Title: Community-level Economic Impacts of a change in TAC for Alaska Fisheries: A Multi-regional Framework Assessment

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OMB Disclaimer

The findings and conclusions in the paper are those of the author and do not necessarily represent the views of the National Marine Fisheries Service, NOAA.

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ABSTRACT

A marine heatwave caused the total biomass of Gulf of Alaska (GOA) Pacific cod to plummet by 67% from 2015 to 2018. Based on the results from GOA Pacific cod stock assessment model, the North Pacific Fishery Management Council cut the GOA Pacific cod total allowable catch (TAC) by 80% in 2018. This study uses a 10-region multi-regional social accounting matrix model to compute the economic impacts of the cod fishery disaster on the six borough and census areas (BCAs) in Southwest Alaska plus effects on the other four regions. We consider both the negative effects of the reduction in the cod harvest and the offsetting effects from an observed increase in the price of the fish to calculate the "net" economic impacts. This study found that the offsetting effects from the price increase are significant; the reduction in total regional output in the rest of the United States is 15% less severe if effects of the price changes are taken into account. Furthermore, the region suffering the largest impacts on total seafood industry output (Aleutians East Borough) from the reduced TAC is not necessarily the region where the largest total regional impact occurs (rest of the U.S.).

Key Words: Pacific cod fishery; marine heatwave; multi-regional social accounting matrix model

1. Introduction

The Gulf of Alaska (GOA) is an arm of the eastern Pacific Ocean defined by the curve of the southern coast of Alaska, stretching from the Alaska Peninsula and Kodiak Island in the west to the Alexander Archipelago (where Glacier Bay and the Inside Passage are found) in the east. The coast of GOA is heavily indented with bays and inlets, with Cook Inlet and Prince William Sound being the two largest connected bodies of water (Figure 1).

The Pacific cod (*Gadus macrocephalus*) fishery is one of the most important commercial fisheries in the GOA. In 2016, the fishery harvested 64.1 kilotons (kt) in round weight which earned $40.9 million (ex-vessel revenue) (Fissel et al. 2019, Tables 1 and 3). The total biomass of GOA Pacific cod decreased significantly by 67 percent from 2015 to 2018. The downturn has been attributed to the impacts of a marine heatwave[1] which affected the region in 2014 through 2016, dubbed "the Blob" (Bond et al. 2015). The heatwave has been shown to have caused significant reductions in productivity in the ecosystem (Whitney 2015). These reductions in productivity, coupled with higher metabolism in ectotherms like Pacific cod, caused a rapid depletion of forage species which led to increased rates of starvation and increased mortality (Barbeaux *et al.* 2019).

In addition, few young cod were produced during this time period likely due to a combination of temperatures exceeding the narrow thermal range of Pacific cod eggs (Laurel and Rogers 2020) and poor survival of larvae at elevated temperatures (Laurel *et al.* 2008). The total biomass of GOA Pacific cod was estimated to be at its lowest point in the history of the

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[1] Marine heatwaves are directly related to climate change (Laufkötter et al. 2020) and analyses have indicated that the magnitude and duration of recent marine heatwaves in the Gulf of Alaska would not be possible without anthropogenic radiative forcing (Walsh et al. 2016; Litzow et al. 2020).

modern fishery in 2018 at 127 kt, down from its highest in 1988 at 778 kt (Barbeaux *et al.* 2019).

The sharp decline in the GOA Pacific cod stock triggered the North Pacific Fishery Management Council (Council) to reduce the GOA Pacific cod total allowable catch (TAC) by 80% in 2018 compared to the projected TAC from 2017, and then after continued declines in spawning biomass through 2019, closing the federal directed fishery in 2020.[2] With this large of a cut in the TAC for a fishery as important as GOA Pacific cod, the economic impacts will likely be significant. Seafood processors and vessel owners and operators and fishing crews will all feel the adverse impacts directly. The steep reduction in TAC will also have indirect impacts on industries supporting the fishery that supply inputs (e.g., fuel, supplies and groceries) to the fishery. In 2019, the U.S. Commerce Secretary declared a fishery resource disaster for the 2018 GOA Pacific cod fishery. Congress has allocated disaster relief funds in the amount of $165 million for fiscal year 2019 which will be distributed among stakeholders in fishery failures, including the GOA Pacific cod fishery failure, in seven different states.[3]

Federal laws mandate that economic analysis of a proposed fishery management action on fishing communities be conducted. These laws include the Magnuson-Stevens Fishery Conservation and Management Act (MSA, reauthorized in 2007), National Environmental Policy Act (NEPA), and Executive Order 12866, among others. In particular, National Standard 8 of the MSA requires that conservation and management measures in, and any amendments to, fishery management plans (FMPs) "take into account the importance of fishery resources to fishing

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[2] The average total number of vessels that fished the federal TAC of Pacific cod in the GOA from 2014 to 2016 was 360, including both catcher vessels and catcher processors. The number decreased to 246 in 2017, and to 151 in 2018 (Fissel et al. 2019, Table 9).

[3] NMFS has allocated about $24.4 million for the Pacific cod fishery disaster. However, as of August 21, 2020, the funds had not been disbursed to the affected stakeholders.

communities… in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities" [MSA 301(a) (8)]. To meet this requirement, fishery managers must take into account the economic impacts on affected communities arising due to a change in fishery management or in response to environmental shocks such as climate change.

Most regional economic models developed for Alaska fisheries are designed to compute the economic impacts for either the whole state or large administrative regions (e.g., the Southeast Alaska region). Examples include Seung and Waters (2009) who developed an Alaska state-level social accounting matrix (SAM) model to assess the economic impacts of a change in pollock total allowable catch (TAC), and Seung et al. (2016) who constructed a similar model to estimate the economic impacts of a declared salmon disaster on Alaska. These models are single-region (i.e., Alaska) models. While these single-region models are useful in some ways, they cannot estimate the economic impacts of Alaska fisheries on states or regions outside Alaska. Consequently some previous studies have developed multi-regional economic impact models to examine the inter-regional effects (spillover and feedback effects) occurring between Alaska, West Coast, and the rest of U.S. (e.g., Seung 2014; Seung 2017; and Waters et al. 2014).

While these models are improvements over single-region models, they are not designed to estimate the economic impacts on smaller areas such as boroughs and census areas (BCAs) or individual fishing-dependent communities. No previous studies have developed models enabling estimation of impacts on individual BCAs in Alaska. One important reason for lack of community-level models is the dearth of reliable regional economic data on Alaska seafood industries needed to develop such models. Based on a dataset developed from a survey of Southwest Alaska (SWAK) seafood industries (Cascade Economics 2016), a recent study, for the first time, developed a BCA-level, 10-region multi-regional SAM (hereafter, 10MRSAM) model for SWAK fisheries (Seung, Waters and Taylor 2020).

The 10 regions in 10MRSAM include an at-sea "region" (AT-SEA), six SWAK BCAs, the rest of Alaska (RAK), U.S. West Coast (WOC, Washington, Oregon, and California), and rest of the U.S. (RUS). The six SWAK BCAs are as follows: Aleutians West Census Area (AWCA – including Atka, Unalaska and Dutch Harbor), Aleutians East Borough (AEB – including Akutan, King Cove and Sand Point), Lake and Peninsula Borough (LPB – including Chignik, Ugashik and Egegik), Bristol Bay Borough (BBB - Naknek), Dillingham Census Area (DCA – including Dillingham and Togiak), and Kodiak Island Borough (KIB). (Figure 1).

Data collected for 10MRSAM indicates that in 2014, the total ex-vessel revenue from all the fish landed in Alaska was $1.28 billion. 67% of this was accounted for by SWAK BCAs with the remainder (33%) by RAK. Total SWAK landings revenue was distributed to each BCA as follows: AWCA (25.9%), AEB (15.8%), LPB (1.7%), BBB (10.5%), DCA (1.9%), and KIB (11.1%). The AT-SEA "region" represents fish harvesting and processing activity conducted on at-sea catcher-processors (CPs) and mothership floating processors (including catcher vessels delivering to motherships) operating in SWAK-region waters [including eastern Bering Sea, Aleutian Islands, and Gulf of Alaska].

This study used the 10MRSAM model to estimate the impacts of a drastic reduction in GOA Pacific cod (*Gadus macrocephalus*) TAC in 2018 due to the effects of uncharacteristically warm water in the region that persisted for several years. The substantial reduction of the TAC was decided by the Council based on results of the GOA Pacific cod stock assessment model (Barbeaux et al. 2019). In assessing the economic impacts, we computed the "net" economic impacts of the sharp decrease in the Pacific cod TAC by bifurcating the offsetting effects of the reduction in harvest and coincidental increase in the Pacific cod price which occurred contemporaneously.

Many previous studies relying on input-output (IO) and SAM models assessed only the economic impacts from a change in the quantity of a commodity sold or produced arising due to a policy change or exogenous shock. These studies seldom consider the effects of a change in the price of the commodity. One obvious reason is that the fundamental assumption underlying these types of models is that prices are fixed. Accordingly, most previous economic impact studies of fisheries carried out within an IO or SAM framework assumed that prices of goods and services (including prices of raw and processed fish) do not change. However, this assumption is too restrictive in this case.

If the price change is large and concurrent with the quantity change, the economic impacts due to the quantity change alone may not correctly estimate the actual result without also taking into account the effect of the price change. This is the case for 2018 GOA Pacific cod fishery disaster. While the GOA Pacific cod TAC was cut substantially in 2018, the price of cod had been rising in the world market. Figure 2 shows the prices of GOA Pacific cod had been trending up since 2015. In particular, ex-vessel and first-wholesale prices of Pacific cod increased by 35% (from \$0.334 to \$0.452 per pound) and 32% (from \$1.97 to \$2.60 per pound), respectively, from 2017 to 2018 (Fissel et al. 2019). The price increase offsets to some degree the adverse economic impacts of lower production from the significantly reduced cod TAC. This study uses the 10MRSAM model to consider and isolate the effects of both the reduced TAC and the increase in price in calculating the “net” economic impacts of the 2018 GOA Pacific cod fishery disaster on regions dependent on the fishery.

This paper is organized as follows. The next section (Section 2) presents the methods used in this study. The section gives a brief account of the GOA Pacific cod stock assessment model, and provides descriptions of the structure of 10MRSAM and the adjustments made to the model for this study. Section 3 (i) discusses issues associated with economic impact analysis of Alaska fisheries, (ii) provides a brief summary of the methods and procedures followed to collect fisheries data via a survey, and (iii) enumerates the steps followed to construct the 10MRSAM. Section 4 describes the two shocks (reduced TAC and price increase) that were applied to the model and presents the results. Section 5 discusses the results from analysis of the two shocks. Final section concludes.

2. Methods

2.1 GOA Pacific cod biological model

GOA Pacific cod is classified in the North Pacific fisheries management system as a Tier 3 species meaning there are reliable estimates of population parameters such as biomass, spawning biomass at 40% unfished biomass ($B_{40\%}$), and fishing mortality rates which reduce the stock to 35% and 40% of the unfished biomass ($F_{35\%}$ and $F_{40\%}$), but no reliable estimate of the probability density function for F_{MSY} (the fishing mortality that produces the maximum sustainable yield). These reference points were estimated using an assessment model constructed in Stock Synthesis version 3.30.12 (SS; Methot and Wetzel 2013). Documentation and links to the archived stock synthesis executables are available at: https://vlab.ncep.noaa.gov/web/stock-synthesis/document-library.

Details on model parameterization for the GOA Pacific cod stock assessment model are described in Barbeaux et al. (2019). The GOA Pacific cod model is a single sex, age-based model with length-based selectivity. The model uses data from three fisheries (longline, pot, and combined trawl fisheries) with a single season and two survey indices: the post-1990 GOA bottom trawl survey (Raring et al. 2016) and the AFSC longline survey (Echave et al. 2013). Length composition data were available for all three fisheries and both indices. Age composition and conditional length at age were available for the three fisheries and AFSC bottom trawl survey (Roberson et al. 2005). Fishery length composition and total catch data were collected by at-sea observers (AFSC 2018) and catch estimates provided through the North Pacific groundfish fisheries catch accounting system (Cahalan et al. 2014). All data and model configurations are available upon request.

Projections derived from runs of the GOA Pacific cod stock assessment model led the Council to reduce the GOA Pacific cod TAC by 80% in 2018 compared to 2017, and to close the Pacific cod directed fishery in federally-administered GOA waters in 2020. The 80% reduction projected for 2018 formed the basis for the Pacific cod fishery disaster scenario developed and analyzed below.

2.2 Structure of 10MRSAM

The Leontief input-output (IO) model (Miller and Blair 1985) has been extensively used for economic impact analysis. The model is able to capture the inter-industry linkages through taking into account the transactions of intermediate inputs among the industries in calculating the economic impacts of a change in final demand, hence it is called a “demand-driven” model. However, one weakness of the IO model is that it cannot account for the effects of income flowing from industry sectors to value-added sectors (labor and capital), and then on to institutional sectors (households and various levels of governments).

A SAM model is an extension of the IO model, and overcomes the weakness of the IO model by capturing these flows in detail. Therefore, with the SAM model it is possible to investigate the distributional effects of a policy on non-industry sectors such as value-added sectors and institutions. More detailed descriptions of SAM models are found in King (1985) and Holland and Wyeth (1993), among others. Most SAM models are single region (a nation or a sub-national region) models. With a single-region model, it is difficult to examine effects transmitted across regions (spillover effects and feedback effects). The multiregional 10MRSAM model used for this study was developed to enable investigation of inter-regional effects with respect to Alaska fisheries.

Alaska fisheries are very complex in several respects. First, fish caught in a fishing area (e.g., BSAI or GOA) are landed at a number of different ports in Alaska which are located in different BCAs. In the case of the GOA Pacific cod fishery, data indicate that fish are landed in BCAs near the BSAI area as well as those within the GOA. Second, a large portion of the primary factors of production (labor and capital) is owned by non-Alaska residents. This means that a large proportion of value-added generated in Alaska seafood industries exits the state. Third, a significant portion of the intermediate inputs used in Alaska fisheries is imported from outside Alaska.

In modeling the regional economic impacts of Alaska fisheries, a single-region model is unable to capture interregional commodity and factor flows or to quantify the geographical distribution of economic impacts resulting from a fishery management action. Addressing the complexity of Alaska fisheries necessitates using a multi-regional model such as the one used in this study that identifies different fishing-dependent BCAs separately and includes their economic linkages to other regions.

The rest of this section describes the structure of the 10MRSAM model and borrows from Waters et al. (2014) and Seung (2017). Table 1 presents the basic structure of an MRSAM with three regions, while Table 2 exhibits the more detailed structure of the 10MRSAM used in this study. For simplicity this section illustrates a three-region SAM. However, the structure of the 10MRSAM used in this study is basically the same. More details on the individual sectors (accounts) in the 10MRSAM are presented in Section 3.2 below.

The MRSAM model can be represented as follows:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} Z_{11} & z_{12} & z_{13} \\ z_{21} & Z_{22} & z_{23} \\ z_{31} & z_{32} & Z_{33} \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} + \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad , \qquad (1)$$

where

$\boldsymbol{y_r}$: column vector of endogenous accounts for region *r*,

$\boldsymbol{x_r}$: column vector of exogenous accounts for region *r*,

$\boldsymbol{Z_{rr}}$: submatrix of coefficients showing intra-regional transactions, and

$\boldsymbol{z_{rs}}$: submatrix of coefficients showing inter-regional transactions.

The elements in $\boldsymbol{Z_{rr}}$ and $\boldsymbol{z_{rs}}$ are obtained by dividing the elements in the columns in the MRSAM by the column totals. Equation (1) can be expressed compactly as:

$$Y = (I - S)^{-1}X \quad , \qquad (2)$$

where $Y = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix}$, S= $\begin{bmatrix} Z_{11} & z_{12} & z_{13} \\ z_{21} & Z_{22} & z_{23} \\ z_{31} & z_{32} & Z_{33} \end{bmatrix}$, and $X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$. Here $\boldsymbol{S}$ is matrix of direct MRSAM coefficients and $(I - S)^{-1}$ is called the MRSAM multiplier matrix or matrix of MRSAM inverse coefficients.

$\boldsymbol{y_r}$ consists of the following endogenous sub-vectors:

$\boldsymbol{A_r}$ = vector of regional industry output

$\boldsymbol{Q_r}$ = vector of regional commodity output

$\boldsymbol{V_r}$ = vector of total primary factor payments

$\boldsymbol{IBT_r}$ = indirect business tax payments

$\boldsymbol{H_r}$ = vector of total household income

$\boldsymbol{SG_r}$ = total state and local government income or revenue

$\boldsymbol{Z_{rr}}$ for region *r* is:

$$Z_{rr} = \begin{bmatrix} 0 & M_r & 0 & 0 & 0 & 0 \\ U_r & 0 & 0 & 0 & C_r & GD_r \\ V_r & 0 & 0 & 0 & 0 & 0 \\ IBT_r & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & F_r & 0 & 0 & STR_r \\ 0 & 0 & SF_r & BTS_r & HTX_r & IGT_r \end{bmatrix},$$

where:

$\boldsymbol{U_r}$ = absorption matrix

$\boldsymbol{V_r}$ = matrix of primary factor payments coefficients

$\boldsymbol{IBT_r}$ = matrix of indirect business tax coefficients

$\boldsymbol{M_r}$ = market share matrix

$\boldsymbol{F_r}$ = matrix of factor payment to household coefficients

$\boldsymbol{SF_r}$ = matrix of state and local factor tax coefficients

$\boldsymbol{BTS_r}$ = matrix of state and local indirect business tax coefficients

$\boldsymbol{C_r}$ = matrix of household consumption coefficients

$\boldsymbol{HTX_r}$ = matrix of state and local government direct household tax coefficients

$\boldsymbol{GD_r}$ = matrix of state and local government demand coefficients

$\boldsymbol{STR_r}$ = matrix of state and local government transfer coefficients

$\boldsymbol{IGT_r}$ = matrix of intergovernmental transfers

$\boldsymbol{z_{rs}}$ is:

$$z_{rs} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & IM_{rs} & 0 & 0 & 0 & 0 \\ 0 & 0 & LK_{rs} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

where $\boldsymbol{IM_{rs}}$ is matrix showing imports from region *r* to *s* and $\boldsymbol{LK_{rs}}$ is matrix of leakage of factor income from region *s* to region *r*.

$\boldsymbol{x_r}$ is a column vector comprising the following exogenous sub-vectors:

$\boldsymbol{ea_r}$ = vector of exogenous demand for regional industry output

$\boldsymbol{eq_r}$ = vector of exogenous demand for regional commodity output

$\boldsymbol{ev_r}$ = vector of exogenous factor payments

$\boldsymbol{et_r}$ = exogenous indirect business tax payments

$\boldsymbol{eh_r}$ = vector of exogenous federal transfers to households

$\boldsymbol{eg_r}$ = federal transfers to state and local government.

In this study, three exogenous demand vectors ($\boldsymbol{eq_r}$, $\boldsymbol{eh_r}$ and $\boldsymbol{eg_r}$) are non-zero vectors. The elements of $\boldsymbol{eq_r}$ are the components of final demand for commodities, including federal government demand, investment demand, and export demand. $\boldsymbol{eh_r}$ includes federal government transfers to households and remittances from rest of the world (ROW) to households. $\boldsymbol{eg_r}$ includes elements showing federal government transfers to state and local government. Final demand components in $\boldsymbol{eq_r}$ and extra-regional payment components in $\boldsymbol{eh_r}$ and $\boldsymbol{eg_r}$ constitute injections of exogenous income into a region. Leakages include taxes paid to the federal government, savings, and payments for commodities imported from ROW.

2.3 Adjustments to 10MRSAM model

Most existing IO and SAM models are demand-driven models whether they are single-region or multi-regional models. However, if applied without modification when computing economic impacts of an exogenous change in productive capacity or output (e.g., fish harvest levels in the present study), these models may yield inaccurate estimates of the impacts [e.g., Seung and Waters (2013) and Seung (2014, 2017)]. Because of this problem, some previous studies (e.g., Leung and Pooley 2002; Roberts 1994) used a mixed endogenous-exogenous model (MEE, Miller and Blair 1985) approach. These studies argue that the MEE model is more suitable than the demand-driven model when calculating the impacts of an exogenous change in the supply side (e.g., change in TAC for a fish species). However, the MEE approach has the weakness that making the originally endogenous variable (the output variable) exogenous forces final demand for the output (originally the exogenous variable) to become endogenous.

Demand-driven models are designed to compute backward linkage effects of a demand-side shock. Backward linkage effects are the effects occurring in industries that provide inputs to the industry whose products are purchased by the final consumers. Forward linkage effects occur in the industries that buy inputs from the industry that receives the final demand shock. One perceived problem with demand-driven models is that they ignore forward linkage effects. This led some studies to use the Ghosh approach (Ghosh 1958) to compute the forward-linkage effects.

But this approach is subject to a theoretical problem (See for example, Oosterhaven 1988, 1989), especially when used to calculate input and output quantities. The issue is that the Ghosh approach relies on the assumption that the level of output is determined by the supply of inputs, rather than by demand for the final product (i.e., the fixed output allocation coefficient assumption). In other words, the Ghosh model assumes that sales from industry *i* to the industries that buy from industry *i* are proportional to the industry *i*'s output. While this assumption seems neither intuitive nor economically valid, it has been shown to be less problematic when used in a "price model" to illustrate relationships between input and output price components (Dietzenbacher 1997). For details on the MEE models and Ghosh models, see Miller and Blair (1985).

In this study, we use an "adjusted demand-driven MRSAM model" approach to overcome the weaknesses discussed above and more accurately quantify economic impacts from an exogenous shock to productive capacity (fish harvest level). More specifically, when running the demand-driven model, the exogenous change in output capacity (i.e., reduced TAC) is treated as a final demand shock. To consolidate the direct effects, regional purchase coefficients (RPCs, the proportion of local demand that is met by local production) for commodities produced in *all* directly impacted industries and forward-linked industries are set equal to zero.

Setting RPCs for the seafood industries to zero is equivalent to setting the row elements for those industries to zero in the matrix of direct MRSAM coefficients, $\boldsymbol{S}$. This fixes the amounts the seafood processing industry buys from fish harvesting industries to exactly the amounts required to attain the pre-determined levels of industry output. RPCs can be applied to either commodities or industries. In this case we set the RPCs to zero for all commodities produced by all seafood industries.

Making these adjustments avoids the issues of the two approaches mentioned above by determining input purchases as a function of output levels rather than vice versa and assuring that total output of Pacific cod is equal to total exogenous demand. For more discussion on this issue, see, for example, Seung and Waters (2013) and Seung (2014, 2017).

This study also calculates the impact of the increase in cod prices separately from the impact of the reduction in cod TAC, to obtain an estimate of the “net” regional economic impact. It is unlikely that the increase in ex-vessel price by itself will affect the use of intermediate inputs, rather, for a given level of output, any increase in revenue will instead be passed on to value-added components (labor and capital) in the harvesting sector. This is because assuming fixed-proportion input coefficients, the quantity of inputs used to produce a given quantity of output is fixed. The prices of the (reduced) quantities of intermediate inputs (goods and services) required to harvest the reduced TAC would not be expected to change in proportion to the increase in ex-vessel prices. Rather the increase in ex-vessel revenue would likely be distributed as increased payments to skippers, crew and/or vessel owners.

Therefore in order to compute the effects of an increase in cod price, we make adjustments to the MRSAM coefficients for the fish harvesting sectors that harvest Pacific cod. First we set the coefficients representing the industry’s use of intermediate inputs to zero, and then normalize the remaining coefficients (i.e., coefficients representing the industry’s use of primary inputs such as labor and capital) so that these sum to one. With these adjustments, applying a shock to the Pacific cod harvesting sector that is equivalent to the increase in ex-vessel revenue arising from the increased price will yield a consistent estimate of the impact of the increased ex-vessel price.

3. Data Methods

This section relies on Seung et al. (2020) which provides a more detailed discussion of the data and methods used to create the 10MRSAM.

3.1 Issues with regional economic data on Alaska fisheries

Economists conducting economic impact analyses often use IMPLAN data sets to develop models such as IO, SAM, or computable general equilibrium (CGE) models. However, the seafood industry data in IMPLAN suffers from several important weaknesses, some of which concerning the Alaska seafood industry are described below. More detailed discussion of this topic is found in Seung et al. (2020).

First, in the IMPLAN data, it is assumed that the production technology for a regional industry is the same as the national average production technology for that industry. This assumption is problematic because the seafood industries in individual U.S. regions harvest different species using different technologies and so may be different from the national average. This is especially true for fish harvesting and processing industries operating in remote regions in Alaska. For this reason, gathering cost and earnings data for regional seafood industries via primary data collection such as surveys is often required.

Second, many crew members on fish harvesting vessels are self-employed, seasonal or part-time workers. But because IMPLAN uses data from state unemployment insurance programs which omit these "uncovered" employees, IMPLAN tends to underestimate seafood industry employment, especially in the harvesting sector.

Third, IMPLAN has only a single fish harvesting sector that combines all commercial fishing activities, regardless of the vessel type, gear used or species caught. Using models that include only a single, aggregate fish harvesting sector it is difficult to assess the economic impacts of fishery management actions affecting different species or harvesting and processing sectors. In order to address the economic impacts from a change in the harvest of a particular species or in the activity of a particular vessel type, it is necessary to disaggregate the harvesting sector into several different subsectors by vessel type and/or species, and to collect data for the disaggregated sectors via a survey.

Fourth, a unique feature of Alaska fisheries is that a large portion of capital (harvesting vessels and processing facilities) is owned by non-Alaskan residents, and many of the crew members and processing workers in Alaska fisheries are non-Alaskan residents. Therefore, a large share of the capital income and labor income generated in Alaska fisheries leaks out of the local region and the state. IMPLAN data does not capture this type of information for the different sectors of the seafood industry but rather uses the average leakage rate across all Alaska industry sectors.

Fifth, industries in Alaska, including seafood industries, rely heavily on imports of goods and services from outside of the state, especially shipments from Washington State. A correct assessment of the regional impacts of fishery management actions, therefore, requires correctly identifying the source, and estimating the magnitude, of goods and services imports used as intermediate inputs by Alaska industries.

3.2 Sectors in 10MRSAM

To overcome these weaknesses in the IMPLAN fishery sector data, a data collection project was implemented to obtain the necessary economic data to develop a model for analyzing SWAK fisheries (Cascade Economics 2016), and the 10MRSAM model was constructed (Seung et al. 2020). The data collection project and procedures used to construct the 10MRSAM is summarized in an Appendix to this paper. The following section provides descriptions of the data elements in the final 10MRSAM. Information presented in the remainder of this subsection is summarized in Tables A.1 and A.2 in the Appendix.

We developed two different versions of the 10MRSAM – a gear-based fishery industries version (GB) and a species-based industries version (SB). The final 10MRSAM has a total of up to 466 endogenous accounts in the GB [34 in the At-sea region + 53 in each of 6 SWAK BCAs + 38 in each of 3 non-SWAK BCA regions]; and 574 endogenous accounts in the SB [52 in the At-sea region + 68 in each of 6 SWAK BCAs + 38 in each of 3 non-SWAK BCA regions]. Note that some of these accounts are zero in some regions. Both MRSAM versions include four overall exogenous accounts that represent final demand for goods and services and help balance financial flows in the MRSAM [savings-investment, federal government revenue and spending, foreign trade (imports and exports), and trade-balancing financial flows]. Below we explain the individual accounts or sectors specified in the MRSAM regions.

3.2.1 Sectors in the SWAK BCAs

There are six fish harvesting sectors in the GB identified depending on the type of fishing vessels and species delivered to SWAK shore-based processors. These sectors include Trawl, Hook and Line, Groundfish Pot, Salmon Gillnet, Crabbers, and Other Gear. We assigned fish harvesting vessels to a fish harvesting industry sector based on the gear type responsible for the largest share of each vessel's ex-vessel revenue. Each fish harvesting sector or industry produces (catches) up to eleven relevant aggregated species "commodities." The eleven species or commodities are: 1. Tanner Crab (tanner crab and snow crab), 2. King Crab (mostly Bristol Bay red king crab but also includes brown king crab and blue king crab), 3. Other Crab (mostly Dungeness crab), 4. Pacific cod, 5. Pollock, 6. Sablefish, 7. Rockfish, 8. Flatfish, 9. Salmon, 10. Halibut, and 11. All other species combined (in the base year of 2014 this was mostly herring).

The endogenous accounts in the GB include up to 19 industries, 24 commodities, six value-added accounts (fisheries labor income, non-fisheries labor income, fisheries proprietors' income, non-fisheries proprietors' income, other property income, and indirect business taxes), three household accounts (low-, medium-, and high-income households),[4] and a combined state and local government account in each of the six SWAK BCA regions. The industry accounts (Table 3) include up to seven seafood-related sectors (6 harvesting industries and 1 processing industry) and 12 other aggregated industries. Commodity accounts include up to 11 fish species, one processed seafood commodity, and 12 aggregated non-seafood commodities. In the GB MRSAM there are six fish harvesting industries (as defined above) and a single shoreside processing industry in each SWAK BCA. Each of these fish harvesting industries "produces" (catches) some or all of the 11 different fish species. These species are processed in the shoreside processing industry in each SWAK BCA.

In the GB, the expenditure functions are defined for fishing and seafood processing industries that produce (catch or process) multiple commodities (species). These functions are useful for estimating the impacts of a change in the activity of a given vessel sector designated by gear type. However, this structure makes it difficult to isolate the impacts of a change in harvest of individual fish species. Therefore, we constructed the SB version where species-specific expenditure (production) functions are defined for each particular species type, rather than by vessel or gear type. These functions show the value of intermediate inputs used in catching and processing each individual species. In order to derive species-specific expenditure functions we first calculated the revenue fraction of each species produced by each gear sector,

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[4] Low-, Medium-, and High-income households are aggregations of the nine household categories in IMPLAN. The Low-income category includes households with income up to $25,000; the Medium-income category includes households with income from $25,000 to $75,000; and the High-income category includes households with incomes in excess of $75,000. Note that the IMPLAN household income brackets have remained the same for some time.

and then applied those fractions to each gear-based fish harvesting sectors' expenditure functions. We used a similar procedure to derive species-specific processing expenditure functions.

Eleven fish harvesting industries are enumerated in the SB, each of which is dedicated to harvesting a single fish type. For example, the pollock harvesting industry catches only pollock. There is also a unique, shore-based processing sector dedicated to processing each of the 11 fish species, resulting in up to 11 total seafood processing sectors in each SWAK BCA.[5] Up to 34 industries and 24 commodities are included as endogenous accounts in each SWAK BCA region in the SB. Industries include up to 22 seafood industries (i.e., the 11 harvesting industries and 11 processing industries) and 12 aggregated non-seafood industries. Commodity accounts include up to 11 raw fish species, one processed seafood commodity, and 12 aggregated non-seafood commodities. The other endogenous accounts (six value-added accounts, three household accounts, and a combined state and local government account) are the same as in the GB.

3.2.2 Sectors in the Non-SWAK Regions

The 38 endogenous accounts comprising each of the three non-SWAK regions are the same in both the GB and the SB. Each non-SWAK region has 14 industries and 14 commodities. The 14 industries include two seafood industries (one harvesting industry and one processing industry) and 12 aggregated non-seafood industries. The 14 commodities include one raw fish commodity, one processed seafood, and 12 non-seafood commodities. The other endogenous

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[5] Since in most cases the collected data were insufficient to associate particular expenditures with the individual species harvested and processed, species-specific expenditure functions were imputed for each SWAK region. Species-specific harvesting expenditure functions were developed by prorating gear-based sectors' total expenditures by the ex-vessel values of species caught, and summing the imputed expenditures across all harvesting sectors that caught that species in the region. Similarly, species specific processing functions were developed by prorating each processors' total expenditures according to the first wholesale value of each species processed in the region.

accounts in non-SWAK regions are defined the same as those for each SWAK BCA region in the two MRSAM versions (i.e., six value-added accounts, three household accounts, and a combined state and local government account).

3.2.3 Sectors in the At-sea Region

The At-sea sector "region" consists only of activities associated with fishing and processing by catcher-processors (CP), mothership processors (MS), and catcher vessels delivering to motherships operating in Bering Sea, Aleutian Islands, and Western GOA. All industry inputs, including factors of production, are imported from other regions in the MRSAM. There are only four industry accounts in the GB At-sea sector (Catcher Processor harvesting, Catcher Processor processing[6], Mothership processing and catcher vessels delivering to Motherships). All seafood products produced by the CP processing and MS processing sectors are assumed exported to RUS and ROW regions. Other endogenous accounts in the At-sea sector region in the GB include 16 non-zero commodities (six non-zero fish species, one processed seafood commodity, and nine non-zero non-seafood commodities), and three non-zero value-added accounts (fisheries labor income, fisheries proprietors' income, and indirect business taxes).

In the SB, endogenous accounts comprising the At-sea sector region include six non-zero industries[7] (i.e., one for each fish species category caught), 14 non-zero commodities (six non-zero fish species, one processed seafood commodity, and seven non-zero non-seafood

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[6] Catcher-processing activity consists of both fish harvesting and fish processing activities occurring on the same vessel. Therefore to be consistent with other fisheries sectors for modeling purposes, the catcher-processing sector is divided into two sub-sectors: harvesting and processing.

[7] The six fish species categories caught and processed by the SWAK At-sea sector are Pacific cod, pollock, sablefish, rockfish, flatfish, and other species. The SWAK At-sea sector does not catch the other five MRSAM species categories.

commodities[8]), and three non-zero value-added accounts (fisheries labor income, fisheries proprietors' income, and indirect business taxes).

Since all value-added generated by the At-sea sector industries is transferred to other regions in the MRSAM, there are no endogenous household or state and local government institutional accounts in the At-sea region in either version of the MRSAM. Similarly, there are no non-fisheries-related value-added accounts such as other labor income, other proprietors' income or other property income.

4. Results

In 2017, the Pacific cod TAC in the GOA was 64.4 kt, however only 48.7 kt was harvested worth an estimated \$35.3 million. In 2017, AEB was the BCA where the largest percentage (43.0% or 20.7 kt with an ex-vessel value of \$15.3 million) of this catch was landed, followed by KIB (31.5% with an ex-vessel value of \$11.2 million) and RAK (5.6% with an ex-vessel value of \$2.0 million). The CP sector caught about 12.8% (6.2 kt) of the total GOA harvest (Lee 2019). Based on this information we estimated the distribution of changes in landings values and quantities and first wholesale revenues that constitute the initial shocks to the model (Table 4).

Direct revenue impacts (ex-vessel revenue or first wholesale revenue) are decomposed into two components – the revenue effect from the quantity change and the revenue effect from the price change. The revenue effect from the quantity change was applied to the model as a quantity shock whereas the revenue effect from the price change was applied as a value-added shock. Let P_0 and P_1 be ex-vessel prices before and after the policy change (i.e., the TAC

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[8] All non-seafood commodities used in the At-sea region are imported from other MRSAM regions.

reduction from GOA Pacific cod disaster), respectively. Similarly, let Q_0 and Q_1, be the quantities of fish harvested before and after the policy change, respectively. Then, $P_1Q_1 - P_0Q_0 = P_0(Q_1-Q_0) + (P_1-P_0)Q_1$, where $P_0(Q_1-Q_0)$ describes the quantity shock effect and $(P_1-P_0)Q_1$ the value-added shock.

In deriving the quantity shock (i.e., the change in quantity of the fish caught) for the Pacific cod harvesting sector, we first normalized the baseline (2017) ex-vessel price of Pacific cod to equal one so that the quantity of fish in the baseline is now defined at the normalized price. Next, the counterfactual (2018) price and quantity of fish were adjusted using the percentage change in price and quantity of raw fish from 2017 to 2018, estimated from data provided by Lee (2019). The quantity shock was estimated by subtracting the baseline quantity from the counterfactual quantity thus obtained. The price shock (to be more precise, a value-added shock or change in value-added derived from the price change) was calculated as the counterfactual (2018) quantity of raw fish harvest multiplied by the change in fish price. The quantity changes were distributed to the five directly-affected regions[9] as initial shocks to the model. For example, the initial direct impact to the AEB Pacific cod harvesting industry is a reduction of $11.7 million at 2017 prices (Table 4). These values represent the change in quantity of fish caught assuming the price of the GOA Pacific cod is fixed at its baseline level.

It was assumed that the entire increase in ex-vessel revenue from the price increase was transferred to suppliers of factors of production (labor and capital) on vessels in the Pacific cod fishery in the regions where the fish is taken and did not change the quantity of intermediate inputs used by the harvesting industry. The largest increase in direct value-added payments

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[9] The five directly impacted regions are AWCA, AEB, KIB, At-sea, and RAK. Although KIB is not generally included in the SWAK, it was included in the model due to its critical importance in GOA Pacific cod fishery. BCAs in the rest of Alaska were lumped into RAK. Fisheries data indicates that 5.6% of total Pacific cod catch from GOA in 2017 was landed in RAK.

arising from the price increase occurs in AEB ($1.3 million, third column in Table 4), followed by KIB ($1.2 million), and the At-sea region ($0.8 million). The quantity and price shocks for processing sectors are similarly derived for each of the five affected regions (three SWAK BCAs, RAK, and At-sea).

Table 5 presents the (negative) impacts of the 80% reduction in GOA Pacific cod TAC without taking into account the effect of the increase in ex-vessel price. The largest total impacts on the seafood harvesting industry occur in AEB where total Pacific cod harvesting output declines by $11.7 million, followed by KIB ($7.7 million) and At-sea ($4.0 million). The largest impacts for the seafood processing industry also occur in AEB where total Pacific cod processing output declines by $23.0 million, followed by KIB ($15.6 million) and At-sea ($9.8 million).

The largest impacts on non-seafood industry sectors occur in the RUS, totaling $51.4 million. The next largest impacts on total non-seafood industry output fall on WOC ($42.7 million) followed by RAK ($10.7 million) and KIB ($4.6 million). The impacts on all industries in SWAK BCAs ($67.1 million, last row in the top panel of Table 5) accounts for 35.3% of the total impacts across all 10 regions ($189.9 million). The geographic distribution of impacts on total seafood industry employment and total regional employment is similar to that for the corresponding output measures. An interesting result is that the impacts on the total RUS output ($51.4 million) and employment (263 jobs) are larger than those for WOC ($42.7 million, 229 jobs) while the impacts on total value-added and total household income are larger for WOC than for RUS.

Impacts on labor income paid by seafood industries are also largest in AEB ($7.0 million), which is the region that suffered the largest loss in total seafood industry output and employment due to the Pacific cod TAC decrease.[10] WOC showed the next largest impacts on seafood labor income ($6.8 million). In contrast, the largest impacts on labor income from non-seafood industries fall on RUS, which also suffers the largest decrease in total regional output as reported above. RUS suffers a loss of $13.8 million in non-seafood labor income. Total value-added and total household income decrease the most in WOC ($38.4 million and $26.0 million, respectively). As expected, the impacts on non-seafood industries in SWAK BCAs where no initial impacts were given (LPB, BBB, and DCA) were extremely small due to very weak economic linkages, in terms of both inter-BCA factor supply and commodity trade, between these and the other BCAs that depend heavily on GOA cod fisheries.

Table 6 presents the "net" impacts resulting from the combination of the reduced cod TAC and increase in cod ex-vessel price in 2018. Compared with Table 5, the negative impacts from the reduced TAC are offset to a large degree by the increase in the cod price. For instance, total non-seafood output in RAK decreases by $10.7 million due to the TAC reduction (Table 5), while the reduction is only $8.5 million (Table 6) after effects of the increased value-added are included. Total regional output in RUS decreases by $51.4 million ignoring the increased value-added income (Table 5), whereas the reduction is only $43.9 million with the increased value-added income (Table 6), or 14.6% less. Comparing Tables 5 and 6, it is seen that the "net" reduction in total US output ($165.4 million, Table 6) is 13% less than the impact that is calculated if the price effect is ignored (total US output, $190.0 million, Table 5).

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[10] This study examined impacts of the TAC reduction in 2018. The GOA Pacific cod fishery was closed for 2020 season due to low stock level. The type of economic impact analyzed in this study was experienced by an Alaska community due to the closure of the fishery. A major processing plant in Sand Point in AEB was closed because there were not enough Pacific cod to process. This closure will likely have lingering economic impacts on the community and the region. See https://kmxt.org/2019/12/tridents-sand-point-plant-closed-for-the-winter-due-to-low-cod-stocks/

5. Discussion

When considering the effects of the change in Pacific cod harvest, including change in the price, we assumed that the resulting increase in ex-vessel revenue and first wholesale revenues due to the price increase will be paid to labor and capital in the Pacific cod harvesting and processing industries without affecting the quantity of intermediate inputs used by either industry. This is a reasonable assumption given that in IO-type models intermediate inputs are used in proportion to the quantity of fish harvested (processed), not to the level of the revenue. Therefore, at least in the short term, the price increase should not cause any additional change in the use of intermediate inputs.

This study finds that RUS, WOC, and RAK are the regions that suffer the largest impacts on non-seafood industry sectors ($51.4 million, $42.7 million, and $10.7 million, respectively, Table 5) when the effects of increase in the price of Pacific cod are ignored. These impacts are due to spillover effects of the shock to the GOA Pacific cod industry. That is, the reduction in Pacific cod harvest causes a reduction in use of intermediate inputs and a drop in imports of commodities from these three regions (especially from RUS and WOC) due to SWAK industries' strong dependence on imported inputs.

In addition, decreased household expenditures arising from lower factor income payments in the SWAK and RAK regions further reduces consumption of non-seafood commodities, a large portion of which is imported from RUS and WOC. This explains why production of non-seafood commodities in the three regions shrinks significantly in response to the reduction in Alaska Pacific cod TAC (Table 5). The additional impacts triggered by the change in the household income in SWAK and RAK regions would not be apparent if we had used an IO model, where households are an exogenous sector, or a single-region SAM model.

The MRSAM model used for this study enables calculation of these additional impacts because the model treats these households as endogenous sectors.

The results highlight the strong dependence of GOA Pacific cod fishery on the economies of RAK and non-Alaska regions (WOC and RUS), and thus help illustrate the strength of those inter-regional linkages. Results also indicate that the region suffering the largest loss in total seafood industry output (AEB, $34.7 million) is not necessarily the region where the largest total regional impact occurs (RUS, $51.4 million) (Table 5).

Results show that WOC suffers the second largest impacts on labor income in the seafood industries ($6.8 million), next to AEB ($7.0 million). This is because a large portion of labor income from GOA Pacific cod fishery (or more generally, from seafood industries in Alaska's fishing-dependent BCAs, including labor in At-sea fisheries) flows to WOC (Table 5).

We found that the impacts on total regional output and employment in RUS are larger than those for WOC while those for total value-added and total household income are smaller for RUS than for WOC. This is so whether or not we include effects of the change in the Pacific cod price. These two US regions (RUS and WOC) have strong economic ties with GOA Pacific cod fisheries via supplying (exporting) both primary inputs (crew, skippers, and vessel owners) and intermediate inputs to the fisheries. Results indicate that the effects of exporting the primary inputs are stronger for WOC than for RUS, while the effects of exporting the intermediate inputs are stronger for RUS than for WOC.

Results therefore highlight the benefit of using the MRSAM model which is capable of evaluating impacts on smaller regions such as BCAs, in contrast to state-level modeling (e.g., Seung and Waters 2009) which is incapable of isolating impacts on smaller regions or communities. The MRSAM model used in this study provides information about how impacts are distributed across different regions. This is important to fishery managers who care about how the economic status of particular fishing-dependent communities will be affected by a given policy.

This study finds that the negative impacts of the reduced harvest are offset to a large extent by the increase in the cod price (Table 6). Since the quantity of fish harvested is assumed to be fixed for all the other Alaska fisheries, total output of other seafood species in Alaska is not affected by the cod price increase. This is a reasonable assumption since each fishery in Alaska is managed based on data and science unique to the species caught and fishing technology used in those fisheries. The additional value-added income from the cod price increase, however, partially offsets the adverse impacts of the lowered TAC. The additional value-added income flows to households in the regions where the factors of production originate. The additional household income is spent on goods and services produced in those regions or imported from elsewhere, thereby helping offset the adverse impacts of the TAC reduction on all regions.

In the world seafood market, the price of a fish species is affected by many factors. In some cases, the price change may be caused by a change in harvest policy, for example, if fish harvest in a region is substantial enough to exert market power in the world market for that species. Alaska pollock may be an example. A reduced supply of Alaska pollock in the world market, due to a lowered TAC, will likely raise its price in the market. In other cases, a price change may be unrelated to a policy change for a given region. The price change may instead be due to a shift in consumers' preferences (including boycotts), currency exchange rate fluctuations or change in supply of the fish or its substitutes elsewhere in the world. The price change may be already occurring in the world market independently of whether a policy change is implemented in a particular region.

Recently Pacific cod prices have been on an increasing trend (Figure 2). The GOA's Pacific cod production accounts for a very small share of total global harvest of cod, and should therefore not exert strong market power on global prices. A report by Alaska Fisheries Science Center indicates that in 2016, Pacific cod catch in the GOA was only about 3.5% of the global catch of the fish (Alaska Fisheries Science Center 2019). This means that change in the price of cod is driven more by global supply and demand factors rather than by any change in the GOA supply.

In some cases the price change may be large enough to offset (or exacerbate if prices and quantities move in the same direction) the economic impacts of a change in harvest quantity. While this study demonstrated the calculation of "net" economic impacts of the fishery disaster by taking into account the opposing effects of reduction in harvest quantities and increase in the Pacific cod price, there are also other factors that may need to be considered. For example, fishing fleets suffering from the drastic reduction in the Pacific cod TAC may increase harvest of other species, which may further offset negative impacts of the Pacific cod disaster. However since opportunities to increase catch of other species are likely to be limited, especially in the short term, under current fisheries regulations and management plans, this study ignored effects of possible increased catch of other species. In addition, as mentioned, Congress has allocated disaster relief funds to be distributed among the stakeholders who suffered due to the GOA Pacific cod fishery disaster. Those payments should further offset negative impacts experienced in communities affected by the Alaska Pacific cod fishery disaster.

6. Conclusion

Previous studies that assessed the economic impacts of a policy change or environmental shock affecting a fishery resource rarely considered effects of a change in the fish price. This study took into account the effect of changes in both the quantity of GOA Pacific cod harvested and its price, utilizing a 10 region MRSAM model that enables estimation of the economic impacts of the cod fishery disaster on individual BCAs in Southwest Alaska plus effects on other regions. This study showed that the economic impacts from the quantity change alone may not accurately capture the actual impacts. We found that the offsetting effects from the price increase are significant; for example, the reduction in total regional output in the RUS region is 15% less severe if effects of the price change are also taken into account. Since the frequency of climate-related environmental shocks, such as the effect of an ocean heatwave on commercial fisheries as addressed in this study, will likely increase in the future (Oliver et al. 2019), the methodology used in this study will be an invaluable tool in understanding the economic impacts of such events on fishing-dependent communities.

References

Alaska Fisheries Science Center, 2019. Wholesale market profiles for Alaska groundfish and crab fisheries. 170 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Barbeaux, S., Aydin, K., Fissel, B., Holsman, K., Laurel, B., Palsson, W., Rogers, L., Shotwell, K., Yang, Q., Zador, S., 2019. Assessment of the Pacific cod stock in the Gulf of Alaska. *In* Plan team for the groundfish fisheries of the Gulf of Alaska, Stock assessments and fishery evaluation report for the groundfish resources of the Gulf of Alaska. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501. Available: https://archive.afsc.noaa.gov/refm/docs/2019/GOApcod.pdf

Bond, N. A., Cronin, M. F., Freeland, H., Mantua, N., 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters, 42, 3414– 3420. https://doi.org/10.1002/2015GL063306

Cascade Economics, 2016. Collecting Borough and Census Area-Level Data for Regional Economic Modeling of Southwest Alaska Commercial Fisheries. Final Report to Pacific States Marine Fisheries Commission and Alaska Fisheries Science Center.

Dietzenbacher, E., 1997. In vindication of the Ghosh model: a reinterpretation as a price model. Journal of Regional Science 37, 629–651.

Echave, K., Rodgveller, C., Shotwell, S.K., 2013. Calculation of the geographic area sizes used to create population indices for the Alaska Fisheries Science Center longline survey. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-253, 93 p.

Fissel, B., Dalton, M, Garber-Yonts, B., Haynie, A., Kasperski, S., Lee, J., Lew, D., Lavoie, A., Seung, C., Sparks, K., Wise, S., 2017. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands area: Economic status of the groundfish fisheries off Alaska, 2016. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK.

Fissel, B., Dalton, M., Garber-Yonts, B., Haynie, A., Kasperski, S., Lee, J., Lew, D., Seung, C., Sparks, K., Szymkowiak, M., Wise, S, 2019. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands area: Economic status of the groundfish fisheries off Alaska, 2018. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK.

Ghosh, A. 1958. Input-Output Approach to an Allocative System. Economica 25 (1), 58–64.

Holland, D., Wyeth, P., 1993. SAM Multipliers: Their Decomposition, Interpretation, and Relationship to Input-Output Multipliers. Research Bulletin XB 1027, College of Agricultural and Home Economics Research Center, Washington State University.

King, B., 1985. What is a SAM?, Pyatt, G. and J. Round, ed., *Social Accounting Matrix*, World Bank.

Laufkötter, C., Zscheischler, J., Frölicher, T.L., 2020. High-impact marine heatwaves attributable to human-induced global warming. Science 369 (6511), 1621-1625. DOI: 10.1126/science.aba0690

Laurel, B.J., Hurst, T.P., Copeman, L.A., Davis, M.W., 2008. The role of temperature on the growth and survival of early and late hatching Pacific cod larvae (*Gadus macrocephalus*). Journal of Plankton Research, 30 (9), 1051-1060.

Laurel, B.J., Rogers, L.A., 2020. Loss of spawning habitat and pre-recruits of Pacific cod during a Gulf of Alaska heatwave. Canadian Journal of Fisheries and Aquatic Sciences 77, 644-650. https://doi.org/10.1139/cjfas-2019-0238

Lee, J., 2019. Personal communication. Pacific States Marine Fisheries Commission.

Leung, P., Pooley, S., 2002. Regional economic impacts of reductions in fisheries production: a Supply-driven approach. Marine Resource Economics 16, 251-262.

Litzow, M.A., Hunsicker, M.E., Ward, E.J., Anderson, S.C., Gao, J., Zador, S.G., Batten, S., Dressel, S.C., Duffy-Anderson, J., Fergusson, E., Hopcroft, R.R., 2020. Evaluating ecosystem change as Gulf of Alaska temperature exceeds the limits of preindustrial variability. Progress in Oceanography, 186, p.102393.

Methot Jr, R.D., Wetzel, C.R., 2013. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142, 86-99. https://doi.org/10.1016/j.fishres.2012.10.012

Miller, R.E., Blair, P.D., 1985. *Input-Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ: Prentice Hall Inc.

Minnesota IMPLAN Group, Inc., 2004. IMPLAN Pro User’s Guide.

Oliver, E.C., Burrows, M.T., Donat, M.G., Sen Gupta, A., Alexander, L.V., Perkins-Kirkpatrick, S.E., Benthuysen, J.A., Hobday, A.J., Holbrook, N.J., Moore, P.J., Thomsen, M.S., 2019. Projected marine heatwaves in the 21st century and the potential for ecological impact. Frontiers in Marine Science 6, p.734.

Oosterhaven, J. 1988. On the plausibility of the supply-driven input–output model. Journal of Regional Science 28 (2), 203–217.

Oosterhaven, J. 1989. The supply-driven input–output model: a new interpretation but still implausible. Journal of Regional Science 29 (3), 459–465.

Raring, N. W., Laman, E.A., von Szalay, P.G., Martin, M.H., 2016. Data report: 2011 Gulf of Alaska bottom trawl survey. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-330, 231 p. https://doi.org/10.7289/V5/TM-AFSC-330

Roberts, D., 1994. A Modified Leontief model for analysing the impact of milk quotas on the wider economy. Journal of Agricultural Economics 45(1), 90-101.

Seung, C., Waters, E., 2009. Measuring the Economic Linkage of Alaska Fisheries: A Supply-Driven Social Accounting Matrix (SDSAM) Approach. Fisheries Research 97, 17-23.

Seung, C., Waters, E., 2013. Calculating impacts of exogenous output changes: Application of a Social Accounting Matrix (SAM) model to Alaska fisheries. The Annals of Regional Science 51 (2), 553-573.

Seung, C., 2014. Estimating effects of exogenous output changes: An application of multi-regional social accounting matrix (MRSAM) method to natural resource management. Regional Science Policy and Practice 6(2), 177-193.

Seung, C., Muse, B., Waters, E., 2016. Net Economic Impacts of Recent Alaska Salmon Fishery Failures and Federal Relief. North American Journal of Fisheries Management 36, 351–362.

Seung, C., 2017. A Multi-regional economic impact analysis of Alaska salmon fishery failures. Ecological Economics 138, 22-30.

Seung, C., Waters, E., Taylor, M., 2020. Developing a Multi-Regional Social Accounting Matrix (MRSAM) for Southwest Alaska Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-399, 33 p.

Walsh, J.E., Thoman, R.L., Bhatt, U.S., Bieniek, P.A., Brettschneider, B., Brubaker, M., Danielson, S., Lader, R., Fetterer, F., Holderied, K., Iken, K., 2018. The high latitude marine heat wave of 2016 and its impacts on Alaska. Bull. Am. Meteorol. Soc, 99(1), S39-S43.

Waters, E., Seung, C., Hartley, M., Dalton, M., 2014. Measuring the multiregional economic contribution of an Alaska fishing fleet with linkages to international markets. Marine Policy 50, Part A, 238-248.

Whitney F.A., 2015. Anomalous winter winds decrease 2014 transition zone productivity in the NE Pacific. Geophysical Research Letters 42, 428–31.

Figure 1 Map of Alaska boroughs and census areas

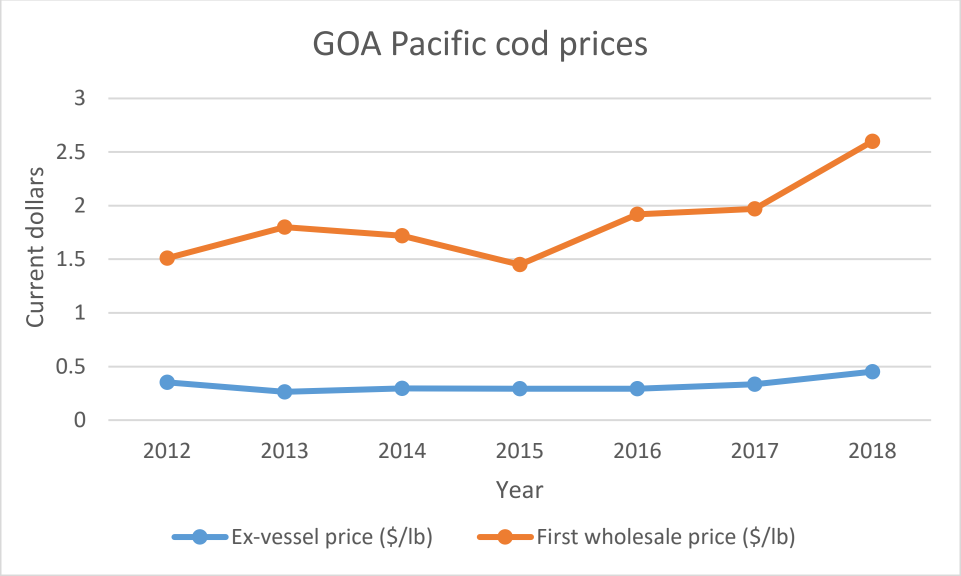

Figure 2 **Ex-vessel and first-wholesale prices of GOA Pacific cod (Fissel et al. 2017, 2019)**

Note: Prices are not adjusted for inflation.

Table 1 **Illustration of Basic MRSAM structure (Waters et al. 2014)**

	Alaska (AK)	West Coast (WC)	Rest of U.S. (RUS)	Rest of the World (ROW)
Alaska (AK)	Alaska Economy	WC purchases from AK	RUS purchases from AK	AK Exports
West Coast (WC)	AK purchases from WC	West Coast Economy	RUS purchases from WC	WC Exports
Rest of U.S. (RUS)	AK purchases from RUS	WC purchases from RUS	RUS Economy	RUS Exports
Rest of the World (ROW)	AK Imports	WC Imports	RUS Imports	

Table 2 Depiction of the 10-Region SWAK MRSAM structure

	At-Sea	**Aleutians West Census Area**	**Aleutians East Borough**	**Lake and Peninsula Borough**	**Bristol Bay Borough**	**Dillingham Census Area**	**Kodiak Island Borough**	**Rest of Alaska**	**Washington, Oregon and California**	**Rest of the U.S.**	***Exogenous Accounts / ROW***
At-Sea	**AS**	*Exports: AS to AWCA*	*Exports: AS to AEB*	*Exports: AS to LPB*	*Exports: AS to BBB*	*Exports: AS to DCA*	*Exports: AS to KIB*	*Exports: AS to RoA*	*Exports: AS to WOC*	*Exports: AS to RUS*	*Exports: AS to RoW*
Aleutians West Census Area	*Imports: AWCA to AS*	**AWCA**	*Exports: AWCA to AEB*	*Exports: AWCA to LPB*	*Exports: AWCA to BBB*	*Exports: AWCA to DCA*	*Exports: AWCA to KIB*	*Exports: AWCA to RoA*	*Exports: AWCA to WOC*	*Exports: AWCA to RUS*	*Exports: AWCA to RoW*
Aleutians East Borough	*Imports: AEB to AS*	*Imports: AEB to AWCA*	**AEB**	*Exports: AEB to LPB*	*Exports: AEB to BBB*	*Exports: AEB to DCA*	*Exports: AEB to KIB*	*Exports: AEB to RoA*	*Exports: AEB to WOC*	*Exports: AEB to RUS*	*Exports: AEB to RoW*
Lake and Peninsula Borough	*Imports: LPB to AS*	*Imports: LPB to AWCA*	*Imports: LPB to AEB*	**LPB**	*Exports: LPB to BBB*	*Exports: LPB to DCA*	*Exports: LPB to KIB*	*Exports: LPB to RoA*	*Exports: LPB to WOC*	*Exports: LPB to RUS*	*Exports: LPB to RoW*
Bristol Bay Borough	*Imports: BBB to AS*	*Imports: BBB to AWCA*	*Imports: BBB to AEB*	*Imports: BBB to LPB*	**BBB**	*Exports: BBB to DCA*	*Exports: BBB to KIB*	*Exports: BBB to RoA*	*Exports: BBB to WOC*	*Exports: BBB to RUS*	*Exports: BBB to RoW*
Dillingham Census Area	*Imports: DCA to AS*	*Imports: DCA to AWCA*	*Imports: DCA to AEB*	*Imports: DCA to LPB*	*Imports: DCA to BBB*	**DCA**	*Exports: DCA to KIB*	*Exports: DCA to RoA*	*Exports: DCA to WOC*	*Exports: DCA to RUS*	*Exports: DCA to RoW*
Kodiak Island Borough	*Imports: KIB to AS*	*Imports: KIB to AWCA*	*Imports: KIB to AEB*	*Imports: KIB to LPB*	*Imports: KIB to BBB*	*Imports: KIB to DCA*	**KIB**	*Exports: KIB to RoA*	*Exports: KIB to WOC*	*Exports: KIB to RUS*	*Exports: KIB to RoW*
Rest of Alaska	*Imports: RoA to AS*	*Imports: RoA to AWCA*	*Imports: RoA to AEB*	*Imports: RoA to LPB*	*Imports: RoA to BBB*	*Imports: RoA to DCA*	*Imports: RoA to KIB*	**RoA**	*Exports: RoA to WOC*	*Exports: RoA to RUS*	*Exports: RoA to RoW*
Washington, Oregon and California	*Imports: WOC to AS*	*Imports: WOC to AWCA*	*Imports: WOC to AEB*	*Imports: WOC to LPB*	*Imports: WOC to BBB*	*Imports: WOC to DCA*	*Imports: WOC to KIB*	*Imports: WOC to RoA*	**WOC**	*Exports: WOC to RUS*	*Exports: WOC to RoW*
Rest of the U.S.	*Imports: RUS to AS*	*Imports: RUS to AWCA*	*Imports: RUS to AEB*	*Imports: RUS to LPB*	*Imports: RUS to BBB*	*Imports: RUS to DCA*	*Imports: RUS to KIB*	*Imports: RUS to RoA*	*Imports: RUS to WOC*	**RUS**	*Exports: RUS to RoW*
Exogenous Accounts / ROW	*Imports: RoW to AS*	*Imports: RoW to AWCA*	*Imports: RoW to AEB*	*Imports: RoW to LPB*	*Imports: RoW to BBB*	*Imports: RoW to DCA*	*Imports: RoW to KIB*	*Imports: RoW to RoA*	*Imports: RoW to WOC*	*Imports: RoW to WOC*	

Table 3 IMPLAN Industries in the 2014 SWAK MRSAM

IMPLAN SECTORS (536 Industries)	INDUSTRIES in MRSAM
Sector 17 (Replaced with estimated data)	At-Sea Catcher-Processor (CPs, harvesting)
Sector 17 (Replaced with estimated data)	CVs delivering to At-Sea Mothership Processors
Sector 17 (Replaced with estimated data)	Trawlers delivering to Shore-based Processors
Sector 17 (Replaced with estimated data)	Longliners delivering to Shore-based Processors
Sector 17 (Replaced with estimated data)	Crabbers delivering to Shore-based Processors
Sector 17 (Replaced with estimated data)	Salmon Netters delivering to Shore-based Processors
Sector 17 (Replaced with estimated data)	Other Harvesters delivering to Shore-based Processors
Sector 93 (Replaced with estimated data)	At-Sea Catcher-Processors (CPs, processing)
Sector 93 (Replaced with estimated data)	At-Sea Mothership Processors (MS)
Sector 93 (Replaced with estimated data)	Shore-based Processors
Sectors 1-16, 18-40	Agriculture and Mining
Sectors 41-51, 519, 522 and 525	Utilities
Sectors 52-64	Construction
Sectors 65-92 and 94-105	Other Food Processing
Sectors 106-394	Other Manufacturing
Sector 395	Wholesale Trade
Sectors 396-407	Retail Trade
Sectors 408-416	Transportation
Sectors 417-440, and 442-517	All Other Services
Sectors 441, and 527-530	Miscellaneous
Sectors 521, 523-524, 526, and 531-534	State and Local Government Services
Sectors 518, 520, and 535-536	Federal Government Services

Table 4 Direct Shock Vectors ($million)

Regions	Harvesting sector		Processing sector	
	Quantity shock	Price (value-added) shock	Quantity shock	Price (value-added) shock
Aleutians East Borough	-11.7	+1.3	-23.0	+3.0
Aleutians West Census Area	-0.4	+0.1	-1.4	-0.1
Kodiak Island Borough	-7.7	+1.2	-15.6	+0.6
Rest of Alaska	-0.9	+0.5	-3.3	+1.2
All AT-SEA (CP + MS)	-4.0	+0.8	-9.8	+0.4

Table 5 Economic impacts from TAC reduction

	AT-SEA	AWCA	AEB	LPB	BBB	DCA	KIB	RAK	WOC	RUS
Industry output ($million)										
Total harvesting	-4.0	-0.4	-11.7	0.0	0.0	0.0	-7.7	-0.9	0.0	0.0
Total processing	-9.8	-1.4	-23.0	0.0	0.0	0.0	-15.6	-3.3	0.0	0.0
Seafood total	-13.8	-1.8	-34.7	0.0	0.0	0.0	-23.3	-4.2	0.0	0.0
Non-seafood total	0.0	-0.2	-2.4	0.0	0.0	-0.1	-4.6	-10.7	-42.7	-51.4
TOTAL ALL INDUSTRIES	-13.8	-2.0	-37.1	0.0	0.0	-0.1	-27.9	-14.9	-42.7	-51.4
Employment (# of workers / jobs)										
Total harvesting	-20	-5	-162	0	0	0	-117	-17	0	0
Total processing	-62	-10	-187	0	0	0	-146	-10	0	0
Seafood total	-82	-15	-349	0	0	0	-263	-27	0	0
Non-seafood total	0	-1	-14	0	0	-1	-31	-60	-229	-263
TOTAL ALL INDUSTRIES	-82	-16	-363	0	0	-1	-294	-87	-229	-263
Value-added ($million)										
Seafood labor income	-2.6	-0.3	-7.0	-0.2	0.0	0.0	-4.4	-1.6	-6.8	-2.0
Non-seafood labor income	0.0	-0.1	-0.6	0.0	0.0	0.0	-1.4	-3.1	-13.0	-13.8
Seafood proprietary income	-1.3	-0.2	-10.8	-0.2	0.0	0.0	-6.5	-3.3	-6.4	-5.2
Non-seafood proprietary income	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.5	-1.8	-2.1
Other property income	0.0	0.0	-0.5	0.0	0.0	0.0	-1.1	-2.3	-8.4	-8.8
Indirect business tax	-0.1	-0.1	-0.7	0.0	0.0	0.0	-0.5	-1.1	-1.9	-1.9
TOTAL VALUE-ADDED	-4.1	-0.6	-19.6	-0.4	0.0	-0.1	-14.1	-12.0	-38.4	-33.9
Household income ($million)										
Low income households	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.5	-0.6
Medium income households	0.0	0.0	-0.6	0.0	0.0	0.0	-1.0	-1.2	-4.8	-5.3
High income households	0.0	-0.2	-2.1	-0.1	0.0	0.0	-4.1	-6.7	-20.7	-17.2
TOTAL HOUSEHOLD INCOME	0.0	-0.2	-2.7	-0.2	0.0	0.0	-5.1	-8.0	-26.0	-23.0
State and local government revenue ($million)										
Total revenue	0.0	0.0	-0.5	0.0	0.0	0.0	-0.9	-1.5	-3.7	-3.4

Table 6 Combined ("net") economic impacts from TAC reduction and price increase

	AT-SEA	AWCA	AEB	LPB	BBB	DCA	KIB	RAK	WOC	RUS
Industry output ($million)										
Total harvesting	-3.2	-0.3	-10.4	0.0	0.0	0.0	-6.5	-0.4	0.0	0.0
Total processing	-9.4	-1.5	-20.0	0.0	0.0	0.0	-15.0	-2.1	0.0	0.0
Seafood total	-12.6	-1.8	-30.4	0.0	0.0	0.0	-21.5	-2.5	0.0	0.0
Non-seafood total	0.0	-0.2	-2.1	0.0	0.0	-0.1	-4.3	-8.5	-37.5	-43.9
TOTAL ALL INDUSTRIES	-12.6	-2.0	-32.5	0.0	0.0	-0.1	-25.8	-11.0	-37.5	-43.9
Employment (# of workers / jobs)										
Total harvesting	-16	-4	-144	0	0	0	-99	-7	0	0
Total processing	-59	-10	-163	0	0	0	-140	-6	0	0
Seafood total	-75	-14	-307	0	0	0	-240	-14	0	0
Non-seafood total	0	-1	-12	0	0	-1	-28	-46	-200	-221
TOTAL ALL INDUSTRIES	-75	-15	-319	0	0	-1	-268	-60	-200	-221
Value-added ($million)										
Seafood labor income	-1.9	-0.2	-5.3	-0.2	0.0	0.0	-3.7	-0.3	-5.2	-1.5
Non-seafood labor income	0.0	-0.1	-0.5	0.0	0.0	0.0	-1.3	-2.4	-11.4	-11.7
Seafood proprietary income	-0.9	-0.2	-8.3	-0.1	0.0	0.0	-5.3	-2.4	-5.0	-4.1
Non-seafood proprietary income	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.4	-1.6	-1.8
Other property income	0.0	0.0	-0.4	0.0	0.0	0.0	-1.0	-1.8	-7.3	-7.5
Indirect business tax	-0.1	0.0	-0.5	0.0	0.0	0.0	-0.5	-0.8	-1.7	-1.7
TOTAL VALUE-ADDED	-2.9	-0.5	-15.1	-0.3	0.0	-0.1	-11.9	-8.0	-32.1	-28.1
Household income ($million)										
Low income households	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.4	-0.5
Medium income households	0.0	0.0	-0.5	0.0	0.0	0.0	-0.8	-0.8	-4.0	-4.4
High income households	0.0	-0.1	-1.6	-0.1	0.0	0.0	-3.5	-4.4	-17.2	-14.2
TOTAL HOUSEHOLD INCOME	0.0	-0.2	-2.1	-0.1	0.0	0.0	-4.4	-5.2	-21.7	-19.0
State and local government revenue ($million)										
Total revenue	0.0	0.0	-0.4	0.0	0.0	0.0	-0.8	-1.0	-3.2	-2.9

APPENDIX

A.1 SWAK fisheries data

The SWAK fish harvesting sector was first disaggregated into six different categories (or industries), depending on the type of fishing vessels delivering to SWAK shore-based processors. These categories include Trawl, Hook and Line, Groundfish Pot, Salmon Gillnet, Crabbers, and Other Gear. Mail-out surveys were conducted in 2016 for five of the six categories of fishing vessels (Trawl, Hook and Line, Groundfish Pot, Salmon Gillnet, and Other Gear). We allocated a fish harvesting vessel to a fish harvesting industry if the vessel's majority of revenue comes from a gear type. For example, a vessel whose majority of revenue is generated by using trawl gear was allocated to Trawl category (industry). Survey was not carried out for SWAK crab fishery vessels because mandatory data is already being collected via the Crab Rationalization Economic Data collection program for the BSAI crab Economic Data Report (EDR)[11].

The survey participants (fishing vessels) were selected using an unequal probability sampling (UPS) procedure. The survey questionnaires were mailed out to a total of 1,590 vessel owners (or operators) determined based on the UPS procedure. The survey elicited information about employment (including its residency information) and expenditures (including geographical distributions) for SWAK fisheries. A total of 550 useable surveys were returned.

Key informant interviews were also conducted to garner economic information from shore-based seafood processors operating in the SWAK region. The economic information obtained include data on cost, types of products produced, employment (including residency information), and expenditures (including geographical distributions). In addition, additional economic data were collected through key informant interviews with suppliers of intermediate inputs used in fish harvesting and processing in SWAK fisheries. More details about the data collection methods and results can be found in Cascade Economics (2016).

Data on the total volume and ex-vessel revenues from landings of each species were summarized from CFEC and AKFIN data extracts. These data include information on the weight and ex-vessel value of fish landings by BCA, species, and gear type. Data on total net weight and first wholesale value of fisheries products processed in each BCA by SWAK shore-based processors were summarized from COAR data extracts.

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[11] While data collected under the crab rationalization EDR is different in scope and focus than the data collected under the voluntary survey, crab rationalization participants were unwilling to cooperate with another economic data collection program.

Table A.1 Endogenous sectors by region in the Gear Based version of 10MRSAM

Broad category	**Sector**	**AT-SEA**	**6 SWAK BCAs**	**3 Non-SWAK regions**
Fish harvesting industries	Harvesting all fish			X
	Catcher-processors - Harvesting	X		
	Catcher vessels delivering to Motherships	X		
	Trawl		X	
	Hook and Line		X	
	Groundfish Pot		X	
	Salmon Gillnet		X	
	Other Gear		X	
	Crabbers		X	
Seafood processing industries	Catcher-processors - processing	X		
	Motherships	X		
	Shore-based processing (all fish)		X	X
Non-seafood industries	Agriculture and natural resources		X	X
	Construction		X	X
	Utilities		X	X
	Other food manufacturing		X	X
	Other Manufacturing		X	X
	Transportation		X	X
	Wholesale		X	X
	Retail		X	X
	All Other Services		X	X
	Miscellaneous		X	X
	State and Local Government Services		X	X
	Federal Government Services		X	X
Raw fish commodities	All raw fish combined			X
	King crab	X	X	
	Tanner crab	X	X	
	Other crab	X	X	
	Pacific cod	X	X	
	Pollock	X	X	
	Sablefish	X	X	
	Rockfish	X	X	
	Flatfish	X	X	
	Salmon	X	X	
	Halibut	X	X	
	Other species	X	X	
Processed seafood commodity	all processed seafood combined	X	X	X
Non-seafood commodities	Agriculture and natural resources	X	X	X
	Construction	X	X	X
	Utilities	X	X	X
	Other food manufacturing	X	X	X
	Other Manufacturing	X	X	X
	Transportation	X	X	X
	Wholesale	X	X	X
	Retail	X	X	X
	All Other Services	X	X	X
	Miscellaneous	X	X	X
	State and Local Government Services	X	X	X
	Federal Government Services	X	X	X
Value-added	labor income from seafood production	X	X	X
	labor income from non-seafood production	X	X	X
	Proprietor income from seafood production	X	X	X
	Proprietor income from non-seafood production	X	X	X
	Other property income	X	X	X
	indirect business tax	X	X	X
Households	low income households		X	X
	medium income households		X	X
	high income households		X	X
State and local government	State and Local Gov. revenue		X	X
Total number of endogenous sectors	466 sectors	34	6 x 53	3 x 38

Note: “X” denotes the sector exists in a region.

Table A.2 Endogenous sectors by region in the Species Based version of 10MRSAM

Broad categories	Sector	AT-SEA	6 SWAK BCAs	3 Non-SWAK regions
Fish harvesting industries	Harvesting all fish			X
	King crab harvest	X	X	
	Tanner crab harvest	X	X	
	Other crab harvest	X	X	
	Pacific cod harvest	X	X	
	Pollock harvest	X	X	
	Sablefish harvest	X	X	
	Rockfish harvest	X	X	
	Flatfish harvest	X	X	
	Salmon harvest	X	X	
	Halibut harvest	X	X	
	Other species harvest	X	X	
Seafood processing industries	Shore-based processing (all fish)			X
	King crab processing	X	X	
	Tanner crab processing	X	X	
	Other crab processing	X	X	
	Pacific cod processing	X	X	
	Pollock processing	X	X	
	Sablefish processing	X	X	
	Rockfish processing	X	X	
	Flatfish processing	X	X	
	Salmon processing	X	X	
	Halibut processing	X	X	
	Other species processing	X	X	
Non-seafood industries	Agriculture and natural resources		X	X
	Construction		X	X
	Utilities		X	X
	Other food manufacturing		X	X
	Other Manufacturing		X	X
	Transportation		X	X
	Wholesale		X	X
	Retail		X	X
	All Other Services		X	X
	Miscellaneous		X	X
	State and Local Government Services		X	X
	Federal Government Services		X	X
Raw fish commodities	All raw fish combined			X
	King crab	X	X	
	Tanner crab	X	X	
	Other crab	X	X	
	Pacific cod	X	X	
	Pollock	X	X	
	Sablefish	X	X	
	Rockfish	X	X	
	Flatfish	X	X	
	Salmon	X	X	
	Halibut	X	X	
	Other species	X	X	
Processed seafood commodity	all processed seafood combined	X	X	X
Non-seafood commodities	Agriculture and natural resources	X	X	X
	Construction	X	X	X
	Utilities	X	X	X
	Other food manufacturing	X	X	X
	Other Manufacturing	X	X	X
	Transportation	X	X	X
	Wholesale	X	X	X
	Retail	X	X	X
	All Other Services	X	X	X
	Miscellaneous	X	X	X
	State and Local Government Services	X	X	X
	Federal Government Services	X	X	X

Broad categories	**Sector**	**AT-SEA**	**6 SWAK BCAs**	**3 Non-SWAK regions**
Value-added	labor income from seafood production	X	X	X
	labor income from non-seafood production	X	X	X
	Proprietor income from seafood production	X	X	X
	Proprietor income from non-seafood production	X	X	X
	Other property income	X	X	X
	indirect business tax	X	X	X
Households	low income households		X	X
	medium income households		X	X
	high income households		X	X
State and local government	State and Local Gov. revenue		X	X
Total number of endogenous sectors	574 sectors	52	6 x 68	3 x 38

Note: “X” denotes the sector exists in a region.

A.2 Constructing the 10-region MRSAM

A.2.1 Constructing vessel-sector level production functions

Step 1: Developing SWAK-level production functions

We started by developing the regional level (i.e., the whole SWAK region consisting of the six combined BCAs) expenditure function (production function) for each vessel type based on the response data from the vessel surveys, and estimating average SWAK-level production functions for each vessel type. To develop the production function for the BSAI crab sector, we used the average expenditure data from the Crab EDR supplemented with survey data collected for SWAK Groundfish Pot harvesting vessels. We also developed SWAK-level expenditure (production) functions for the shoreside processing industry using results from key informant interviews and representative expenditure share data derived from estimates provided by McDowell Group. Then, we mapped the expenditures in the production functions thus developed into corresponding IMPLAN commodity sectors for each vessel type and shoreside processors (based on updated FEAM expenditure category-commodity relationships).

Step 2: Developing SAMs for individual BCAs and non-SWAK regions.

We generated regional economic datasets using 2014 IMPLAN data for each of the six BCAs, RAK (remaining 23 BCAs in the State of Alaska), WOC, and the entire U.S. For each of these nine regions, we assembled IMPLAN GAMS 26-file format datasets to produce both “import-ridden” and “import-purged” SAM versions. Next, we subtracted corresponding elements of the six SWAK BCA SAMs, RAK SAM, and WOC SAM from the entire U.S. SAM to derive the RUS SAM. (Note that the seafood industry information in the SAMs for the SWAK BCAs thus generated have yet to be replaced by the results from the data collection as described in Step 3 below.)

Step 3: Developing SAMs Augmented with Information from Survey Data.

The SAMs in Step 2 above each have only two seafood industries in each region – fish harvesting and fish processing. Therefore, in Step 3, we replaced seafood industry data in the SAMs with data collected and compiled from the survey. More specifically, we scaled the vessel expenditure coefficients for the five fish harvesting sectors by applying total ex-vessel values for each relevant harvesting vessel sector in each BCA derived from AKFIN data. Then, we replaced the expenditure information for the single fish harvesting industry from the IMPLAN-based SAM with the scaled vessel expenditure data described above.

Next, we replaced the elements of the IMPLAN commercial fishing sector Make matrix for each BCA with total ex-vessel value for each of eleven relevant aggregated species "commodities." The eleven species or commodities are: 1. Tanner Crab (tanner crab and snow crab), 2. King Crab (mostly Bristol Bay red king crab but also includes brown king crab and blue king crab), 3. Other Crab (mostly Dungeness crab), 4. Pacific cod, 5. Pollock, 6. Sablefish, 7. Rockfish, 8. Flatfish, 9. Salmon, 10. Halibut, and 11. All other species combined (mostly herring in 2014)].

When deriving BCA-level production functions from regional level (i.e., SWAK) information, we made two implicit assumptions. First, when deriving the BCA-level cost information, it is assumed that for a given vessel sector costs do not vary with the fish species caught. Second, for a given sector, the expenditure function is the same regardless of where (which SWAK BCA) vessels land their fish, although the geographic distribution of expenditures varies based on results from the vessel expenditure survey. More details are found in Seung et al. (2020).

For seafood processing industry accounts, we applied the seafood processor expenditure coefficients derived above to the total processed seafood first wholesale value for each BCA from COAR data. Next, we replaced seafood processing industry purchases of raw fish inputs in each BCA with ex-vessel value totals for each relevant species "commodity" landed in the BCA. Finally, we replaced the element of the IMPLAN processed seafood Make matrix in each BCA with total processed seafood "commodity" first wholesale value data.

SAMs for the remaining regions (RAK, WOC and RUS) were constructed using a single commercial fishing sector account based on IMPLAN sector #17, and a single seafood processing sector account based on data from IMPLAN sector #93 for each region.

A.2.2 Developing species-specific industry production functions

The expenditure functions estimated for seafood industries described above are defined for fishing or seafood processing industries that produce (catch or process) multiple commodities (species). These functions, when incorporated in a model, are useful for estimating the impacts of a change in the activity of an industry (a vessel sector) designated by gear type. However, with these expenditure functions it is difficult to investigate the impacts of a change in harvest of a certain fish species. Therefore, another MRSAM version was developed where the individual SAMs use species-specific expenditure functions defined for particular species group rather than by vessel or gear type. These functions show the value of intermediate inputs used in catching or processing a given species. In order to derive the species-specific expenditure functions for each BCA, we first calculated the fraction of a species produced by each gear sector. Then we applied those fractions to each gear-based fish harvesting sectors' expenditure functions. We used similar procedure to derive species-specific processing expenditure functions.

A.2.3 Commodity trade and factor flows

To estimate multi-regional commodity and factor flows for fishery sectors, we used the results from the surveys and mapped (i) SWAK harvesting vessel expenditures by BCA as explained in Sections A.1 and A.2 above to the nine non-at-sea MRSAM regions, (ii) SWAK vessel income payments to crew, skippers and owners by BCA to indicated residence regions, and (iii) processors' expenditures for intermediate inputs, labor and ownership income by BCA to the nine MRSAM regions. For non-seafood industries, we mapped total purchases of commodity inputs by the non-seafood industries, households and state and local governments in each BCA to the source region based on estimated commodity supplies and relative Gross Regional Product estimates (derived from IMPLAN) for each supplying region in the MRSAM.

A.2.4 Including At-Sea Catcher-Processor and Mothership sectors

We first constructed production expenditure totals for the at-sea Catcher-Processor (CP) and Mothership floating processor (MS) sectors operating in the Bering Sea, Aleutian Islands and western Gulf of Alaska region waters. We used catch and ex-vessel revenue data, and net product weight and first wholesale revenue data summarized from AKFIN and COAR data extracts, respectively.

Because of an absence of ex-vessel revenue data for CPs (since this is an internal transaction occurring on each vessel), a relative paucity of at-sea catch and production data for some species, and potential mismatch between whole weights and net weights reported in the data sets, we used average ex-vessel values, yields, first wholesale prices and procedures used by AFSC in their annual SAFE documents to estimate ex-vessel equivalent values for catch that is self-processed by CPs and delivered by catcher vessels to MS, and corresponding product net weights and first wholesale values.

Expenditure functions (sector and geographical distributions of input purchases) for the at-sea fishery sectors were adapted from prior empirical work on the Amendment 80 trawl head and gut fleet (Waters et al. 2014).

In the At-sea region, only seafood-related economic activities occur which generate fishery-related value-added income; neither non-seafood industries nor households exist in the At-sea region. Therefore, all the value-added income generated by the At-sea sector exits the region (mostly to WOC and RUS), while the intermediate inputs used in the At-sea region are all imported from other regions (nearly all from WOC and RUS).

A.2.5 Sectors in the final-10 region MRSAM

Once construction of all the SAM elements for the ten regions (nine regions plus the at-sea sector region) was completed, we assembled the individual SAM components into a 10 x10 array of intra- and inter-regional transactions matrices (Table 2). The 10 intra-regional transactions matrices comprise the principal diagonal of the 10x10 MRSAM array. The non-diagonal components of the array represent inter-regional transactions. Finally two MRSAM versions were constructed: a gear-based harvesting sector version (based on vessel sectors and processors defined by the survey results), and a species-specific fishery industries version where all harvesting and processing activities are focused on the individual species commodities harvested and processed in the SWAK region.