), REAs and specifically economic contribution analyses are used in natural resource settings to communicate the economic importance of resource-based industries (recreational and commercial fishing, farming, forestry, aquaculture, etc.) to policymakers, elected officials, and the general public. For example, National Oceanic and Atmospheric Administration (NOAA) Fisheries has released reports highlighting the economic contributions of the U.S. recreational fishing industry (see Lovell et al. [2020] for the latest report) and the U.S. commercial fishing industry (see National Marine Fisheries Service [2018] for the latest report). Additionally, economic contribution analyses of other resource-based sectors such as crop farming, animal production, and forestry, are released on a statewide level (Ward and Salisbury, 2016; Team Pennsylvania, 2018; Court & Ferreira, 2020). As many of these analyses confirm, resource-based industries are often integral components of local and regional economies; however, to portray this accurately, it is necessary to perform sector-specific economic contribution analyses. Providing transparent and objective quantification of the economic contributions of existing sectors can inform decision-making, which is necessary for evaluating the efficacy of policies that might affect these sectors. These assessments have been especially useful in the context of fisheries and seafood production but have generally focused on the commercial and recreational fishing industries (Adams et al., 2002; Fedler, 2009; Arita et al., 2013; National Marine Fisheries Service, 2018; Lovell et al., 2020). In comparison, there has been limited analysis of aquaculture production (Murray & Hudson, 2013; Northern Economics, Inc., 2013; Cole et al., 2017; Lipton et al., 2019).

U.S. aquaculture provides jobs and economic opportunities throughout the U.S., while increasing and diversifying fish and seafood production (NOAA Fisheries, 2020). Aquaculture production accounted for 22% of U.S. fish and seafood production in 2017 (National Marine Fisheries Service, 2020), though that percentage is expected to grow. A 2013 World Bank report projected that U.S. and Canadian aquaculture production will increase by 40% between 2010 and 2030, while suggesting capture fisheries production in the region will decrease by 0.1% during the same time period (World Bank, 2013).[1] Aquaculture is expected to play a larger part in U.S. seafood production as a sustainable food production method. However, growth in the U.S. aquaculture industry is not guaranteed as this sector has faced and continues to face impediments to expansion. In many areas of the U.S., aquaculture production has been unable to expand due to substantial regulation and leasing requirements (Knapp & Rubino, 2016; Garlock et al., 2020), which in many cases, have increased producer costs and decreased technical efficiency (van Senten & Engle, 2017; van Senten et al., 2018; Engle et al., 2019; van Senten et al., 2020). Social factors have also played a role in limiting aquaculture expansion in some regions, such as the "not in my backyard" (NIMBY) attitude (Dear, 1992; Beckensteiner et al., 2020), antagonistic relationships between wild fishers and farmers (Tiller et al., 2013; Froelich et al., 2017; Clavelle et al., 2019),

[1] The reference cited provides only combined projections for the United States and Canada. Ideally, U.S. specific projections would be used, but none were available separately from reliable sources.

the prioritization of commercial fishing and tourism over aquaculture (Garlock et al., 2020), and negative stakeholder perceptions (Knapp & Rubino, 2016). These social components might act independently to stymie aquaculture directly or can lead to regulatory requirements that act similarly. To the extent that stakeholder's negative attitudes towards aquaculture stem from not understanding the sector's economic contributions, aquaculture-specific REAs might affect these social factors.

There have been efforts to provide economic contribution estimates of existing aquaculture industries in several regions of the U.S. Northern Economics, Inc. (2013) conducted a study using survey responses from industry producers and an Input Output (IO) framework to evaluate the economic contributions of shellfish aquaculture in the Pacific Northwest of the U.S. The same approach was used to estimate the economic contributions of both shellfish and finfish aquaculture production in Maine (Cole et al., 2017). The Virginia Institute of Marine Science (VIMS) has previously included REAs within their annual shellfish aquaculture situation and outlook report (Murray & Hudson, 2013), but has since focused primarily on revenue and production statistics (Hudson, 2019). In addition, a recent collaborative study by NOAA and the University of Maryland estimated the economic contributions of crawfish, salmon, clam, and other aquaculture in the U.S. using publicly available data (Lipton et al., 2019). This particular study highlighted a number of data issues addressed in this research and went as far as to outline the information that would be needed to accurately estimate the economic contributions of U.S. aquaculture production on an annual basis. While these studies provide a starting point for a methodological framework for estimating the economic contributions of U.S. aquaculture, the paucity of such studies is a direct result of the data issues that are limiting the development of accurate aquaculture-specific REA tools.

While there is a need and increasing interest in assessing the economic contributions of aquaculture via REAs, the data and tools to do so precisely are lacking. For example, many attempts to estimate the direct value of aquaculture industries in terms of industry output or sales revenue via Census or survey techniques have been beleaguered by low average response rates.[2] The U.S. Department of Agriculture (USDA) 2018 Census of Aquaculture had a response rate of 39% for Florida aquaculture operators. Additionally, the USDA 2017 Census of Agriculture, which includes less detailed information about aquaculture production, had a nationwide response rate of 71%. These numbers are conspicuously low for surveys that aim to provide a "complete count" of a population (as is always the aim of a census). Therefore, published values might significantly underestimate the true value of aquaculture sales (USDA, 2019). This lack of readily available, systematically collected, and consistent data on the direct economic contributions of aquaculture industries (e.g. direct output or sales revenues, direct employment, direct labor income, etc.), which would be inputs to an economic contribution analysis, has hindered the use of REAs for aquaculture on a regular basis.

[2] While we focus on sources of aquaculture data within the U.S., similar issues are present around the world. The Fisheries Division of the Food and Agriculture Organization (FAO) of the United Nations publishes one consistent source of data on global aquaculture production. However, Botta et al. (2020) found that these data are potentially unreliable for certain countries and do not provide much detail on aquaculture type (species or technology).

In the few cases where consistent and reliable data on the direct value of aquaculture sectors have been developed, inadequate modeling tools can hamper their application and utility. Whereas economic contribution analyses for larger or more established animal production sectors (e.g., poultry or cattle production) are assessed with IO models that explicitly represent these sectors, this is not the case for aquaculture. Within the U.S., the major IO or social accounting matrix (SAM) based modeling software systems (IMPLAN©, RIMS, REMI, IO-Snap, etc.) that are used to estimate economic contributions employ built-in databases that measure economic linkages. In each of these databases, the aquaculture industry is just one component of an aggregate animal production industry that represents all types of animal production except poultry and cattle.[3] Not surprisingly, this sector contains a very diverse set of animal production activities. Analyses of the aquaculture sector that are conducted using this aggregated sector implicitly assume that the aquaculture sector purchases input goods and services in a manner consistent with the weighted average of the diverse set of animal production activities present in the region, which is usually incorrect. The vast differences in aquaculture production and other land-based animal production (e.g. hogs, equines, companion animals, earthworms, etc.) as well as the varied nature of aquaculture production itself, (e.g., shellfish vs. finfish, pond vs. recirculating aquaculture systems vs. net-pen, etc.) necessitate sector-specific data for accurate estimates.

The inadequacy of sector-specific aquaculture data and the non-existence of modeling tools that explicitly include aquaculture sectors prevent accurate and precise estimates of the economic contributions of aquaculture in the U.S. Using reliable input data on the value of the aquaculture industry within an IO model that does not explicitly represent the aquaculture sector can produce misleading descriptions of broader regional economic contributions (indirect and induced effects). On the other hand, the development of IO models that explicitly represent the aquaculture sector for use with input data that are known to be underestimated (i.e., USDA Census of Aquaculture data) will correspondingly underestimate the broader regional economic contributions of the sector. While in many cases, some information is better than no information, researchers and policy makers should be aware of and explicitly mention the limitations and implicit assumptions behind all estimates provided to inform decision-making. Because aquaculture specific analyses are still so rare, policymakers and indeed some practitioners might not be aware of the issues related to improperly conducted REAs. To understand the need for more reliable data and tools that explicitly include aquaculture as an individual sector, it is necessary to demonstrate how differences in modeling approach can impact the results of REAs, in this case, economic contribution analyses.

This paper will provide an overview of economic contribution analyses, the challenges associated with applying these analyses to U.S. aquaculture production, and techniques to limit these issues. It will use the Florida shellfish aquaculture industry as an example to highlight how data and modeling issues might affect analysis results and potentially lead to inaccurate and

[3] This issue is also not unique to the U.S. Other countries have a similar but slightly different situation. Harmonized input-output data for other countries published by the Organisation for Economic Co-operation and Development (OECD) or resources such as the World Input-Output database, are in most cases based on the System of National Accounts (SNA) adopted by the United Nations Statistical Commission (UNSC) (United Nations, et al., 2009). Within this framework, aquaculture production is a component of the aggregated sector labeled "Fishing and aquaculture", which includes all types of commercial fishing activity as well as aquaculture production. While the activities within the aggregate sector are different, the implications remain the same.

unreliable contribution estimates. The remainder of the paper is organized as follows: the next section provides a brief introduction and overview of economic contribution analyses and examines the data issues associated with applying built-in models to aquaculture analyses. Then, the data requirements and implementation of both a built-in model and a hybrid model (which is better suited to the data limitations of aquaculture analyses) are presented for Florida shellfish aquaculture. This is followed by the results of the Florida shellfish aquaculture industry contribution analysis, a discussion of the resulting estimates, and concluding remarks.

Economic contribution analysis

Background

Economic contribution analyses utilize an IO framework that characterizes financial linkages in a regional economy between industries, households, and institutions. This framework codifies information on the purchases of input goods and services (i.e., expenditure patterns of a given industry), and the demands satisfied by industry outputs, trade flows, capital investment, taxes, and transfer payments (such as social security, welfare, retirement pensions, and savings by household) (Miller & Blair, 2009). The IO framework allows for the estimation of economic multipliers, which can be used to estimate an industry's broader contribution to the regional economy. The multipliers account for multiple rounds of spending associated with supply chain purchases that result from an initial level of final demand for the output of the industry of interest. For example, to meet a certain level of final demand for shellfish aquaculture products, a shellfish aquaculture producer will purchase input goods and services (oyster seed, cages, boat fuel, etc.), which will trigger these industries to purchase input goods and services to satisfy the demand of shellfish aquaculture producers, and so on throughout the various supply chains.

Multipliers can be broken down into three components: direct, indirect, and induced effects.[4] Direct effects measure the value of the existing activity in the industry of interest. Indirect effects measure the inter-industry transactions that take place throughout the rounds of supply chain spending. Induced effects measure the spending of the employee wages paid as a result of both direct and indirect effects. The total economic contributions represent the sum of the direct, indirect, and induced effects and can be measured by several metrics. These include employment (fulltime and part-time jobs), labor income (wages, salaries, benefits), value added (Gross State Product or Gross Domestic Product), output (sales of goods and services), and taxes paid. These metrics can also be summarized with an imputed multiplier, which is the ratio of the total effects to the direct effects (Miller & Blair, 2009).

There are several public (free) and licensed (for purchase) databases and software packages available that make IO- or SAM-based analysis straightforward for practitioners in the U.S. (e.g., IMPLAN, RIMS, REMI, IO-Snap, etc.). These regional economic modeling systems are often used in academiand the private sector for REAs. Through their built-in databases and simple user

[4] Induced effects are only present in IO models that are considered "closed with respect to households", meaning that the row and column corresponding to labor income and household consumption, respectively are endogenized or incorporated into the matrix of interindustry transactions as opposed to being exogenous components of value added and final demand. See Miller & Blair (2009) for additional details on model closure and Type II multipliers.

interfaces for modeling, these tools allow for the estimation of economic multipliers and REAs of several types using the algebraic procedures described in Miller and Blair (2009). However, a simple user interface does not imply that the underlying data, methods, and assumptions are not complex. For clarity and ease of replication, results from REAs should always explicitly state modeling assumptions and provide detailed information on input data.

Issues with analyzing aquaculture

Within the U.S., IO databases, such as those within the IMPLAN© modeling system, usually use an industry sectoring scheme that is identical or very similar to those published in national IO databases available from the Bureau of Economic Analysis or the Bureau of Labor Statistics. These sources publish databases comprised of roughly 75 industry sectors annually and detailed databases comprised of around 400 sectors every 5 years. Often, sectors are comprised of several diverse industries that have been aggregated for data reporting purposes, masking heterogeneity in spending patterns.

In the case of U.S. aquaculture, the industry is aggregated with all animal production that is not cattle or poultry related. This sector also includes the production of hogs, equine, goats, companion animals, apiculture, and even lesser-known practices such as earthworm farming. Depending on the extent to which the aquaculture sector is tied to other sectors within the regional economy through the purchases of goods and services and depending on how these local ties compare to those of other animal production activities in the region, the use of this aggregate sector to model the economic contributions of aquaculture can lead to imprecise or misleading estimates of the industry's economic contributions. The vast differences in aquaculture production and other land-based animal production (e.g., hogs, equines, companion animals, earthworms, etc.) as well as the varied nature of aquaculture production itself, necessitate sector-specific data for accurate and precise estimates. It is necessary to supply detailed, sector-specific data on regional expenditure patterns to estimate the economic linkages caused through rounds of spending accurately and precisely.

The direct use of such built-in databases to calculate the economic contributions of the aquaculture sector will affect both the partitive and holistic accuracy of results (Jensen, 1990). Partitive accuracy refers to the correctness of individual cells within the inter-industry transactions matrix and the resulting technical coefficient matrix and Leontief Inverse matrix (or multiplier matrix) (Jensen, 1980). For example, the correctness of the cell within the Leontief Inverse matrix that measures the change in output for boat fuel that is associated with $100 of final demand for shellfish production (i.e., a consumer spending $100 on farmed clams). Conversely, holistic accuracy refers to the correctness of the estimate of total economic contributions across all sectors of a region's economy resulting from the complete representation of the aquaculture sector within the model (Jensen, 1980). For example, the correctness of the measure of the total output contributions across all sectors of the Florida economy that result from $100 of final demand for farmed clams.

Partial solution

Hybrid models have been used to address the issues with both holistic and partitive accuracy (Propst & Garilis, 1987). These models augment the built-in models with local primary data often collected through industry surveys, allowing for the use of production data that more accurately represent the industry of focus and can increase both holistic and partitive accuracy (Jensen et al., 1979; Jensen, 1980). This can be done in two ways. The first method is to modify the proportion of each input good or service that is purchased locally, which can improve the accuracy of local spending in the first round of direct effects (Ralston et al., 1986; Clouse, 2020*a*). The second method adjusts the distribution of inputs used to produce an industry's output, in other words, it modifies the production function that represents the expenditure pattern of the industry of interest more accurately (Lazarus et al., 2002; Jackson and Court, 2013; Clouse, 2020*a*).

For the reasons previously mentioned, aquaculture REAs have struggled with both holistic and partitive accuracy (Lipton et al., 2019).[5] Additionally, it is difficult to achieve holistic accuracy without a tailored data collection process. Traditionally, data collection focuses on random sampling to address sampling errors and bias in economic hypothesis testing. However, for REAs, randomness is less important in data collection aimed at measuring an industry's usage of input goods and services from other industries as well as usage of value added components (i.e., employee compensation, proprietor income, other property income, taxes on production and imports, etc.). If a production process for an aquaculture commodity uses 30 different inputs, but only a few of those inputs represent nearly all of the total input costs, then it is most important to accurately detail those particular input costs. Also, regions in which only a handful of large producers represent a majority of aquaculture production might have issues with holistic accuracy if data cannot be obtained from all the large producers.

Not only are aquaculture expenditures quite different than other types of animal production, but the input costs are highly variable across different types of aquaculture production. For example, intensive aquaculture practices require substantial input costs (e.g., salmon farming, which requires significant costs associated with feed and net pen procurement and maintenance), while extensive aquaculture practices have less costs to consider (e.g., mussel farming which only requires a rope or stake for the mussel fry to attach itself to) (Asche et al., 2008). Sector-specific data on expenditures patterns (i.e., production functions) for an aggregate aquaculture sector is a first step towards more accurate estimates of the economic contributions of aquaculture activities; however, further detail allowing for the disaggregation of an aquaculture by type (species or technology) will further improve these measures.

Applications to Florida shellfish aquaculture

Aquaculture has been one of the world's fastest growing food production technologies in recent decades, driving the increase in global per capita fish consumption (Smith et al., 2010; Garlock et al., 2020). Much of aquaculture's success around the world can be attributed to the ability to

[5] While Lipton et al. (2019) does not directly use the terms partitive and holistic accuracy, the authors do address the issue. The authors note issues with accurately measuring output levels and their effects on other industries (partitive accuracy) and issues measuring how aquaculture production affects other industries (holistic accuracy).

control the production process, which has allowed technological innovations to lower production costs, offer a more attractive product for consumers, and provide an economically competitive source of animal protein (Asche, 2008). Global shellfish aquaculture production has experienced varying levels of success across different regions as new methods of production have been introduced (Shamshak and King, 2015; Botta et al., 2020). Because shellfish aquaculture production patterns are highly variable across regions, it is worthwhile to assess its' economic contributions at a regional level. This paper will focus on the Florida shellfish aquaculture industry to highlight how data and modeling issues might affect analysis results and potentially lead to inaccurate and unreliable contribution estimates. While the data developed for these analyses are time, industry, and region-specific, the methodologies are generalizable to other times, regions, and other types of aquaculture.

The shellfish aquaculture industry is the largest food-use aquaculture industry in Florida. The USDA estimated that Florida's shellfish aquaculture sales totaled $15.5 million in 2018, accounting for approximately 22% of all Florida aquaculture sales (USDA, 2019). Production in Florida is primarily focused on two species, the Eastern oyster (*Crassostrea virginica*) and the hard clam (*Mercenaria mercenaria*). Shellfish aquaculture leases managed by the Florida Department of Agriculture and Consumer Services (FDACS), Division of Aquaculture, are present on both coasts of Florida, with most of the production occurring along the Florida panhandle and the region known as the "Big Bend" (Figure 1).

[*Figure 1 here*]

Lacking a more reliable source for overall production, both analyses will be driven by the data available from the USDA 2018 Census of Aquaculture (USDA, 2019). The census data include total aquaculture sales and total farms by aquaculture type for each state. Both analyses below employ the Florida shellfish aquaculture sales revenue data for 2018 (USDA, 2019) as the direct output contributions of aquaculture that will drive the model. As a result, these applications will effectively highlight the differences resulting from modeling techniques.

This section discusses the data requirements and analysis steps needed to measure the annual economic contributions of the Florida shellfish aquaculture industry, using both the built-in model, and the hybrid model methods. We examine both methods to highlight the steps that must be taken to ensure partitive and holistic accuracy. While the built-in model might appear attractive to practitioners estimating the economic contributions of aquaculture due to lesser data requirements and easier calculations, the ease of estimation can come at the cost of less accurate contribution estimates, potentially compromising policy recommendations.

"Built-in model" method

Data requirements

Data requirements for this method are minimal, comprising only the measure of total industry output (sales revenue) for Florida shellfish aquaculture, available from the USDA 2018 Census of Aquaculture (USDA, 2019) and access to regional level input-output data or an IO-based software tool. For the purposes of this analysis, we will use the database representing the economic structure of the state of Florida in 2018 and IMPLAN Pro software available from IMPLAN©.

Analysis

An industry change activity was created following Clouse (2020*b*), assigning the USDA 2018 Census of Aquaculture value for total industry output (sales revenue) for Florida shellfish aquaculture ($16,049,000) to IMPLAN© Sector 14 – *Animal production, except cattle, poultry, and eggs*, of which aquaculture production is a component (Table 1). The event year is set to 2018. The model is closed with respect to households, employing Type SAM multipliers where households (all income levels), employee compensation, and proprietor income are endogenized, and uses the Trade Flows specification for estimating trade flows for all IMPLAN© commodities between Florida and other regions in the U.S. (IMPLAN Group, LLC, 2020). The model was not constrained for economic contribution analysis as detailed in IMPLAN (2019) because the shellfish aquaculture sector represents only a small portion of the activity in the overall *Animal production, except cattle, poultry, and eggs* sector. A single region analysis was then processed within the IMPLAN© software and results were generated.

"Hybrid model" method

Data requirements

In addition to the data requirements noted above for the "Built in model" estimates, this method also utilizes Florida shellfish aquaculture production estimates (Sturmer 2020) and more detailed expenditure data gathered from previous published research and industry specialists. Average annual production estimates were combined with published estimates of survival rates, per piece prices, and the USDA sales revenue value to estimate the total production value for both oysters and clams. Costs associated with labor, fuel, production inputs, equipment and bag maintenance, work gloves and boots, insurance and administrative costs, and product packaging were estimated based on the estimated total production values and previously published industry surveys, economic studies, and production budgets. Parameters used in the analysis and their sources are presented in Table 2 and cost category estimates as a percentage of industry revenue and their sources are presented in Table 3.

Analysis

To better approximate how the aquaculture industry spends money within Florida's economy, an analysis by parts approach was used (Lucas, 2020*a*), in which the data derived from the production budgets, economic feasibility studies, and industry surveys populate several of IMPLAN's Event Type options. This is the suggested technique when analyzing an industry that is a subset of a current IMPLAN© industry sector (Clouse, 2020). The data from Tables 2 and 3 were used to estimate total Florida shellfish aquaculture industry (both clam and oyster farming) expenditures across multiple expenditure categories. Categories included seed, labor, fuel, consumable equipment and inputs, equipment repair costs, insurance and administrative fees, and regulatory fees. Each expenditure type was then assigned to the most appropriate IMPLAN© commodity sector (Table 1). Assignment of events to a commodity as opposed to an industry is more appropriate when the expenditure is more representative of an item that is purchased as opposed to the output of an entire industry (Lucas, 2020*b*). Additionally, local purchase percentages were adjusted for each commodity based on the Florida SAM values to more accurately account for imports and leakages during the multiple rounds of spending. As in the "Built-in Method", the event year is set to 2018. The model is closed with respect to households, employing Type SAM multipliers where households (all income levels), employee compensation, and proprietor income are endogenized, and uses the Trade Flows specification for estimating trade flows for all IMPLAN© commodities between Florida and other regions in the U.S. (IMPLAN Group, LLC, 2020). Likewise, the model was not constrained for economic contribution analysis. A single region analysis was then processed within the IMPLAN© software and results were generated.

[*Table 1 here*]

[*Table 2 here*]

[*Table 3 here*]

Results

Regional economic contributions

The estimated economic contributions of Florida's shellfish aquaculture industry are summarized for each method in Table 4. Results for the "Built-in model" method indicate that in 2018, Florida's shellfish aquaculture industry supported 203 total jobs, $12.3 million in labor income, $20.9 million in total value added (Gross State Product), and a total of $26.1 million in industry output (sales revenues). This method suggests an imputed industry output multiplier of 1.63, indicating that for every $100,000 of final demand for shellfish aquaculture products, an additional $63,000 in sales revenues are supported through multiplier effects throughout Florida's economy. Furthermore, of the 203 total jobs supported by shellfish aquaculture expenditures, 68 of those jobs were supported throughout other industries as a result of indirect and induced effects.

Results for the "Hybrid model" suggest that in 2018, the Florida shellfish aquaculture industry supported 434 total jobs, $11.3 million in labor income, $17.4 million in total value added (Gross State Product), and $29.3 million in industry output. This method suggests an imputed industry output multiplier of 1.83, which is slightly higher than measured in the "Built-in model" method, indicating that the shellfish aquaculture has stronger linkages to the regional economy than suggested by the aggregate *Animal production, except cattle and poultry and eggs* sector. Of the 434 total jobs supported by shellfish aquaculture expenditures in the "Hybrid model", 88 were supported throughout other industries as a result of indirect and induced effects.

[*Table 4 here*]

Economic contributions by industry group

Although all of the direct economic activity associated with the shellfish aquaculture industry occur in one sector (Sector 14 – *Animal production, except cattle and poultry and eggs*), the indirect and induced effects can occur throughout the economy across many industry sectors as input goods and services are purchased and households spend their incomes (Table 5). Beyond the contributions (mostly direct) within the *Animal production, except cattle and poultry and eggs* sector, the "Built-in model" method estimated the largest total contributions to be in *Owner-occupied dwellings* ($1.04 million), *Hospitals* ($513 thousand), and *Other real estate* ($490 thousand) industry sectors (Figure 2). The *Other animal food manufacturing* ($161 thousand) and *Wholesale – Other nondurable goods merchant wholesalers* ($116 thousand) industry sectors had some of the larger total contributions that mainly occurred through indirect activities that are caused by additional rounds of spending (Figure 3).

Aside from the contributions (mostly direct) within the *Animal production, except cattle and poultry and eggs* sector, the "Hybrid model" method estimated the largest total contributions to be in the *Owner-occupied dwellings* ($953 thousand), *Insurance agencies, brokerages, and related activities* ($548 thousand), and *Other real estate* ($505 thousand) industry sectors (Figure 2). The *Animal production, except cattle and poultry and eggs* ($1.2 million), *Other state government enterprises* ($377 thousand), *Insurance agencies, brokerages, and related activities* ($355 thousand), and *Commercial and industrial machinery and equipment repair and maintenance* ($333 thousand) industry sectors had large total contributions that mainly occurred through indirect activities (Figure 3).

[*Table 5 here*]

[*Figure 2 here*]

Discussion and concluding remarks

REAs of U.S. aquaculture production can aid management agencies, state government representatives, and regional economic development councils in understanding the role that this industry plays within the state. These analyses have the potential to lessen some of the obstacles (negative public and sector perception that can drive burdensome regulations, restrictive leasing, and NIMBYism) to aquaculture growth in the U.S. by providing information on the industry's economic importance. While there is an increased interest in aquaculture focused REAs, data limitations and issues associated with the application of regional economic impact modeling systems to aquaculture production have limited the use of these analyses. In this paper, we have provided insights into the basics and applications of REAs, highlighted some of the issues surrounding U.S. aquaculture REAs, and provided an example analysis demonstrating how the results of a more accurate hybrid analysis model can vary significantly from those resulting from the use of a built-in model.

Data limitations and sector-specific IO tools are two limiting factors to the application of REAs to aquaculture production in the U.S. While it is tempting to use built-in model relationships to measure the economic contributions of specific aquaculture sectors due to lesser data requirements and ease of use, the example presented in this paper displays how such an approach can lead to inaccurate contribution estimates. The "Hybrid model" approach that is driven by more accurate production budget data for shellfish aquaculture allowed for a more targeted analysis, ultimately providing more reliable economic contribution estimates. The "Hybrid model" estimated higher economic contributions in total indirect effects across all output metrics, as well as total jobs supported, and total economic activity.

The differences between the results of the two models arise from the different representations of the expenditure pattern of the shellfish aquaculture sector within the region. The extent to which the production function of the *Animal production, except cattle and poultry and eggs* sector is representative of aquaculture is dependent upon the presence and size of aquaculture production and these other animal production types within the region as well as the similarities or differences in expenditure patterns across these different animal production types. By using the "Hybrid model", there is a more accurate representation of the expenditures on input goods and services associated with aquaculture operations, supporting more accurate estimates of the relationships between the shellfish aquaculture sector and the rest of the regional economy. In the case of Florida shellfish aquaculture, the "Hybrid model" resulted in larger employment and output values and a higher imputer output multiplier, but lower labor labor income and value added to output ratios as compared to those in the "Built-in model". These results suggest that use of the "Built-in model" method would underestimate employment and output contributions, overestimate labor income and total value added contributions, and underestimate the extent to which the shellfish aquaculture sector is tied into the state economy. Thus, using a detailed hybrid model will more adequately capture the economic linkages of this industry, which will be useful for policymakers to illustrate the importance of shellfish aquaculture to the state economy and the manner in which shellfish aquaculture expenditures support activity across multiple industries in Florida.

While the methods presented are generalizable to other regions and other types of aquaculture, the conclusions of this analysis are specific to Florida shellfish aquaculture in 2018. The direction and magnitude of differences between the "Built-in model" and the "Hybrid model" can vary over time as the overall economic structure of the region changes and can vary by region and type of aquaculture even in the same time period. Use of the "Hybrid model" method can help combat aggregation bias inherent in the use of "Built-in model" methods for economic contribution analyses for U.S. aquaculture sectors (Lipton et al., 2019). Improvements in annual aquaculture production data will also imrpove the accuracy of total economic contribution estimates; however, because the input-output model is a system of linear equations, changes in the overall value of shellfish aquaculture with which we drive results will not change the nature of the differences between the two methods.

We echo the sentiments of Lipton et al. (2019) regarding the need for timely and relevant information on aquaculture production costs and systems, systematic collection of annual aquaculture production data (species, volume, and value), and greater information on the seafood market chain both with regards to product flows and upstream industries (hatcheries and nurseries). However, while these data would greatly increase the ability to conduct accurate REAs of U.S. aquaculture production they are not prerequisites for all studies. Similar to other recent studies (Northern Economics, Inc., 2013; Lipton et al., 2019;), we present an REA that uses industry input and publicly available data to more reliably measure industry contributions. The issues outlined in this paper and the example provided show that, even with aquaculture data limitations, a knowledge of industry production practices and estimated production values affords the opportunity to estimate overall economic contributions.

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Tables

Table 1. IMPLAN© input categories and costs by method.

Method	IMPLAN© Code[6]	IMPLAN© Sector Name	Cost (Thousand $)
Built-in model	14	Animal production, except cattle and poultry and eggs	16,049
Hybrid model	3014	Animal products, except cattle and poultry and eggs	2,555
	3105	Manufactured ice	160
	3119	Textile bags and canvas	491
	3128	Apparel accessories and other apparel	24
	3145	Paper from pulp	324
	3188	Plastics pipes and pipe fittings	216
	3408	Retail services - Gasoline stores	460
	3445	Insurance agencies, brokerages, and related services	181
	3453	Commercial and industrial machinery and equipment rental and leasing services	339
	3456	Accounting, tax preparation, bookkeeping, and payroll services	127
	3465	Advertising, public relations, and related services	160
	3473	Business support services	160
	3515	Commercial and industrial machinery and equipment repair and maintenance	380
	3531	Other products and services of State Government enterprises	439
	Custom assignment[7]	Miscellaneous supplies	446
	EC	Employee compensation	6,741

[6] The IMPLAN© code used for the "built-in model" method refers to the industry sector, while the IMPLAN© codes used for the "hybrid model" method refer to the commodity codes.

[7] The value of Miscellaneous supplies was allocated to individual commodities in proportions that match the purchase of intermediate inputs of the Commercial Fishing sector, which was assumed to be more appropriate at representing miscellaneous purchases of the shellfish aquaculture sector than the intermediate inputs of the Animal Production, except cattle and poultry and eggs sector.

Table 2. Production and cost estimates with source.

Parameter	Clam	Source	Oyster	Source
Annual Production (# of units)	129,590,909	Sturmer, 2020; Grice and Walton, 2019[8]	3,900,000	Sturmer, 2020
Weighted Average Cost Per Unit	$0.11[9]	Court et al., 2020	$0.46	Grice and Walton, 2019
Annual Production Value	$14,255,000		$1,794,000	
Survival Rate	56%	Adams and van Blokland, 1998	80%	Dame, 2018
Seed Costs	$.0105	NCDACS, 2001	$.0257	2019 Interviews with SE US Hatcheries (L. Sturmer, personal communication)
Labor Costs Per Hour	$14.37[10]	BLS, 2019	$14.37	BLS, 2019
Labor Hours Per Year Per Farm	2,103[11]	NCDACS, 2001	2,860[12]	Grice, 2020

Table 3. Cost estimates by category as a percentage of revenue with sources.

Cost Category	Clam	Source	Oyster	Source
Seed	17.1%	See Table 1	7.0%	See Table 1
Labor	41.7%	BLS, 2019; NCDACS, 2001	44.7%	BLS, 2019; Grice, 2020
Fuel (boat and truck)	2.5%[13]	Adams and Sturmer, 2004	5.4%	Grice, 2020
Capital Replacement (bags and nets)	3.2%	Adams and Sturmer, 2004	1.7%	Ropicki, 2020

[8] Clam production was estimated using the 2018 USDA Census of Aquaculture total Florida shellfish production estimates combined with oyster production estimates. 2018 Oyster production (Sturmer, 2020) and per unit value estimates (Grice and Walton, 2019) were used to estimate the total value of 2018 oyster production, which was subtracted from total shellfish production value to estimate the value of clam production and number of clams produced using cost per unit data from Court et al. (2020).

[9] This value is an estimate of the weighted average of production across all clam sizes (pasta, 7/8", 1").

[10] Mean hourly wage per U.S. BLS for farmworkers, farm, ranch, and aquaculture animals.

[11] Labor rate is for a farm producing 660,000 clams per year.

[12] Labor rate is for an oyster farm producing 200,000 oysters per year.

[13] Clam culture fuel costs were updated to reflect 2018 fuel prices using U.S. Energy Information Administration data.

Regulatory Costs (leasing, licensing, and permitting fees)	2.2%	FDACS licensing data (pers. comm. with C. Culpepper and M. Cockrell, July 2020)	6.9%	FDACS licensing data (pers. comm. with C. Culpepper and M. Cockrell, July 2020)
Miscellaneous Supplies	3.0%	Murray and Hudson, 2013	1.0%	Murray and Hudson, 2013
Equipment Maintenance	2.4%	Adams and Sturmer, 2004	2.4%	Grice, 2020
Containers and Packaging	2.0%	Murray and Hudson, 2013	2.2%	Grice, 2020
Building and Equipment Rent or Depreciation	2.0%	Murray and Hudson, 2013	3.0%	Murray and Hudson, 2013
Capital Replacement (durable equipment)	1.1%	Adams and Sturmer, 2004	3.0%	Ropicki, 2020
Insurance (boat and truck)	1.1%	Adams and Sturmer, 2004	1.1%	Grice, 2020
Ice	1.0%	Murray and Hudson, 2013	1.0%	Murray and Hudson, 2013
Advertising and Marketing	1.0%	Murray and Hudson, 2013	1.0%	Murray and Hudson, 2013
Payroll Taxes	1.0%	Murray and Hudson, 2013	3.0%	Murray and Hudson, 2013
Employee Health Insurance	1.0%	Murray and Hudson, 2013	1.0%	Murray and Hudson, 2013
Utilities/Phone	1.0%	Murray and Hudson, 2013	1.0%	Murray and Hudson, 2013
Bookkeeping and Payroll	0.8%	Adams and Sturmer, 2004	0.5%	Adams and Sturmer, 2004
Work Apparel (gloves and boots)	0.2%	Adams and Sturmer, 2004	0.1%	Adams and Sturmer, 2004

Table 4. Summary of economic contributions of Florida's shellfish aquaculture industry, 2018.

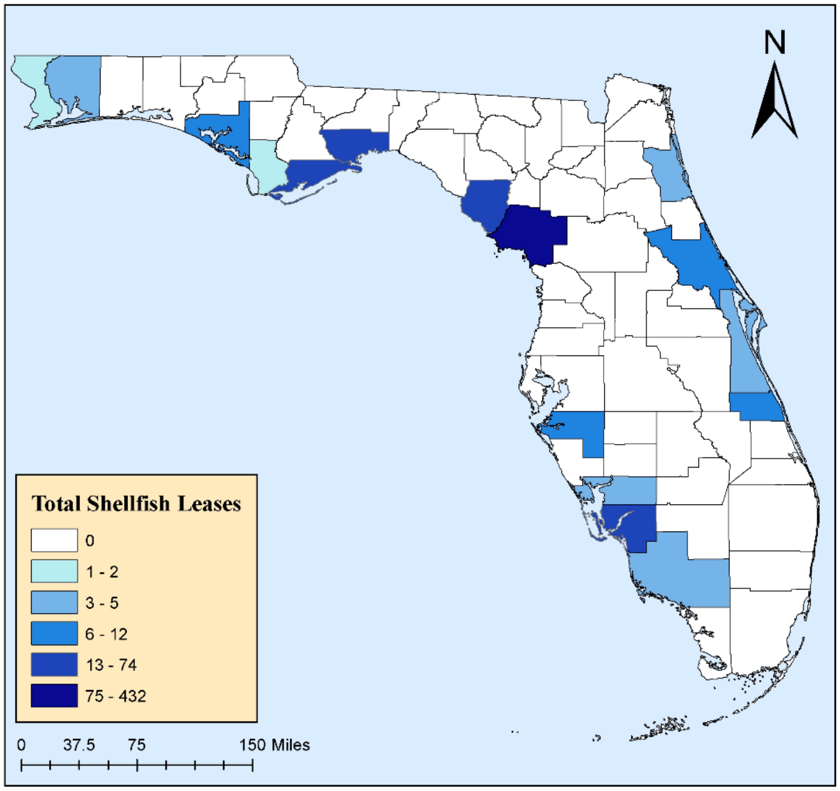
Method	Contribution Type	Employment (Jobs)	Labor Income (Thousand $)	Value Added (Thousand $)	Industry Output (Thousand $)
Built-in model	Direct contributions	136	9,203	15,282	16,049
	Indirect contributions	5	233	382	790
	Induced contributions	63	2,872	5,274	9,322

	Total contributions	203	12,308	20,938	26,161
Hybrid model	Direct contributions	346	6,741	9,585	16,049
	Indirect contributions	31	1,889	2,932	4,566
	Induced contributions	57	2,697	4,969	8,779
	Total contributions	434	11,327	17,486	29,394

Table 5. Total industry output (thousand $) of the top 15 supported industry sectors for each method.

Industry Sector	Built-in Model	Industry Sector	Hybrid Model
Animal production, except cattle and poultry and eggs	16,119	Animal production, except cattle and poultry and eggs	17,233
Owner-occupied dwellings	1,044	Owner-occupied dwellings	953
Hospitals	513	Insurance agencies, brokerages, and related activities	548
Other real estate	490	Other real estate	505
Offices of physicians	340	Hospitals	468
Insurance carriers, except direct life	337	Other state government enterprises	383
Full-service restaurants	252	Commercial and industrial machinery and equipment repair and maintenance	347
Insurance agencies, brokerages, and related activities	224	Retail - Gasoline stores	345
Wholesale - Other nondurable goods merchant wholesalers	220	Commercial and industrial machinery and equipment rental and leasing	333
Limited-service restaurants	218	Insurance carriers, except direct life	326
Tenant-occupied housing	206	Offices of physicians	311
Monetary authorities and depository credit intermediation	196	Full-service restaurants	238
Other financial investment activities	192	Accounting, tax preparation, bookkeeping, and payroll services	217
Other animal food manufacturing	165	Monetary authorities and depository credit intermediation	203
Retail - Nonstore retailers	159	Limited-service restaurants	202
All other sectors	5,488	All other sectors	6,533

Figures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Total Shellfish Leases
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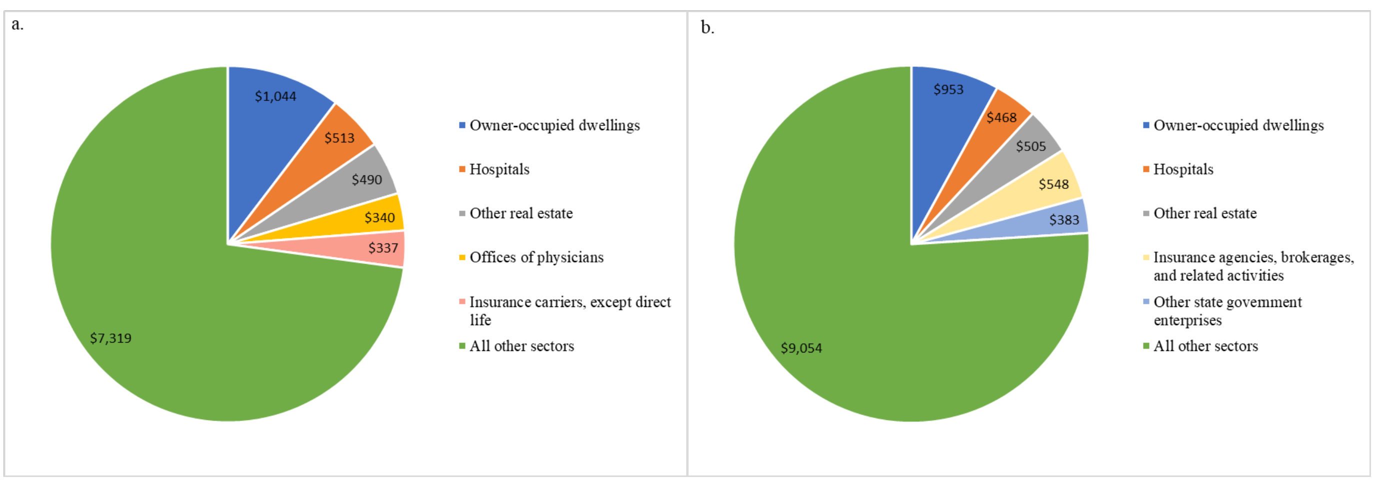
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Owner-occupied dwellings
Hospitals
Other real estate
Offices of physicians
Insurance carriers, except direct life
All other sectors
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Owner-occupied dwellings
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Other real estate
Insurance agencies, brokerages, and related activities
Other state government enterprises
All other sectors

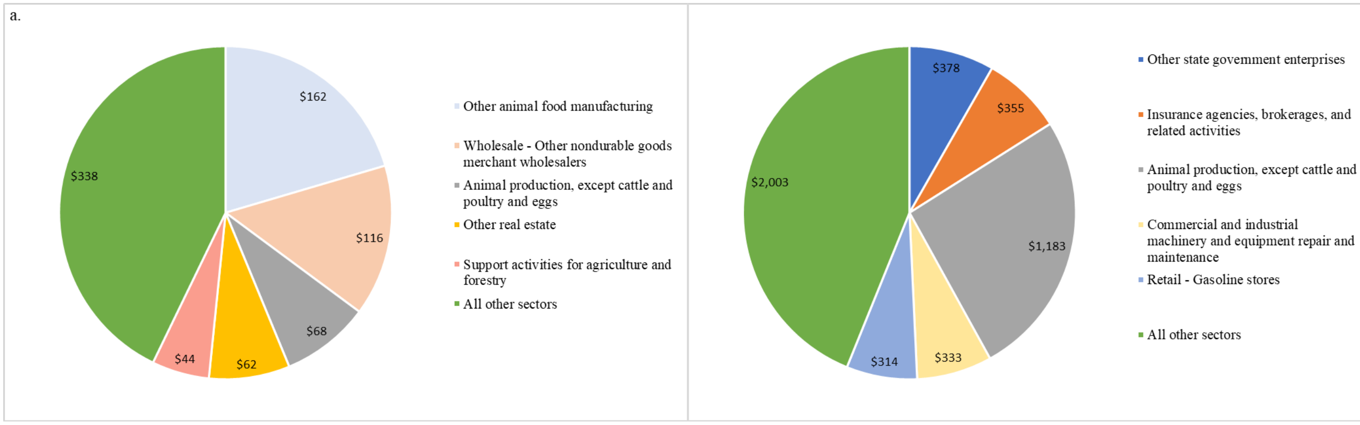

Figure captions

Figure 1. Total number of shellfish leases by county in 2019. Data obtained from FDACS, Division of Aquaculture (C. Culpepper and M. Cockrell, personal communication, June/July 2020) and created in ArcGIS software.

Figure 2. Total contributions of industry output (thousand $) for the top five supported industry sectors (excluding the "Animal production, except cattle and poultry and eggs" sector), where a) includes results from the "Built-in model" method and b) includes results from the "Hybrid model" method.

Figure 3. Indirect contributions of industry output (thousand $) for the top five supported industry sectors, where a) includes results from the "Built-in model" method and b) includes results from the "Hybrid model" method.