CURRENT PRACTICES, CHALLENGES, AND IMPROVEMENTS TO U.S. FEDERAL FISHERIES ASSESSMENT WORKFLOWS

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Current Practices, Challenges, and Improvements to U.S. Federal Fisheries Assessment Workflows

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[6] NMFS Northeast Fisheries Science Center
[7] NMFS Northwest Fisheries Science Center
[8] NMFS Pacific Islands Fisheries Science Center
[9] NMFS Alaska Fisheries Science Center

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and NOAA Administrator

National Marine Fisheries Service
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EXECUTIVE SUMMARY

Assessing the status of a U.S. federally managed fish population involves four general parts of a workflow: (1) collecting and analyzing the data; (2) developing a base model and running sensitivity analyses; (3) writing an assessment report to communicate the assessment results as determined by each Fishery Management Council's Terms of Reference; and (4) conducting a peer review and translating assessment results into management advice. The NOAA Fisheries Office of Science and Technology reviewed these components of fish stock assessment workflows across the agency to identify ways to semi-automate and streamline the process. Data preparation and report development were both identified as priority areas that might benefit from a semi-automated workflow. To guide these efforts, a steering committee was assembled composed of one to two stock assessment scientists from each NOAA Fisheries region. During initial discussions, the steering committee asked that the semi-automation of assessment report development be prioritized first over data preparation for stock assessment modeling since data preparation is a more involved process, with data streams and data caveats highly specific to each region and, sometimes, species.

This report contextualizes the work that is being done to improve stock assessment workflows. We provide a review of the different report generation processes and practices currently in place at the science centers in different fishery management regions across the United States. Many regions have semi-automated some aspects of their stock assessment workflows, which are described here. Existing tools that can be used to interface with existing stock assessment model platforms are then reviewed. These tools typically provide functionality to produce figures and tables and to organize and interpret model results. Many tools also make it easier for the user to work with the output by making it machine readable. Most tools are coded in the R language and are relatively easy to use. For each region, stock assessment reports follow a specific template.

In response, the stock assessment workflows team, consisting of members of the NOAA Fisheries National Stock Assessment Program and regional steering committee of NOAA stock assessment scientists, (hereafter "team") developed the Automated Stock Assessment Report {asar} package to semi-automate the generation of stock assessment reports. Although the format and content of stock assessment reports vary from one region to the next, the team identified common aspects from each region, which, after review by the steering committee, were used to develop the sectioning and content in the semi-automated stock assessment reporting tool. A standard collection of figures and tables were also identified for use in {asar} and reviewed by the steering committee.

The team is also planning to better understand potential challenges and bottlenecks in the portion of the stock assessment workflow that involves going from raw data to formatted

stock assessment input files. We are developing a questionnaire, which will solicit information from federal NOAA Fisheries stock assessment scientists and data providers on the challenges they experience when providing data for assessments and when formatting and analyzing that data to create stock assessment model input files. A longer term goal is to help develop semi-automated data workflows for each region that would enable data to be pulled from their respective databases, identify and remove outliers, and process or statistically analyze the data for input into stock assessment models. However, there are many differences in data type and format between regions, making standardizing this process at a national level intractable.

1. INTRODUCTION

A fish stock assessment evaluates the status of fish populations to generate harvest advice. Assessing the status of a fish population involves four general parts of a workflow: (1) collecting and analyzing the data, (2) developing a base model and running sensitivity analyses, (3) writing a document to communicate the assessment results as determined by each council's Terms of Reference, and (4) assessing peer reviews and translating assessment results into management advice (Figure 1). Regions involve stakeholder feedback at different points in the stock assessment process to varying degrees.

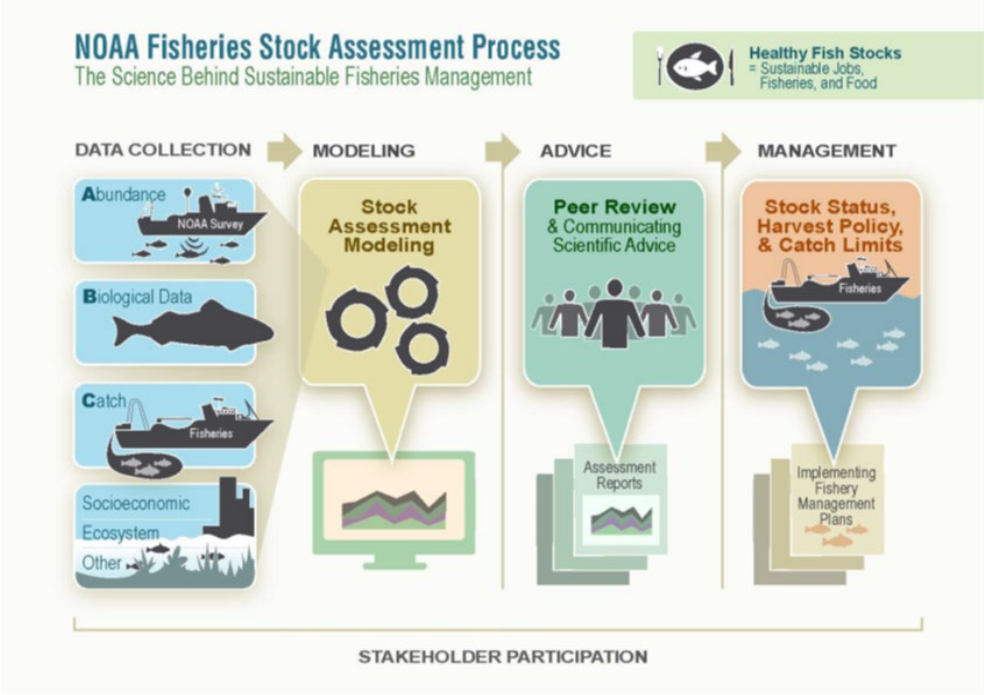

Figure 1: Schematic of the fisheries stock assessment workflow process.

Stock assessment workflows across the country vary widely from region to region and sometimes from one scientist to another. The NOAA Fisheries science centers are partitioned into five different regions to serve the needs of the councils and the Office of Sustainable Fisheries (OSF), with multiple scientific laboratories and one regional office in each region (Figure 2). NOAA stock assessment scientists are employed in each of the six NOAA Fisheries science centers and report their scientific findings to the councils and OSF to make management decisions.

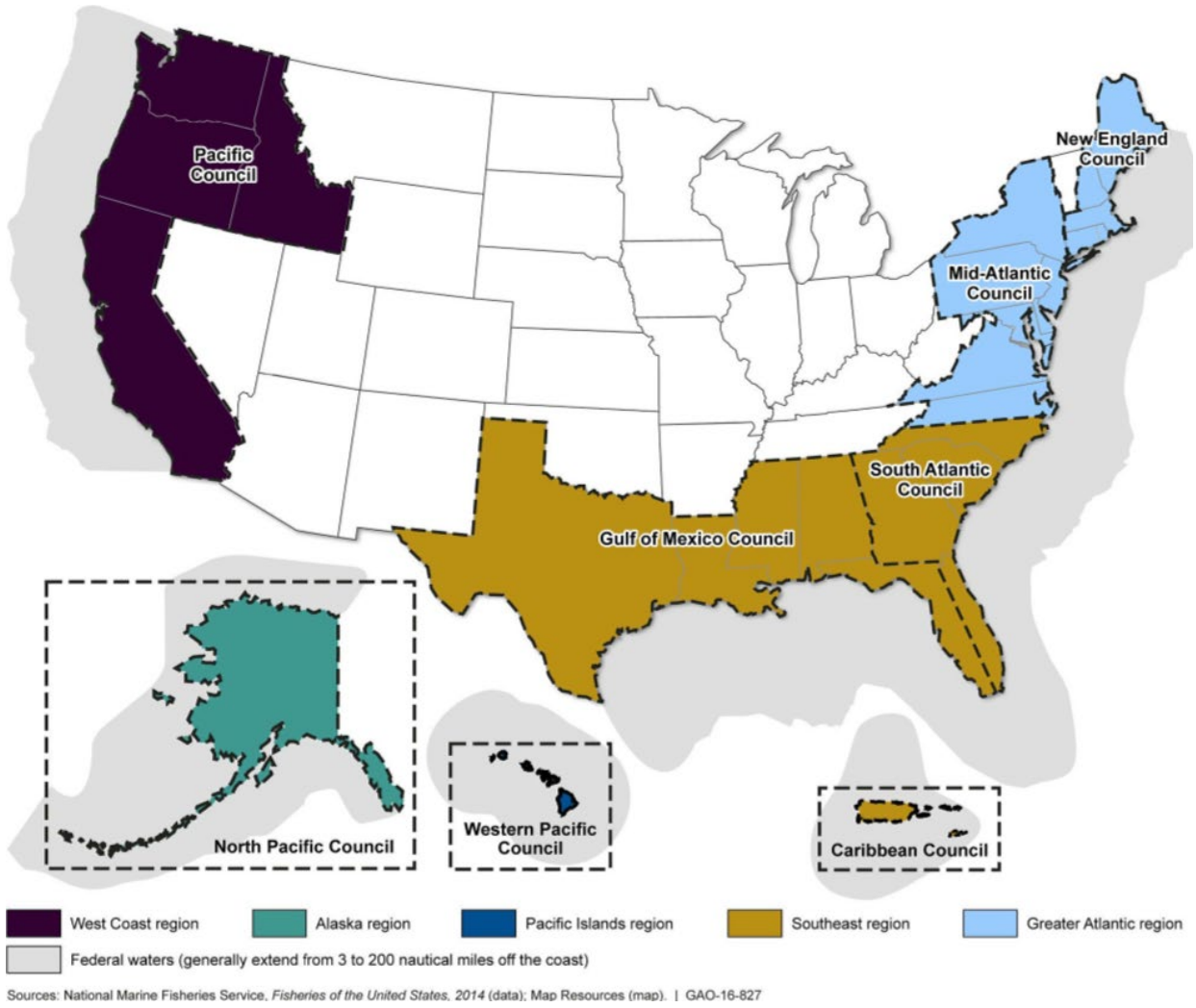

Figure 2: Map showing the Fisheries Management Council jurisdictions outlined by dashed lines and the five NOAA Fisheries science regions in different colors.

Terms of Reference are developed prior to a stock assessment to guide the analytical approaches and reporting format, and they are unique to each region, the species being assessed, and the available data. Data preparation for an assessment and the extent to which parts of this task are semi-automated vary widely. The selection of stock assessment modeling platforms also varies. Descriptions of the most commonly used assessment platforms and the regions that use them are provided in Section 4. National formatting guidelines or best practices for stock assessment report development do not exist and are largely based on advice from a regional science center, a formalized assessment process that a region may have in place, or on input from the regional Fishery Management Council. In some regions, report structure varies depending on who served as the lead analyst.

Thus, each region in the country uses its own workflow, and although there are some differences, they all follow similar steps, and the reports that are generated contain similar sections and material. A review of different stock assessment reports from all scientific and management regions was performed by the assessment workflows team and revealed that despite some differences, all reports tend to have the same general sections and material. This report discusses in greater detail how each regional fisheries science center approaches stock assessment reports and what guides their actions, and it shares any current tools and templates that are available to improve their process and increase throughput.

There have been efforts for improving the reproducibility of stock assessment workflows and reducing the time it takes to move through the assessment process from raw data analysis and formatting to modeling to stock assessment report completion. Improvements and efforts differ among regions of the United States with each of the NOAA regional fisheries science centers across the United States having their own workflows to assess a stock and produce a report. The reporting part of the stock assessment process takes considerable time due to the volume of tables and figures that need to be included. Report length varies widely by region and analyst, from 10 pages to well over 300. The goal of the report is to communicate the best scientific information available about the status of the fish stock for use by NOAA Fisheries and the regional Fisheries Management Councils to develop management advice, so it's critical that this advice is communicated in a clear, concise, and accessible way.

A small team evaluated the components of a stock assessment workflow (data preparation, model development, reporting, peer review, and policy recommendations) in the different regions across the United States. The steering committee advised the team on project direction and science center needs. The team conducted oral semi-structured interviews with stock assessment scientists from the six NOAA Fisheries science centers to obtain their feedback on what aspects of stock assessment workflows are working well and what aspects could be improved. We discussed with respondents the aspects of stock assessment workflows that might benefit from semi-automation. If semi-automated procedures were already in place in a region for some aspect of the stock assessment workflow, we also asked science center staff to share with us the specifics of these procedures and how helpful they are in increasing the timely completion of assessments and throughput. This led us to identify that the semi-automated development of stock assessment reports, as a component of the overall workflow, would most benefit throughput.

Findings from the interviews identified similarities and differences in the stock assessment workflow process from one region to another. This information, together with contributions from the steering committee, is included in this report. Basic descriptions of the different stock assessment models used in each region, with references to the technical

documentation, are also provided. Any already existing semi-automated processes to develop stock assessment reports and figures and tables from stock assessment model output or organize assessment model data inputs are also described in this report.

2. STOCK ASSESSMENT MODELS

Stock assessment models vary widely in their complexity and the types of data they can use. Traditional model types include data-limited, biomass dynamic models, virtual population analysis, and statistical catch-at-length or catch-at-age models (for review, see Cope, 2024; Schaub et al., 2024; Dichmont et al., 2016; Maunder and Punt, 2013). The model selected for a particular species and fishery is largely dictated by the data available for that stock and its ability to inform statistical model fit. Most stock assessment models are integrated mathematical and statistical models, which estimate parameters that maximize the likelihood and best fit to the data. More information on U.S. stock assessments can be found at **https://www.fisheries.noaa.gov/** or the NOAA Fisheries Stock Assessment Improvement plan by Lynch et al. (2018).

The four most commonly used age-structured stock assessment models in the United States are Stock Synthesis (SS3), Beaufort Assessment Model (BAM), Assessment Model for Alaska (AMAK), and Age-Structured Assessment Program (ASAP). The ASAP model is currently being phased out and has been replaced either by SS3 or by The Woods Hole Assessment Model (WHAM) in the U.S. Northeast. These models performed comparably when they were configured similarly (Li et al., 2021).

However, assessment modeling methods are not limited to those four. Additional models include data-limited models, harvest projection models, and assessment software written by individual authors. The material that follows contains a brief summary of the stock assessment modeling platforms most used by government scientists. The citations and references contained in the material below provide detailed and technical descriptions for each of these modeling platforms.

2.1 STOCK SYNTHESIS 3

SS3 is a statistical framework for modeling fisheries population dynamics, supporting the construction of age- and size-structured stock assessments (Methot and Wetzel, 2013). It has been applied to over 100 stocks in the United States and internationally. Several tools are available to assist with SS3 workflows. For example, the Stock Assessment Continuum Tool is a Shiny app that helps users create input files, run models, and generate visual outputs. {r4ss} is an R package that produces plots and tables from SS3 results, while {ss3diags} performs advanced diagnostics. {sa4ss} facilitates the creation of R Markdown-based stock assessment reports. Packages like {ss3sim} and {SSMSE} enable simulation

studies or the use of SS3 as an operating model in Management Strategy Evaluations. More information can be found on the SS3 website.

2.2 WOODS HOLE ASSESSMENT MODEL

WHAM is a flexible state-space, age-structured stock assessment framework designed to account for environmental effects on population processes (Stock and Miller, 2021). WHAM can be configured to estimate a variety of assessment models and uses an input data file structure similar to that of ASAP. The R package {WHAM} includes several plotting functions for visualizing input data, results, and diagnostics.

2.3 BEAUFORT ASSESSMENT MODEL

BAM is a statistical age-structured population model frequently used for stock assessments along the Southeast Coast (Williams and Shertzer, 2015). While some components of BAM's source code are generalized, others require customization for specific assessments. This often entails modifying source code and configuring input files. The R package {FishGraph} assists with generating diagnostics and visualizations from BAM outputs.

2.4 AGE-STRUCTURED ASSESSMENT PROGRAM (ASAP)

The ASAP model is an age-structured assessment framework that uses forward computations and assumes separation of fishing mortality by year and age to estimate population sizes (Legault and Restrepo, 1998). The R package {ASAPplots} generates standard plots from ASAP results and includes functions for compiling selected figures with captions into Microsoft Word documents.

2.5 ASSESSMENT MODEL FOR ALASKA (AMAK)

AMAK is a generalized tool for developing age-structured statistical models (AFSC, 2015). It has been applied to a number of stocks, including walleye pollock (*Gadus chalcogrammus*) in the Aleutian Islands Region (Barbeaux et al., 2019). Several tools have been developed to complement AMAK, such as the R package {jjmR}, which provides graphics and diagnostics libraries for the Joint Jack Mackerel model used by South Pacific Regional Fisheries Management Organization.

2.6 FISHERIES INTEGRATED MODELLING SYSTEM (FIMS)

The Fisheries Integrated Modeling System (FIMS) is a next-generation framework of stock assessment models to help streamline fisheries assessment tools into a single, flexible software platform that can accommodate a larger percentage of the assessments around the country. This system, currently under development, offers the NOAA Fisheries and the

global fisheries science communities an advanced set of generalized stock assessment models. These tools can be used separately or in combination to incorporate ecosystem and socioeconomic data and models, as well as climate effects and other drivers within the marine environment, into stock assessment models. For many years, NOAA Fisheries has relied on regionally developed stock assessment models to conduct stock assessments for fisheries management. This new effort represents a system of tools that capitalizes on the expertise of NOAA Fisheries scientists and software development best practices in consultation with the broader fisheries science community. The system is designed to be modular, maintainable, and extensive. FIMS also enables stock assessment tools to leverage technological developments, such as high performance computing, cloud resources, or parallel processing. It streamlines collaboration by using versioning protocols and open-source development practices.

2.7 OTHER MODELS

There are a variety of other fisheries assessment tools that are used in different contexts to understand the status of fish stocks. The modeling platforms discussed above are typically applied to assess "data-rich" stocks. They all share similar conceptual, mathematical, and statistical frameworks. Generally speaking, the stock assessment modeling tool used for a particular fish stock is typically selected as a function of the type of data available for that species in that region. If only fishery catch and effort (or catch per unit of effort) time series are available, then biomass dynamics models (Fox, Schaefer, Pella-Tomlinson) are often used (Quinn and Deriso, 1999). Platforms such as Just Another Bayesian Biomass Assessment (JABBA) provide flexible options to best fit biomass dynamics models (Winker et al., 2018). When fishing effort or catch per unit effort time series are not available but a time series of catch is available, then estimates of plausible biomass estimates with confidence intervals can be made using catch-maximum sustainable yield approaches (Martell and Froese, 2013; Froese et al., 2017). If length catch data are available, then a variety of approaches can be used to estimate fishing mortality and length-based spawning potential ratio (SPR; Pons et al., 2020; Hordyk et al., 2015; Rudd and Thorson, 2018; Ehrhardt and Ault, 1992; Quinn and Deriso, 1999).

2.8 HARVEST PROJECTION MODELS

Many integrated stock assessment models, such as SS3, contain their own harvest projection functions that allow the analyst to forecast trajectories of biomass, catch, spawning biomass, recruitment, and other metrics under different fishing mortality scenarios (Quinn and Deriso, 1999). Other models are not able to forecast these trajectories, either because they do not contain sufficient information (such as the data-limited length-based approaches described above) or because a forecasting component

was not written in the code (i.e., ASAP). For these models, standalone software, such as Pro2Box, exists to forecast trajectories from the assessment model's estimated trajectories. Many of these modeling tools are available in the Fisheries Integrated Toolbox (FIT).

3. TOOLS AND RESOURCES

There is no current standardized or accepted best practice for producing a stock assessment report. Some centers rely on the use of LaTeX, while others utilize more recently developed programs like R Markdown and Quarto, which both use LaTeX as a basis for their production. Others utilize the capacity of Microsoft Word. The use of text editing software, like Microsoft Word, could make the reproducibility of a report more time consuming, especially if manually developing figures and tables external to the text editing software.

There are a variety of existing software tools, resources, and templates that have been developed over the years to streamline and improve the stock assessment workflow. These tools can help expedite the stock assessment process by partially automating aspects such as report generation or data cleaning and preparation. Most of the existing tools were developed to address an immediate need in one of the regions. Tools like these help improve throughput and enable the assessment of more species in each region.

3.1 TOOLS

3.1.1 AFSCDATA

This tool is an R package and is available in GitHub, but the user must have access to the NOAA Fisheries Alaska Fisheries Science Center (AFSC) internal network and permissions to use the databases in order to execute this package as intended. The goal of this package was to extract AFSC fishery and survey data to use as input into stock assessment models and other general exploration.

3.1.2 AFSCASSESS

The {afscassess} tool was developed by scientists at the AFSC to streamline the workflow for specific assessment models. The package consists of assessment models and associated R functions that help the analyst better organize and interpret model results. It utilizes AD Model Builder (ADMB) to run the models and R to better organize the results and create plots. The development of this package created a structure for organizing basic parts of the stock assessment workflow such as creating connections between the model, interpretation, and reporting, as well as creating an organized folder/file structure for

pieces of the process such as storing model results. The tool can be found on GitHub at https://github.com/BenWilliams-NOAA/afscassess.

3.1.3 R4SS

The {r4ss} package is a collection of R functions that interact with the SS3 assessment model to help scientists work with the model and better interpret its results (Taylor et al., 2021). The package encompasses a wide variety of functions from reading or reformatting SS3 output files to creating a set of plots related to the SS3 output. A series of example plots produced from {r4ss} are available online. The tool can be downloaded from GitHub at https://github.com/r4ss/r4ss.

3.1.4 ASAPPLOTS

{ASAPplots} is an R package that contains functions that interact with output from ASAP. The functions within the package help an assessment scientist working with ASAP outputs to explore and develop visualizations used for the interpretation and presentation of model results. {ASAPplots} can be downloaded from GitHub at https://github.com/cmlegault/ASAPplots.

3.1.5 FISHGRAPH

{FishGraph} is an R package publicly available on GitHub. This package was developed to streamline the production of figures commonly reported in stock assessment reports from the U.S. South Atlantic division in the Southeast Fisheries Science Center. The package fluidly interacts with outputs from BAM and is maintained by scientists at the NOAA Southeast Fisheries Science Center (SEFSC). The set of functions in {FishGraph} can produce a variety of visualizations from diagnostics to visualizations from stock assessment model output. This package is an important tool in the stock assessment workflow for the Southeast (Prager et al., 2015).

3.1.6 ADMB2R

ADMB2R is a collection of routines in ADMB that allows the user to convert complex data structures into objects that are readable in an R environment (Martin et al., 2006). While many stock assessment models are built in ADMB, assessment scientists commonly use R to visualize model output and interpret its results. In its raw format, outputs from the model are not readable or easily interpreted by the assessment scientist. This tool transforms the output into an R object list containing model information and notes, vectors, matrices, data frames, or other lists for particular results that will be used in their analysis. The interface of ADMB2R is used in conjunction with FishGraph to produce typical graphs

found in fisheries stock assessment reports (SARs). Analogous functions are available for C2R and Fortran2R with more information found here.

3.1.7 SWFSCMISC

Scientists at the NOAA Fisheries Southwest Fisheries Science Center (SWFSC) have developed an R package to perform miscellaneous tasks from calculating latitude and longitude of the destination along a sphere to making consistent shape icons designating the stock's sex on a plot. This R package can help improve throughput for the scientist by reducing tedious tasks. The package can be downloaded through GitHub at https://github.com/EricArcher/swfscMisc; an older version can be found on CRAN.

3.1.8 SAFE REPORT TEMPLATE

Stock Assessment and Fishery Evaluation (SAFE) reports are prepared annually by assessment scientists at NOAA Alaska Fisheries Science Center to help the North Pacific Fisheries Management Council (NPFMC) create a fishery management plan for each species. A modularized template for SAFE reports was developed using R. This tool creates an R Markdown template for the user that includes the required sections, formatting, and functions ready for user entry. This template requires the user to have an understanding of Markdown notation and general Markdown work. The framework of the template incorporates space for the user to enter important parameters or reference points that can be used throughout the document. Directions within the document and in-text examples of content are provided in the template to guide the user through producing a new SAFE report. This tool can be found at https://github.com/BenWilliams-NOAA/safe. Once the tool is downloaded, the user can create an R markdown template on their machine by opening a new R Markdown document and selecting the template from the section "From Template."

3.1.9 SA4SS-SS3 REPORT TEMPLATE

{sa4ss} is an R package found publicly on GitHub that generates a stock assessment document from stock synthesis output. This package utilizes many of the functions from {r4ss} to ease the overhead that comes with producing status updates of marine species. This tool was specifically designed to outline a stock assessment report for the Pacific Fishery Management Council. It utilizes the rmarkdown:draft() function to create a folder of premade R Markdown files that the assessment author can use. This tool was initially developed for stock assessment scientists at the Northwest Fisheries Science Center (NWFSC) and SWFSC. The template can easily be adapted for other stock assessment reports but requires manipulation of the documents after the initial draft function is run.

The package can be found at https://github.com/pfmc-assessments/sa4ss. The package requires the user to download "tinytex" and "Pandoc;" however, these are dependencies that are required to render other R Markdown files.

3.1.10 SEDAR-ASSESSEMENT REPORT TEMPLATE

This tool is a structural organization of R Markdown documents within a GitHub repository that allows the user to create a stock assessment report from SS3 outputs specifically focusing on the requirements needed to report to the Southeast Data and Assessment Review (SEDAR). The tool is less formally adopted in the region than the others described here but still provides a structured workflow to clearly organize and present the results of a stock assessment model. Because of confidentiality restrictions, this tool is not publicly available; nonetheless, it is a great tool utilized in the stock assessment workflow of the Gulf of Mexico Branch and the Caribbean Branch in the Southeast.

3.1.11 NMFSREPORTS

NOAA Fisheries scientists have recently devoted time to improving workflows in many aspects including developing tools for automated reporting of other documents that are not stock assessments. NMFSReports is a tool that allows the user to build a report and include additional functions to help the user complete tedious but necessary tasks. The R package is built around the buildReport function, which creates a set of R Markdown documents with completed or semi-filled YAML and sectioning. The default template provides directions to the user to guide them through the document and other processes during writing. The entire system is set up using a guiding R script, which designates various inputs like authors, titles, and supporting scripts and renders the final report.

The R package can be found at NMFSReports GitHub Repository. The repository is currently archived, indicating that it is no longer maintained, but remains available to the assessment community.

3.1.12 NOAA TECHNICAL MEMORANDUM TEMPLATE

The NOAA-tech-memo-template is a template repository in GitHub that allows the user to create both a template for a new GitHub repository and a Quarto document styled with the elements for a NOAA Technical Memorandum. The tool was developed to help users take advantage of the features in a Quarto document and reduce the burden of formatting according to NOAA standards. The user base for this tool includes any NOAA employee who wants to draft a Technical. The tool can be found at **https://github.com/nmfs-opensci/NOAA-tech-memo-template**.

3.2 ARCHIVING RESOURCES

3.2.1 PFMC-ASSESSMENTS

PFMC-Assessments is a GitHub organization that contains repositories related to stock assessments for the Pacific Fisheries Management Council (PFMC). The organization provides a convenient place for scientists, managers, and other related individuals to access materials without the restrictions of Google Drive or other storage locations that have a barrier to entry. The *PFMC Groundfish Assessment Best Practices Handbook* is maintained in this organization, providing guidance to assessment scientists at NOAA who work on stocks falling under PFMC management. Other repositories such as sa4ss and r4ss are housed in a GitHub repository which can be accessed publicly at **https://github.com/orgs/pfmc-assessments/repositories**.

3.2.2 NEFSC STOCK ASSESSMENT SUPPORT INFORMATION (SASINF)

The Stock Assessment Support Information (SASINF) is an archive and living site that holds SARs and associated documents produced from the Northeast Fisheries Science Center (NEFSC). This site is used to communicate easily with management, scientists, and other parties involved with discussing the stock and providing management advice. It allows users to search for current and historical records of species managed by the NEFSC. SASINF can be found at https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php.

3.2.3 SPECIES INFORMATION SYSTEM (SIS) AND STOCK SMART PORTAL

The Species Information System (SIS) is a national database that stores the results from stock assessments including stock status determination and annual catch limit information across NOAA Fisheries program offices. It provides scientists, resource managers, and policy coordinators with applications for data entry, retrieval, and report generation. A detailed version of the program and entry of information into the database are only accessible internally to NOAA Fisheries staff. However, members of the public can access the data stored in SIS through the public-facing user interface, the Stock Status, Management, Assessments, and Resource Trends portal (Stock SMART).

4. REGIONAL WORKFLOWS

The stock assessment workflow processes in the different regions across the country follow the same basic steps: data assimilation, analysis and formatting for model input, stock assessment model development, report writing, peer review, and the presentation of report results to management bodies. However, there are some specific differences in how each of these steps is executed from one region to another and sometimes among analysts

in the same region. This section of the report highlights some of these similarities and differences. Information about the workflows used in each region was obtained by interviewing several assessment scientists in each region. We also asked the steering committee, which is composed of one member from each region, to review the material we obtained and provide edits and additions. Assessments are conducted regularly, either following a set schedule or as needed (Table 1), depending on the species and the way each region prioritizes species for assessment. The Stock Assessment Prioritization Plan (Lynch et al., 2018) includes a general rubric to guide regions in determining the frequency and order of species assessed.

Table 1: Regional assessment cycles or lack thereof across NOAA Fisheries

	Assessment Type		
Region	*Management Track/Operational (Full)*	*Management Track/Operational (Update)*	*Research Track*
AFSC	Based on tier level	Based on tier level	-
NEFSC	Annual to up to every 6 years	Annual to up to every 6 years	5+ years
NWFSC	Biennial (groundfish and HMS[1]) Annual (salmon)	Biennial (groundfish and HMS) Annual (salmon)	-
PIFSC[2]	3–5 years	3–5 years	As needed
SEFSC	As needed/added into schedule	As needed/added into schedule	No cycle
SWFSC	Biennial (groundfish and HMS) Annual (salmon) Coastal Pelagic species (3/4/8 years)	Biennial (groundfish and HMS) Annual (salmon) Coastal Pelagic species (3/4/8 years)	-

4.1 AFSC

The AFSC operates and develops stock assessments in coordination with the NPFMC and SAFE reporting guidelines. There are multiple reports that are produced:

- Operational Full provides a complete documentation of the assessment; evaluates model structure, model inputs, and new data streams; and provides diagnostics.

[1] Highly migratory species

[2] Pacific Islands fisheries science center

- Operational Update references the last assessment but includes updates to time series data and diagnostics.
- Harvest Projection Report exclusively contains forecasts and harvest projections.
- Catch Report provides updated catch information.

These assessments are conducted in one-, two-, or four-year increments based on stock prioritization and the tier level (Table 2). Stocks are prioritized using a tier-based system, which are distinguished by the quality of the model's estimates. For example, tiers 1–3 have estimates provided by an age-structured assessment model, while tiers 4–5 have estimates provided by fishery-independent surveys and tier 6 from catch (Hulson et al., 2021). After generating a report that is similar to that in other regions, assessments are reviewed by the species-associated plan team, the Science and Statistical Committee (SSC) and Advisory Panel, then finally the council (NPFMC, 2020).

The AFSC has committed significant resources to improve their workflows, tackling one step of the process at a time. They do not have a generalized workflow that can be used for every assessment, but they do utilize some processes that are slightly adjusted to apply from one species to another. In regard to extracting inputs, the AFSC has one of the most progressive approaches in the form of the afscdata R package and other SQL scripts for data query. The afscassess R package could then be used to clean up some of the data and generate figures and other associated processes. While these resources are useful, only some assessment scientists implement them into their workflows due to either the variety of other approaches or incompatibility with the need for their assessment target stock or workflow. However, whenever these pieces of the workflow are applied, the functions are tailored to pull data or perform functions for each species on which an assessment scientist works.

Some of the reports produced by AFSC follow the SAFE guidelines, which focus on the condition of the stock, essential fish habitat, and socioeconomic conditions of recreational and commercial fisheries. The AFSC is not the only region that produces these type of reports, but it is the one to develop the SAFE report template based on R Markdown. This tool has improved some workflows by partially automating them and making them reproducible. It is noteworthy that a substantial effort has been put into both creating and maintaining this tool.

4.1.1 CHALLENGES

Without a standardized workflow to follow and regardless of the advancements made in workflows at the AFSC, issues remain. Some of these issues could be solved by increased adoption of these valuable resources, but the initial time commitment to learn a new

workflow is a barrier for adoption. Differences in workflows from scientist to scientist can create challenges for new employees joining the agency or staff who are new to stock assessments. It can be confusing and hard to follow the process of another scientist, especially if they are not available (e.g., because they have been moved to another position) to explain their process. In addition, there are differences in the data structures between the Gulf of Alaska, Bering Sea, and Aleutian Islands. Reconciling these differences requires more time, which can be challenging during an assessment when deadlines and deliverables must be met. When writing reports, a large amount of tables and figures can slow the process and may not be necessary.

Table 2: Assessment cycles following the tier list described in the NPFMC stock assessment guidelines followed by NOAA Fisheries AFSC

	1-year cycle		2-year cycle			4-year cycle		
Year	**Tiers 1–3**	**Tiers 4–6**	**Tiers 1–3**	**Tiers 4–5**	**Tier 6**	**Tiers 1–3**	**Tiers 4–5**	**Tier 6**
1	full/ update	full/ update	full/ update	full/ update	full/ update	full/ update	full	full/ update
2	full/ update	full/ update	harv proj[3]	catch rep[4]	catch rep	harv proj	catch rep	catch rep
3	full/ update	full/ update	full/ update	full/ update	full/ update	harv proj	catch rep	catch rep
4	full/ update	full/ update	harv proj	catch rep	catch rep	harv proj	catch rep	catch rep

4.2 NEFSC

The NEFSC stock assessment workflow has some distinct differences from those in other regions, primarily due to their use of either a management track or research track. While their research track is fairly similar to that of other regions, the management track is where the NEFSC has diverged in their approach. In 2017, the NEFSC in conjunction with the New

[3] Harvest projection

[4] Catch report

England and Mid-Atlantic Fishery Management Councils agreed to produce stock assessment reports that strictly report on results focusing on their impact on policy decisions. The NEFSC management track reports outline the state of the stock, reference points, projections, and responses to reviewer comments. Assessment cycles vary depending on the type of assessment and need.

Research track assessments for individual stocks are generally conducted every five years or longer. Research track assessments can also cover specific topics, such as state space models or methods for estimating recruitment, which may cover several stocks at once. Management track assessments are specific to one stock and are performed every one to six years depending on several factors, including management cycles and the timing of at-sea data collection. The level of management track assessment peer review scales are based on a scoring system. This scoring system is indicated by level 1, 2, or 3. Level 1 management track is a direct delivery that updates the previously approved assessment with new data and can include only minor adjustments. Level 2 is an expedited review in which additional flexibility for deviations from previously accepted assessments is approved but only if a peer review can be conducted. Level 2 includes some public input as well. Level 3 is an enhanced review where extensive changes beyond those indicated in level 2 are applied. Level 3 requires a more extensive peer review (NRCC, 2022).

Assessment models used in this region can include but are not limited to WHAM, SS3, and, in the past, ASAP. Additionally, the NEFSC follows a LaTeX template for its reports, which is completed for each species and consolidated into a larger management track report for that year. The LaTeX template is not publicly available; however, it is a somewhat modularized template that contains separate LaTeX files that contain reviewer comments, a preamble, the actual text, and a title page. Tables are also written in separate LaTeX files then connected with the main text. Figures are created outside the template then referenced in the main text. These documents are compiled together by a single assessment author and made accessible through a system of LaTeX files developed by contractors who support NOAA. Stock assessment scientists interact with the template via an R script, similar to a primitive version of R Markdown.

4.2.1 CHALLENGES

It is important to acknowledge that this automation is only available for management track reports. It is almost impossible to automate research track assessments due to their variable nature. Additionally, while the center has invested considerable time and funding making their documents 508 compliant for accessibility, a lot of processing is required by a single user to make this possible. This process can take up to 2 weeks for a single analyst at the center. The workflow is still labor-intensive and can have a barrier to entry if users are not familiar or comfortable with R or LaTeX.

4.2.2 LESSONS LEARNED

- Improved compatibility for acronyms and complex tables with screen readers is needed, but the current tools have made the NEFSC documents highly accessible to readers.
- Stock assessment reports do not need to be long or overly detailed to be useful to clients. Managers, in fact, often appreciate being able to quickly and easily locate the components of the report most useful to them. It can be beneficial to develop a separate report for managers, which can be short, relatively easy to automate, and made accessible, and another report for reviewers, which can be much more detailed.

4.3 NWFSC

The NWFSC is responsible for producing stock assessments for more than 60+ species on the U.S. West Coast. These species are evaluated based on the data available by categorizing the assessment between 1 and 3. Category 1 stocks are data-rich, and the overfishing limit (OFL) is based on fishing mortality at the maximum sustainable yield (F_{MSY}) or an F_{MSY} proxy from model output. Category 2 stocks are considered data-moderate or face sufficient modelling challenges for misspecification that higher uncertainty is warranted. Their OFL can be derived from model output or natural mortality, or it can be based on a proxy for the fishing mortality rate at maximum sustainable yield (F_{MSY} proxy). Category 3 stocks are data-limited, and the OFL is derived from historical catch data (PFMC, 2022). Full stock assessments are only conducted for category 1 and 2 stocks and are typically conducted using SS3. The complete list of stock assessment types produced by the NWFSC include the following:

- Update assessments
- Catch-only projections
- Data-moderate assessments
- Data-limited assessments
- Catch reports

More information on these specific report types can be found on the PFMC's website (PFMC, 2022). Workflows at the NWFSC can be highly variable. R scripts are typically written for analyzing and summarizing data for the assessment model, running an assessment, generating the report, tables, and figures, and conducting additional analyses. Like all of the other regions, many parts of the workflow are modified for each species.

State agencies and several online databases and code repositories provide resources for developing formatted data for model input. For example, the NWFSC survey repository contains code to extract survey data for West Coast groundfish from an online data warehouse of publicly available survey data. These types of resources can reduce preparation time for running an assessment model but are not fully optimized. For scientists using SS3, the r4ss R package provides a resource to create figures and summarize model comparisons. The r4ss package in combination with the sa4ss package can greatly improve productivity for those using SS3 in their workflows. Reports and model files are submitted to the PFMC's websites, which are available for public access.

4.3.1 CHALLENGES

While the NWFSC has made some of the largest advancements in improving and streamlining workflows, there are still things that have posed a challenge. First, the NWFSC still has no standardized process for creating a large number of tables required by the PFMC groundfish assessment terms of reference. Second, it is difficult to keep pace with required changes during every stock assessment cycle to ensure that automated documents meet 508 compliance. Third, while all staff benefit from shared tools, a smaller subset of staff have the skills and interest in producing and maintaining them. This creates challenges around redundancy and workload.

4.3.2 LESSONS LEARNED

- It is often difficult to track what needs to be updated, and updating every data object that is sourced in an assessment document is time consuming. Thus, the use of a package like {targets} could help users know what portions of their document need to be updated and what can remain the same. This has been proved successful in other divisions of the NWFSC, such as for economic analyses, and within the assessment field but not for assessment documents.

- Having a template that is changing during an assessment season is difficult because users do not want to start fresh; users prefer that the updates be automatically incorporated into the text that they have already written, which is sometimes impossible. Everyone wants to customize the template to make it look better, but often there is no time to make it applicable to all populations, so the code does not get shared. It is important to ensure that all code is on GitHub, uses versioning control, and that changes to the code inform those who maintain the package.

- Some reviewers still prefer Microsoft Word or the ability to mark up documents using the method they are familiar with to provide comments, and doing so when a pdf is submitted can be difficult for them.

- Often, the center workflow is not amenable to changing fleet structure or population structure, and thus, when a change is asked for by a review-panel, such changes to the basic model/data structure assumptions can trigger significant resource hours to alter the document/code structures. Thus, workflow structure and flexibility become a key consideration for work-load tradeoffs, especially as assessment deadlines approach and/or during the review process.

4.4 PACIFIC ISLANDS FISHERIES SCIENCE CENTER

The PIFSC is responsible for producing stock assessments for both domestic and international stocks. The center works with the Western Pacific Fishery Management Council to manage the domestic stocks, while the managing bodies for international stocks vary depending on the target species. The center has made great strides in better automating their workflows by developing a roadmap for their assessments. Scientists at the center have developed a method for creating input files for the target assessment model using Google Sheets and R. The centralized Google Sheets file for parameterizing the assessment model for a species allows R scripts to automate other steps of the process such as creating the input files for SS3 or other relevant modeling software, executing the model, and running diagnostics and summarizing the output into a quickly digestible document using Quarto. While this is a general process, each species' or stock's workflow is a bit different due to its specific needs. With regard to reporting, there are two approaches. The first uses a template for a NOAA Technical Memorandum that is available to download through GitHub. This tool is a pre-formatted R Markdown document that the user can fill in for their report. Another method for creating reports is using a modularized R Markdown system similar to but different from that of the other regions. The template is not available publicly but contains an R Markdown structure similar to sa4ss.

4.4.1 CHALLENGES

As with other regions, it is hard to fully automate and make a generalized workflow for every species managed by the region. With regard to reporting, it can be difficult to form a general reporting structure due to international requirements and the need to accommodate the assessment of species complexes. Most assessments only focus on one species, so increasing to two or even a group complex limits the ability to automate the process. Additionally, there are similar barriers to entry when using an R Markdown or Quarto framework because documents created using these methods can make it hard to incorporate iterative changes during the review process.

4.4.2 LESSONS LEARNED

- Creating automated processes and reports works well for groups of species that have a similar model structure (e.g., 9 American Samoa bottomfish or 3 billfish species) but is difficult for complexes (e.g., Main Hawaiian Islands Deep 7).
- Using a variety of modeling software for all of the different stocks makes it difficult to create one tool for everyone to use.

4.5 SEFSC

Stock assessment staff at the SEFSC are distributed across four branches pertaining to the three water bodies in the southeastern United States (the South Atlantic, Gulf of America and Caribbean) as well as the high seas of the Atlantic for Atlantic highly migratory species (HMS). Additionally, the science center is the only one that interacts with three U.S. fishery management councils (South Atlantic Fishery Management Council, Gulf of America Fishery Management Council, and Caribbean Fishery Management Council). They also support an inter-governmental fishery management organization (the International Commission for the Conservation of Atlantic Tunas [ICCAT]). In the United States, the SEFSC and councils join together to produce research or operational stock assessment reports through the Southeast Data and Assessment Review (SEDAR) process. SEDAR is a council-run and public process with input from the SEFSC. The SEFSC can make recommendations but does not dictate what stocks are assessed and when. Planning can be difficult, especially when species are added or dropped from the SEDAR schedule based on the council's latest perception of needs. As a public process, all assessment decisions must be made in a public forum with meetings announced well in advance in the Federal Register. This creates low efficiency in favor of high transparency.

For Atlantic HMS, assessments are handled somewhat differently given that the managing body is international. In the SEDAR process, assessments are then reviewed by a committee determined by SEDAR rather than a council. Stock assessment results from the SEDAR process are then sent to NOAA Fisheries OSF for further review and use in the development of management advice. Since international HMS are managed by ICCAT, these assessments follow their standard of assessment and reporting; however.

Starting in 2025–2026, SEDAR has decided to remove assessment types. The needs for each assessment will be decided on an assessment by assessment basis before starting the assessment. Some stocks may require a schedule that is very much like a benchmark with multiple workshops and a comprehensive independent peer review. Other assessments may be designed as strict updates, with only SSC review. Most assessments will likely fall in between those extremes with workshops to address known issues or new data sources. The goal is to depart from rigidly defined assessment categories to allow flexibility in the process for any given assessment. Any additional information or research needed for an

assessment might be created as add-on sections. The SEDAR process specifies guidelines for assessment reports. These include the placement of tables and figures at the end of reports and a table of fishery management history before the assessment report, which SEDAR or management council staff produce and contribute. Final reports, associated working papers, and other documents produced during the assessment review process are stored on SEDAR's website for public access.

Generally, data inputs for assessments are pre-processed by data analysts at the SEFSC or by partnering agencies (e.g., state agencies, academic partners). Those data are summarized and analyzed from the raw data located in their databases. This process for evaluating and formatting data can vary between stocks, assessment model needs, and data types but is generally similar within the region. It is important to note that these data are not simple to work with, and many factors need to be considered during analysis. The raw data provided by different data providers typically follow different formats, and formats can vary from one assessment cycle to the next, which increases the amount of time required to merge datasets and the chance of errors.

Data providers have recently made considerable efforts to improve the consistency and transparency with which data are provided for assessments. The SEFSC Sustainable Fisheries Division Data Analysis and Support (DAAS) Branch is responsible for providing a number of fishery dependent data products. The DAAS Branch has invested time and effort into automating data pulls and analyses, as well as standardizing reporting (e.g., for SEDAR working papers). Similarly, the SEFSC Fisheries, Assessment, Technology, and Engineering Support Division's Biology and Life History Branch is working on producing a database template to standardize the formats in which age and reproduction data are being submitted to streamline the production of life history data and parameter estimates for stock assessment. It is not uncommon for data to require an additional level of formatting and synthesizing after submission to the assessment team (i.e., beyond what is done at the data provider level). For that, individual stock assessment leads have typically created their own workflows (e.g., in R or Excel) to fit their specific needs.

All data used in SEDAR stock assessments are archived on an internal server ("S-drive") for all SEFSC SEDAR data providers and analysts to access. The use of the S-drive has been a considerable improvement to the stock assessment workflow because it (1) provides standard descriptive file names and locations, which are requisites for increased automation of data analyses and reports, (2) improves transparency and organization, and (3) improves communication and efficiency by minimizing the provision of data through email. As a region, the SEFSC needs to be especially judicious in its handling of fishery dependent data to ensure confidentiality. Fishery dependent data for some species have only a few samples per strata, thus care must be taken when providing summarized information as some of the strata may only represent one or two vessels or businesses,

rendering the summarized value for that strata confidential. This can make it difficult to share workflows and add processing time due to the need to manually check that summarized information meets confidentiality requirements.

The workflow for the South Atlantic Branch at the SEFSC deviates from other branches. The South Atlantic Branch typically applies the BAM to evaluate their respective stocks. The initial input data file for an assessment follows a routine structure but is manually created. Once the initial input file is created, the process is automated using R scripts to create input files for the purpose of uncertainty analysis, which typically takes the form of Monte Carlo/Bootstrap ensemble modeling. BAM contains a set of standardized functions and routines, but the analyst must still work with ADMB source code for any stock-specific features. The branch utilizes ADMB2R routines to create an R object that contains all model input and output, and it uses FishGraph to produce figures for diagnostics and for reports. Projections are coded as R scripts, which like BAM, are customizable but with standardized, reusable functions and routines. The South Atlantic Branch has found customization of assessment and projection models to be useful to accommodate stock-specific features and nonstandard projection requests from the council, its SSC, or the regional office.

For creating reports, the South Atlantic Branch has a LaTeX template somewhat similar to that of the NEFSC. The template incorporates a set of figures produced from FishGraph but also LaTex tables produced from reusable R scripts. The report is not completely automated, but the current template helps reduce processing time. The organization of these files and the workflow are on a species by species basis. Assessment scientists familiar with this workflow find it to be familiar, quick, and fairly helpful to produce assessments in a timely manner.

The Gulf of America Branch's workflow typically uses the SS3 assessment model for evaluating their stocks, so they are able to take advantage of associated tools for SS3 like r4ss. The branch primarily works with the SS3 report file to help automate their reporting process. They do not use sa4ss as a template for assessments and instead have their own R Markdown template to produce a report. The template is stored in a private repository containing a modular breakdown of R Markdown files and customized parts for each species. The report is changed year to year by coding in-line parameters and referencing a preamble R chunk, which the analyst must change based on the current year and species of the report. With each new stock assessment, the repository from another assessment is forked, and the respective changes are made for the new assessment.

The Caribbean Branch at the SEFSC is responsible for stock assessments primarily in the U.S. Caribbean (Puerto Rico and the U.S. Virgin Islands). Where possible, they use the SS3 model for evaluating stocks but often need to rely on data-limited approaches. The branch is currently in the process of developing a more optimized workflow. Their current process

for generating reports focuses on generating tables and figures outside of the report then reading them into R Markdown files.

4.5.1 CHALLENGES

Currently, the process is not fully automated, and the custom needs of the assessment model, projections, and report writing can be time consuming. Files created during model development are stored locally on an internally shared drive rather than in a repository like GitHub. This can reduce transparency in the process. Some branches make use of a standardized folder and file naming structure with notes in "readme" files of a GitHub repository within each partition. The biggest hurdle to increased efficiency is not automation of assessments and report writing, as much of this has been mitigated by the approaches described above. In the Southeast in general, the biggest hurdle to efficiency is data provision. Much of this is out of NMFS' control, given the many partners (NMFS, states, academics) that contribute data to any given assessment.

The stock assessment reports developed by the SEFSC in general tend to be lengthy and therefore take extra time for the analyst to develop. The use of R Markdown can pose a steep learning curve for users, but the branch has begun to overcome this challenge through practice and use of the R Markdown template for assessment reports. Specifically, one challenge has been how to efficiently alter reports from one stock to another. For similarly structured assessments, adapting the report to the new stock is a straightforward process. However, if the structure of the assessment changes, it can be time consuming to recode the report. For example, there is no automated way to go from reporting a single sex stock assessment to a sex-specific stock assessment model or a single region stock assessment to a multi-region stock assessment.

Stock assessment reports from the SEFSC also contain tables and figures that allow the reader to compare some key trends from the previous assessment with those from the current assessment. Developing comparative plots and tables can be time intensive to produce. There are no automated processes yet for meeting section 508 accessibility compliance standards, so this must be performed manually. Because of confidentiality issues, raw SS3 input files are not shared with the public. Therefore, information related to the model inputs needs to be described in the assessment report.

The Caribbean Branch is in the process of developing an optimized stock assessment workflow. The current R Markdown-dependent process has difficulties with references, tables, and figures. The limited knowledge of R Markdown and Quarto in the branch makes it challenging for analysts to use the workflow under development. Additionally, update assessments in the region tend to feel like benchmark assessments due to the lengthy requests of additional information, tables, or figures in a report.

4.6 SWFSC

Some parts of the stock assessment workflows for scientists at the SWFSC overlap with the NWFSC due to their shared responsibility for managing some fish stocks along the U.S. West Coast. They also share similar guidelines for their processes and reports. The region also uses the SS3 assessment model and incorporates tools like r4ss (Section 5.1.3) and ss3diags into their workflows. The SWFSC has a great resource called swfscMisc, which provides a collection of functions that scientists are able to use throughout their workflow. The package does not target a specific part of the workflow but provides help to perform various tedious tasks.

For generating reports, there is a centralized R Markdown process available that can be customized from species to species adapted from 'sa4ss' (Section 5.1.9). Some of the scientists use Microsoft Word for writing reports, which provides familiarity but limits reproducibility of the workflow. Some of their reports and associated files are available on the PFMC GitHub page or PFMC website.

4.6.1 CHALLENGES

The SWFSC has had difficulties moving toward a more reproducible and transparent workflow that would increase productivity. When workflows started to become semi-automated, the region had trouble with data acquisition and handling due to data confidentiality and data storage. Data for the region are handled in data systems and servers as well as on the local NOAA internal shared drive. Since workflows are highly variable, the transition for new employees into the region can be challenging. The workflows are not highly organized and do not follow a linear path, making it unclear. Last, the region struggles with adding accessibility features into their reports in an automated way.

5. CONCLUSIONS

Current technological advancements make possible the partial automation of the stock assessment workflow. This includes extracting and analyzing of raw data, preparing and formatting data for model input, running the model, and developing the stock assessment report. For a stock assessment modeling platform, most regions use SS3, with the exception of the Beaufort Laboratory in the Southeast, which uses the BAM; the Alaska Region, which uses the AMAK but is shifting to SS3; and the Northeast Region, which uses the WHAM. Data-limited approaches such as JABBA or the Length-Based Spawning Potential Ratio estimator are used for stocks that cannot be otherwise assessed due to data limitations. This includes stocks in the Pacific Islands Region and in the U.S. Caribbean Branch of the Southeast Region.

The most salient challenge that most regions identified was the extraction, processing, and formatting of raw data to develop stock assessment model inputs. We discussed this challenge with the steering committee, with an interest in developing a standardized, national-level workflow for data processing. However, after conversations with analysts from each region, we determined that there are too many differences in data types, formatting, and structure from one region to another to develop a national-level workflow until data storage and collection are more unified within the agency. The NOAA Fisheries Office of Science and Technology will lead a scoping exercise to better understand the specific bottlenecks each region manages when developing stock assessment model inputs from raw data.

Portions of the stock assessment workflow have been semi-automated by several different NOAA Fisheries Science Center regions. These efforts have focused on report development and, to a lesser extent, data preparation and formatting. Most regions have moved forward with some form of semi-automated report development, but progress has been limited in most cases and is not generalizable to other regions. The Stock Assessment Workflows Team in the NOAA Fisheries Office of Science and Technology, together with representative analysts from each NOAA Fisheries region as steering committee members, has developed a generalized, semi-automated stock assessment report development tool in R using Quarto (asar). This includes a data converter, which can gather the outputs from different stock assessment modeling platforms and organize the information into a standard format. The first version was released in January 2025 and is being designed to interface with the main stock assessment modeling platforms being used and develop the majority of a stock assessment report for the user. These current developments can be found here:

Automated Stock Assessment Reporting (asar): https://github.com/nmfs-ost/asar

Stock Assessment Tables and Figures (stockplotr): https://github.com/nmfs-ost/stockplotr

These two tools will increase throughput, allowing the assessment of more species by releasing the burden of overhead that comes with developing extensive reports and assessment model inputs. In addition to {asar} and {stockplotr}, a review and adoption of a national standard set of stock assessment report guidelines will create a more cohesive and consistent approach to U.S. federal fisheries stock assessments.

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