

**[Implementing a Next Generation Stock Assessment Enterprise:
An Update to NOAA Fisheries' Stock Assessment Improvement
Plan]**

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DISCUSSION PURPOSES



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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
SILVER SPRING, MD 20910

**IMPLEMENTING A NEXT GENERATION STOCK ASSESSMENT
ENTERPRISE**
AN UPDATE TO NOAA FISHERIES' STOCK ASSESSMENT IMPROVEMENT PLAN

EDITED BY ...
NATIONAL MARINE FISHERIES SERVICE, OFFICE OF SCIENCE AND TECHNOLOGY
SILVER SPRING, MD 20910

DATE

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116 **Executive Summary**

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120 PLACEHOLDER, TO BE COMPLETED

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SECTION I. INTRODUCTION TO THE STOCK ASSESSMENT IMPROVEMENT PLAN

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135 **Chapter 1—Background and Purpose**

136 **Chapter highlights:**

- 137 • **This Stock Assessment Improvement Plan (SAIP) describes a vision for a Next Generation Stock**
138 **Assessment Enterprise (NGSA) that improves timeliness and efficiency of assessments,**
139 **prioritizes work, expands the scope of assessments, and uses innovative technologies and**
140 **techniques to conduct assessments.**
- 141 • **Adaptive strategies need to be incorporated into the stock assessment process to account for**
142 **changing ecosystems and a growing demand for assessments.**
- 143 • **Stock assessments provide necessary information to fishery managers and apply broadly to**
144 **other aspects of coastal and ocean management and policy.**

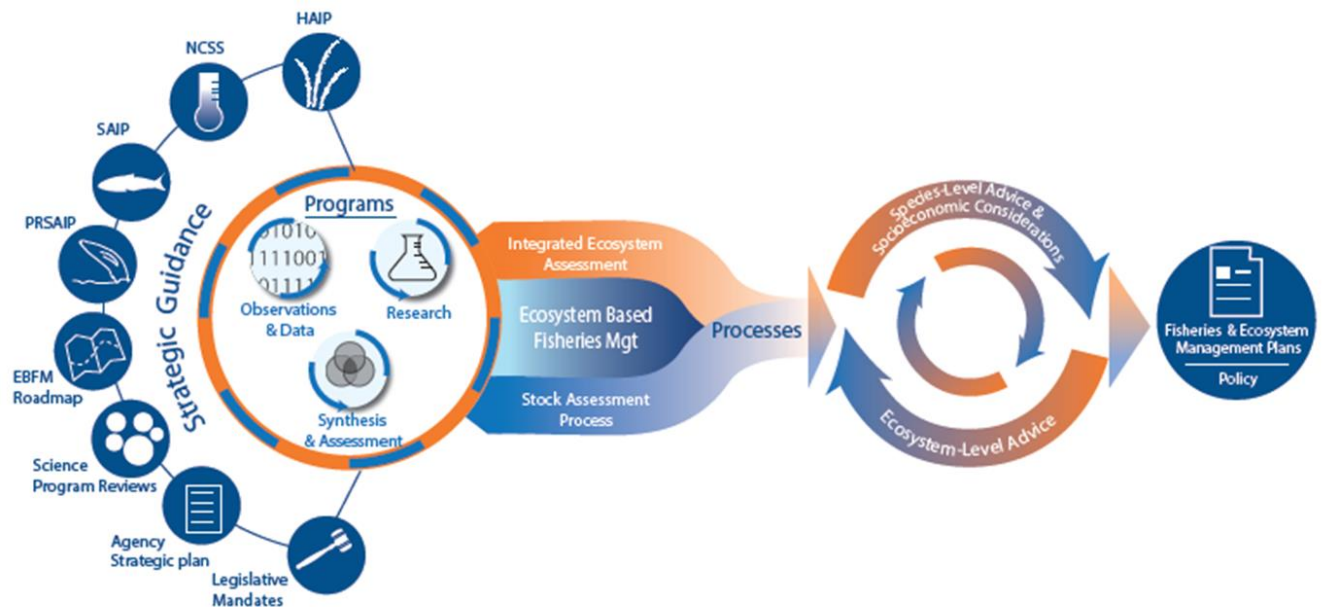
145 In 2001, NOAA Fisheries published the SAIP. Effectively, this document sought to bolster NOAA's
146 capacity and infrastructure for conducting assessments, and to expand the content and extent of these
147 assessments. The SAIP also led to the development of important performance metrics that gauge
148 progress in NOAA Fisheries' stock assessment enterprise. The 2001 SAIP provided a strategic vision that
149 enhanced program performance in the years following the release of the SAIP (see Chapter 2 for an
150 overview of accomplishments). Thus, the SAIP plays an important role in NOAA Fisheries' strategic
151 efforts to advance the stock assessment enterprise, and the objectives of this SAIP update are to
152 summarize the accomplishments and evolution of NOAA Fisheries' stock assessment enterprise since
153 the release of the original SAIP in 2001, and to outline a vision for the next generation of NOAA
154 Fisheries' assessments.

155 Although the SAIP focuses on stock assessments, it also complements many other strategic efforts that
156 collectively help NOAA Fisheries best accomplish its overall mission (Fig. 1.1). In particular, this new SAIP
157 responds to results of recent independent reviews of NOAA Fisheries' science programs and helps
158 facilitate progress toward fishery management approaches that are more ecosystem-based and climate-
159 smart. The following sections describe NOAA Fisheries' NGSA Enterprise.

160

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161
162 **Figure 1.1.** NOAA Fisheries' scientific programs are guided by numerous strategic efforts and products to
163 provide advice to fishery managers under an interdisciplinary ecosystem-based approach to fishery
164 management. Strategic guidance includes the Habitat Assessment Improvement Plan (HAIP), the
165 National Climate Science Strategy (NCSS), the Stock Assessment Improvement Plan for fisheries (SAIP)
166 and Protected Resources (PRSAIP), the Ecosystem-Based Fisheries Management Roadmap (EBFM
167 Roadmap), Science Program Reviews, Agency Strategic Plans, and Legislative Mandates. Ultimately, this
168 process results in scientific advice necessary for developing fishery management plans (FMPs) and
169 fishery ecosystem plans (FEPs).

170 **1.1. What is a stock assessment?**

171 **Stock assessments**—These assessments provide the scientific underpinning of successful and
172 sustainable fishery harvest management. A stock assessment is based upon the scientific processes of
173 collecting, accessing, analyzing, and reporting species demographic information, and provides an
174 evaluation which summarizes the effects of fishing (and other drivers) on fish¹ populations, quantifies
175 uncertainty, and supports projections of future catch and stock status. The assessment process
176 culminates in a scientific product (report) that provides fishery managers with a basis for implementing
177 sustainable harvest policies. Thus, stock assessments can be considered both a product and a process.
178 Further, a stock assessment is operational science and is more focused than general research on the
179 population dynamics of a harvested fish stock: The assessment is conducted with the specific intent of
180 using the results to provide the scientific basis for fishery management decisions.

¹ The term "fish" is used throughout this document to collectively refer to all aquatic taxa affected by fishing in marine systems.

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181 The three fundamental components of the stock assessment process include:

- 182 1. **Data collection and processing**—This information includes total catch from commercial,
183 recreational, and subsistence fisheries; changes in abundance informed by scientific surveys
184 and/or fishery catch rates; and biological data on fish stocks.
- 185 2. **Stock assessment modeling**—Mathematical models of stock and fishery dynamics are
186 configured and then calibrated using analytical and statistical methods. These methods relate
187 the models to patterns observed in the data used in the assessment.
- 188 3. **Developing and communicating recommendations**—Model results are summarized and
189 bracketed by scientific uncertainty, then communicated as scientific advice for fishery
190 managers.

191 Stock assessments provide advice on the following important aspects of a fish stock:

- 192 1. What are the biological limits to sustainable fishing and what fraction of the stock should be
193 harvested each year? Addressing these questions generates **harvest policy** recommendations;
194 i.e., control rules that provide a basis for determining an optimum harvest level that provides a
195 sufficiently low risk of overfishing.
- 196 2. How hard have we been fishing and what is the current **stock status**? Is the stock **overfished** or
197 undergoing **overfishing** (becoming overfished) relative to reference points that are linked to the
198 harvest policy?
- 199 3. What short-term future catch level (**forecast**) would implement the harvest policy given the
200 current stock status and prevailing environmental conditions?

201 **Harvest policies**—These policies are agreed-upon strategies for modulating catch to achieve a specified
202 objective. In the United States, harvest policies are generally focused on the concept of maximum
203 sustainable yield (MSY^2), which is the maximum catch that can be harvested from a stock on a
204 continuing basis. MSY is obtained when the fishing rate (F) is sustained for the foreseeable future at a
205 level that provides the maximum average catch. Thus, MSY is a biologically based upper limit for harvest
206 of a particular stock. However, various factors such as ecosystem and economic considerations, as well
207 as uncertainty in the calculation of MSY and the capability of actually maintaining F at the F_{MSY} level, lead
208 to recommendations for optimum yield that are somewhat less than MSY . Overall, stock assessments
209 play an important role in the development and implementation of harvest policies. In addition to
210 considering individual stock dynamics from assessments, these policies are an ideal place in the
211 management process to infuse ecosystem and socioeconomic considerations.

212 **Stock status**—These determinations are based primarily on estimates of stock biomass and fishing
213 intensity relative to established management objectives, such as the level of biomass and fishing

² Most stock assessments in the United States use proxies for MSY that are based on life history characteristics (e.g., natural mortality, growth, maturity, fecundity, and proportional harvest by age or size).

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214 intensity that produce the MSY (B_{MSY} and F_{MSY}). Fishing at a higher rate than F_{MSY} is considered
215 “overfishing,” and if a stock falls below a specified fraction of B_{MSY} , the stock is considered to be
216 “overfished.” Stock assessments provide the scientific information necessary to determine stock status.
217 Knowing a stock’s status has helped fishery managers modify their harvest policies to reduce instances
218 of overfishing and rebuild many previously overfished stocks.

219 **Forecasts**—Short-term predictions of annual harvest levels and stock status (under prevailing conditions)
220 are used to help identify optimum yields and rebuilding strategies. There are uncertainties in these
221 calculations, so stock assessments strive to provide a probability-based risk framework in which the
222 chance of overfishing is balanced with the attainment of a large fraction of the maximum possible
223 biological yield. Providing a probabilistic framework allows fishery managers, stakeholders, and other
224 interested parties to make informed decisions in the face of uncertainty. The level of uncertainty in
225 assessment forecasts is reduced in cases where high-quality data exists, particularly with respect to the
226 reproduction (newly born or young organisms) that will support future harvest opportunities. Beyond
227 prevailing conditions, a wide range of scenarios and strategies can be explored. These evaluations seek
228 to define the range of reasonable harvest strategies and management options under varying conditions
229 (e.g., ecosystem, socioeconomics) to identify a set of robust choices for achieving the goals of
230 maximizing fishing opportunity and minimizing overfishing. Forecasts are a proactive result of stock
231 assessments and offer another critical place to infuse ecosystem and socioeconomic information in the
232 fishery management process.

233 **1.2. What is the context for stock assessments?**

234 Stock assessments are fundamental to sustainable fisheries management. Assessments use a
235 quantitative framework to provide recommendations to fishery managers on how much biological catch
236 can occur while preventing overfishing. In the U.S. system, fishery managers use these
237 recommendations to set annual catch limits (ACLs), which represent targets for managed fisheries. By
238 law, ACLs cannot exceed the levels recommended from the scientific process. To buffer against
239 uncertainty, managers often set lower catch targets based on risk policies that take into account
240 uncertainties in the stock assessment, ecosystem, and management processes. Thus, stock assessments
241 play a key role in fishery management by setting scientifically based and legal upper bounds on annual
242 harvest levels. Although assessments allow the agency to meet its fishery management mandates, they
243 also support other aspects of NOAA Fisheries’ mission, such as ecosystem-based fisheries management
244 (EBFM) via integrated ecosystem assessments (IEAs). NOAA Fisheries leads the nation’s efforts to
245 evaluate the status and condition of a wide range of living marine resources. These resources include a
246 broad array of marine taxa, and especially those targeted for commercial, recreational, or subsistence
247 harvest. NOAA’s stock assessment efforts are implicitly mandated by key sections of the Magnuson-
248 Stevens Act (MSA), including the following:

- 249 • Status of stocks relative to established reference points
- 250 • Whether stock rebuilding needs to occur

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- 251 • Annual quotas available for catch and the most suitable harvest rates
252 • Other impacts to these marine taxa
253 • Potential impacts to the food webs, habitats, and ecosystems associated with these marine taxa

254 Under the MSA, approximately 474 fishery stocks are managed by 8 regional fishery management
255 councils³ and the Highly Migratory Species Division of NOAA Fisheries⁴. The agency also provides various
256 levels of support for the management of living marine resources found in state waters, international
257 waters, and related jurisdictions. Further, other mandates merit consideration of the status of and
258 impacts to marine stocks. Examples include:

- 259 • The cumulative effects to an ecosystem (National Environmental Policy Act – NEPA).
260 • Adequate forage for protected species (Marine Mammal Protection Act – MMPA Endangered
261 Species Act – ESA).
262 • Effects of other activities on living marine resources and fishing (NEPA).
263 • Effects of fishing on other parts of marine ecosystems (NEPA).
264 • Effects of development and water quality on fish stocks (Coastal Zone Management Act – CZMA
265 Clean Water Act – CWA).

266 These additional mandates are rely on knowledge of how the various ecosystem factors affect stock
267 status. Facets of other mandated management activities, whether from system-level advice or protected
268 species advice, inform and are informed by species-specific stock assessments. As such, stock
269 assessments have wide utility, mandated need, and broad application within the full suite of scientific
270 responsibilities executed by NOAA Fisheries and its partners to manage living marine resources in the
271 United States.

272 Within NOAA Fisheries' scientific portfolio, extensive programs are executed to support and enhance
273 stock assessments (Fig. 1.1). Data collection programs are fundamental to obtaining and processing the
274 traditional data inputs used to inform stock assessments (Chapter 4). The agency strives to sustain and
275 improve its data collection infrastructure, use of advanced sampling technologies, electronic
276 technologies for data collection and data management, and analytical tools, education, and training for
277 current and future professionals. This portfolio includes several programs that focus on population
278 dynamics, where scientists work to develop and implement stock assessment models and conduct
279 research to improve models. This research can consist of studies that seek to expand assessments by
280 including ecosystem and socioeconomic factors.

281 NOAA Fisheries' suite of internal programs directs and funds crucial research and promotes the
282 transition from research to operational science. The main project themes include exploring ecosystem
283 linkages, climate change impacts, economic impacts, fisheries dynamics, and habitat dependencies. The

³ <http://www.nmfs.noaa.gov/sfa/management/councils/>

⁴ <http://www.nmfs.noaa.gov/sfa/hms/>

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284 agency also supports analytical methods development, management strategy evaluations, harvest
285 control rule development, and operational improvements with innovative technologies. These funds are
286 distributed broadly throughout NOAA Fisheries and to agency partners to ensure that the most qualified
287 individuals are addressing the most important problems. Further, many efforts not only have application
288 to stock assessments but also cross-cut the agency by informing protected species science, habitat and
289 ecosystem assessments, and other marine resource management considerations. As such, efforts to
290 bolster stock assessments have been beneficial to a wide range of activities, just as the stock assessment
291 process has benefited from the extensive suite of scientific efforts conducted by NOAA Fisheries. The
292 interplay among the variety of strategic guidance (Fig. 1.1) and related programs clearly demonstrates
293 the value of and need for coordinating related efforts across NOAA Fisheries' entire science enterprise.
294 One aim of this document is to advocate for the continued integration and interchange across the full
295 suite of NOAA Fisheries mandates and programs.

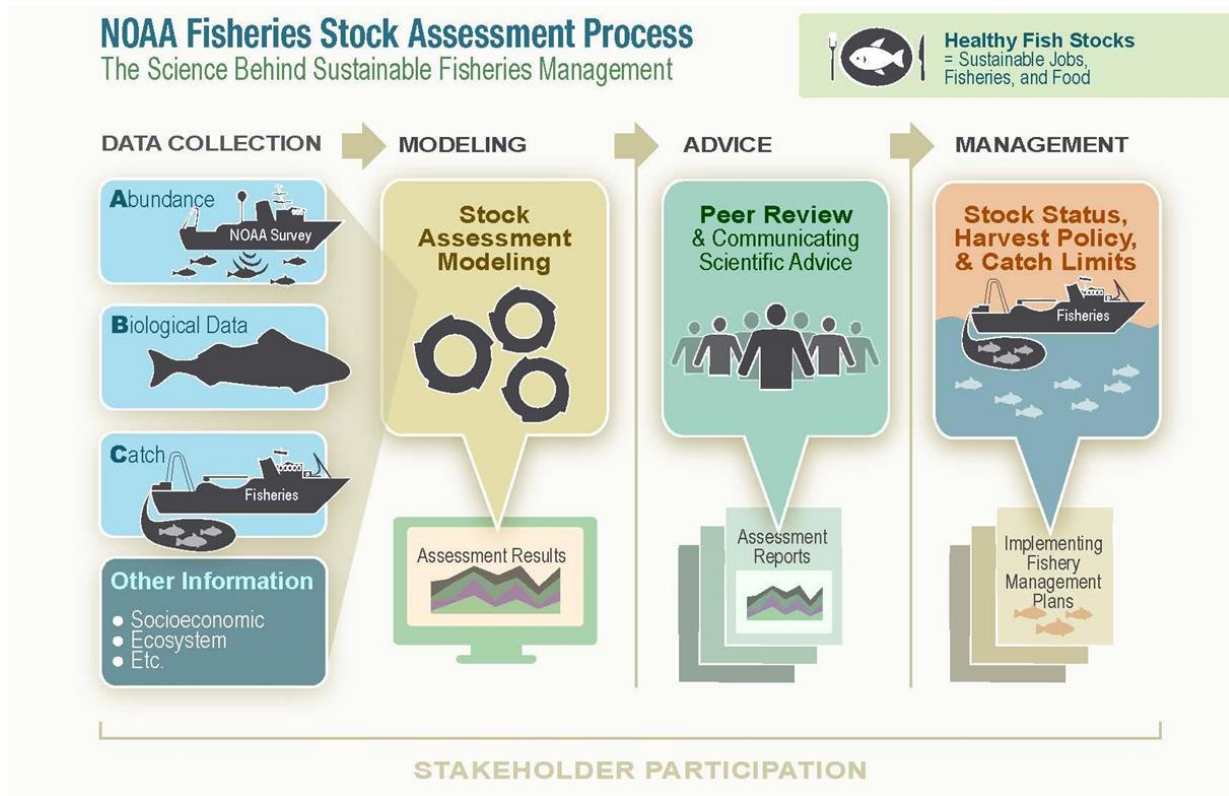
296 1.3. How are stock assessments conducted?

297 The stock assessment process consists of a full suite of efforts, including data collection and processing,
298 stock assessment modeling, and developing and communicating recommendations (Fig. 1.2). Each step
299 in the process requires technical expertise as well as substantial coordination and collaboration with
300 multiple partners and stakeholders. The quantitative advice provided by assessments is generally
301 derived from models that include mathematical representations of population and fishery dynamics,
302 and are analyzed using statistical methods. Assessments rely on data collected from commercial,
303 recreational, and subsistence fisheries; from NOAA research vessels and chartered vessels; and by
304 academic and industry partners. Data crucial for stock assessments include a full and accurate
305 accounting of the total catch (and discards) over time, measures that track changes in stock abundance,
306 and stock-specific biological information. Where available and appropriate, additional data, such as
307 information on ecosystem and socioeconomic trends, can be incorporated to make assessments more
308 comprehensive.

309 In addition to data collection and sampling, models must be developed to integrate a wide range of
310 information for a stock or group of stocks, model outputs must be reviewed, and ultimately
311 management advice must be provided. For some, the term "stock assessment" invokes particular facets
312 of the process, such as conducting scientific surveys or running assessment models. However, in this
313 document we use the term "stock assessments" to mean the full process from data collection to the
314 provision of advice.

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316 **Figure 1.2.** Overview of the stock assessment process from data collection through the provision of
317 scientific advice to fishery managers. Stakeholders may participate in each step of the assessment
318 process.

319 **1.4. Why should stock assessments be improved?**

320 There are three primary reasons to reevaluate NOAA Fisheries' stock assessment efforts, given the
321 number of developments, advances, challenges, and opportunities that have occurred since the SAIP
322 was published in 2001.

- 323 **1. Expanding the scope of stock assessments**—The scope of many stock assessments, which tend
324 to focus on single-species population dynamics, needs to expand to better account for the direct
325 impacts of changing conditions that affect overall productivity. For instance, stock productivity
326 can be influenced by dynamics in habitats, oceanography, predators and prey, toxins, diseases,
327 parasites, climate-scale factors, and other relevant variables. (Note that the term “ecosystem” is
328 used from now on to refer collectively to these living and non-living dynamics that affect marine
329 species.) The need to incorporate ecosystem dynamics is demonstrated indirectly by
330 unexplained issues that can arise when running diagnostic tests on certain stock assessment
331 models. For example, when observed patterns in data are not well represented by an
332 assessment model's structure, the model may not account for crucial aspects of the ecosystem,
333 which is necessarily a simplification of stock dynamics.

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335 In addition, ecosystem information can improve assessments in cases where fishing intensity has
336 been reduced and the natural variation in fish stocks makes it more difficult to estimate fishing
337 rates when they are at a scale similar to natural processes. More direct evidence for the need to
338 improve ecosystem linkages comes from studies that reveal the strength of interactions among
339 species and between species and their environment. Biological factors that drive stock
340 productivity, such as natural mortality, growth, and reproduction, are not strictly inherent
341 properties of a species, but instead result from a species' interaction with its ecosystem. As
342 fishing and other factors impact ecosystem dynamics, related shifts should be expected in the
343 biological factors that form a basis for calculating sustainable fishery rates. In some cases,
344 ecosystem changes may be small enough to justify the use of simpler approaches, and in other
345 cases there are not sufficient data to look closely at ecosystem effects. Nevertheless, there is a
346 clear need to evaluate the effects of ecosystem dynamics on stock productivity to the extent
347 possible, and develop harvest control rules that are robust to these changes. These goals may be
348 best accomplished by linking certain stock assessments to ecosystem dynamics.

349
350 The original SAIP recognized the need to improve linkages between stock assessments and
351 ecosystem factors; however, the document did not explain these needs in depth. In fact, the
352 original SAIP recommended initiating a dialogue between NOAA Fisheries and the public to
353 determine how far-reaching and comprehensive these additional considerations should be. This
354 dialogue has been ongoing, and now in this updated SAIP, the need for greater inclusion of
355 ecosystem factors into stock assessments is paramount.

356
357 Further, as the collection and understanding of socioeconomic information has improved, there
358 has been an increase in the ability to account for socioeconomic dynamics in the provision of
359 management advice. Federal fisheries law requires fishery managers to optimize yield for
360 fisheries while achieving an acceptably low risk of overfishing (as mandated in National Standard
361 1 of the MSA). One tool for conducting such investigations is a management strategy evaluation
362 (MSE). NOAA Fisheries has the capability to conduct MSEs that characterize the performance of
363 a science–management–fishery system. However, resources required for MSEs vary
364 substantially depending on the type of analysis being conducted. To date, only a few MSEs have
365 been used to inform fishery management decisions. Of these MSEs, most have addressed
366 ecosystem effects while fewer have examined the economic consequences of addressing
367 uncertainty in assessments. Reinforcing the use of and capacity to conduct MSEs is crucial for
368 helping fishery managers make wise decisions that promote sustainable fisheries and resilient
369 coastal communities.

370
371 **2. Prioritizing stock assessments**—Considering the number of demands on what are projected to
372 be highly limited resources, the wise allocation of resources to conduct stock assessments
373 increasingly requires that assessments are more formally prioritized. NOAA Fisheries' budget for

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374 improving and expanding assessments has grown since the 2001 SAIP, and the number of
375 assessments conducted per year has increased with the budget. However, in recent years the
376 resources available and number of assessments conducted has essentially plateaued. However,
377 there are still increasing demands to assess more stocks and conduct more frequent
378 assessments of some stocks. One of the major gaps identified in the original SAIP was to conduct
379 assessments of all managed stocks; therefore, there is a need to evaluate and prioritize stock
380 assessment efforts during the next decade and beyond. Although advocating for more resources
381 is warranted, the number, scope, extent, and focus of the full national stock assessment
382 enterprise merits more thorough examination to balance resources to best meet assessment
383 needs with limited capacity.

384
385 Additionally, there is tension among the rate at which stock assessments are conducted, the
386 thoroughness of those assessments, and the degree of transparency throughout the process.
387 Independent reviews of stock assessments are necessary to ensure that the best science
388 information is being used to guide management and to gain the trust of the affected public.
389 However, during the past 15 years, the increase in stock assessments has highlighted the need
390 to balance the frequency of more rigorous, independent peer reviews of assessments with a
391 streamlined review processes to ensure timely assessments for management decisions. The
392 mandate to specify annual catch limits for all federally managed stocks suggests a demand for
393 more frequent production of stock assessments. Certain assessments will always require
394 thorough reviews, although streamlined processes should be explored where possible to
395 increase assessment throughput.

396
397 **3. Utilizing innovative methodology and technology**—Most assessment models estimate stock
398 abundance and mortality rates by calibrating the models with observed trends in fishing
399 intensity and indices of relative abundance from fishery-independent sources (e.g., resource
400 surveys). The models tend to perform better when there is a contrast in fishing intensity and
401 abundance over time (i.e., periods of high and low fishing rates and abundance). However, as
402 fishery management has become more effective at controlling fishing rates, the degree of
403 contrast in the observations is diminishing for many stocks. Therefore, another source of
404 calibration data may be required, and one potentially beneficial option may be the use of
405 advanced sampling technologies to create surveys that directly measure absolute stock
406 abundance, not just relative abundance. For instance, the use of acoustic and optical (photo and
407 video) sampling technologies can be used to improve understanding of the degree to which
408 traditional methods are sampling available fish, which simplifies the ability to better scale
409 abundance measurements to actual abundance (rather than relative measures). Even if not
410 estimated for every year in an assessment, these measures of absolute abundance would help
411 anchor a stock assessment at reasonable levels of stock biomass. Additionally, advanced
412 sampling technologies can be used to expand sampling efforts into areas that are not easily
413 sampled with more traditional methods, thereby improving data for assessments.

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415 Beyond sampling technologies, new analytical tools are needed to improve standard assessment
416 models. Some important developments include advances in multispecies models and
417 approaches that facilitate better connections between stock assessments and ecosystem
418 dynamics, as well as improved analytical tools for data-limited stocks. Further, methodological
419 advances could be adopted from other fields, such as infrastructural and analytical
420 considerations associated with big data, risk analyses, financial forecasting, chaotic dynamics,
421 and related quantitative approaches. The exploration of innovative methodologies warrants an
422 evaluation of novel data needs. New approaches may rely on new sources of information, such
423 as enhanced ocean observing systems for more efficient sampling, genomics, isotopes, fatty
424 acids, and other chemical, electronic, or acoustic signatures of fish stocks and their ecosystems
425 (Chapter 8).

426
427 Much of the theory on which the stock assessment enterprise is based has had a solid, multi-
428 decade history of testing. However, to address current issues in fisheries science and
429 management, the proposal, development, and evaluation of theoretical advancements should
430 be pursued. Thus, NOAA Fisheries' NGS A Enterprise must provide the ability, expectation,
431 venues, and time for the agency to play a leading role in expanding and advancing the stock
432 assessment enterprise.

433 **1.5. What is in this SAIP update?**

434 Ultimately, the goals of this SAIP update are to summarize the accomplishments and evolution of NOAA
435 Fisheries' stock assessment enterprise since the release of the original SAIP in 2001. In addition, this
436 update outlines a vision for the next generation of NOAA Fisheries' assessments. With these goals in
437 mind, the three fundamental components of this SAIP include the following:

- 438 • A recap of accomplishments from the original SAIP (Chapter 2)
- 439 • An updated description of the current stock assessment enterprise (Section II)
- 440 • A description of the NGS A Enterprise (Section III)

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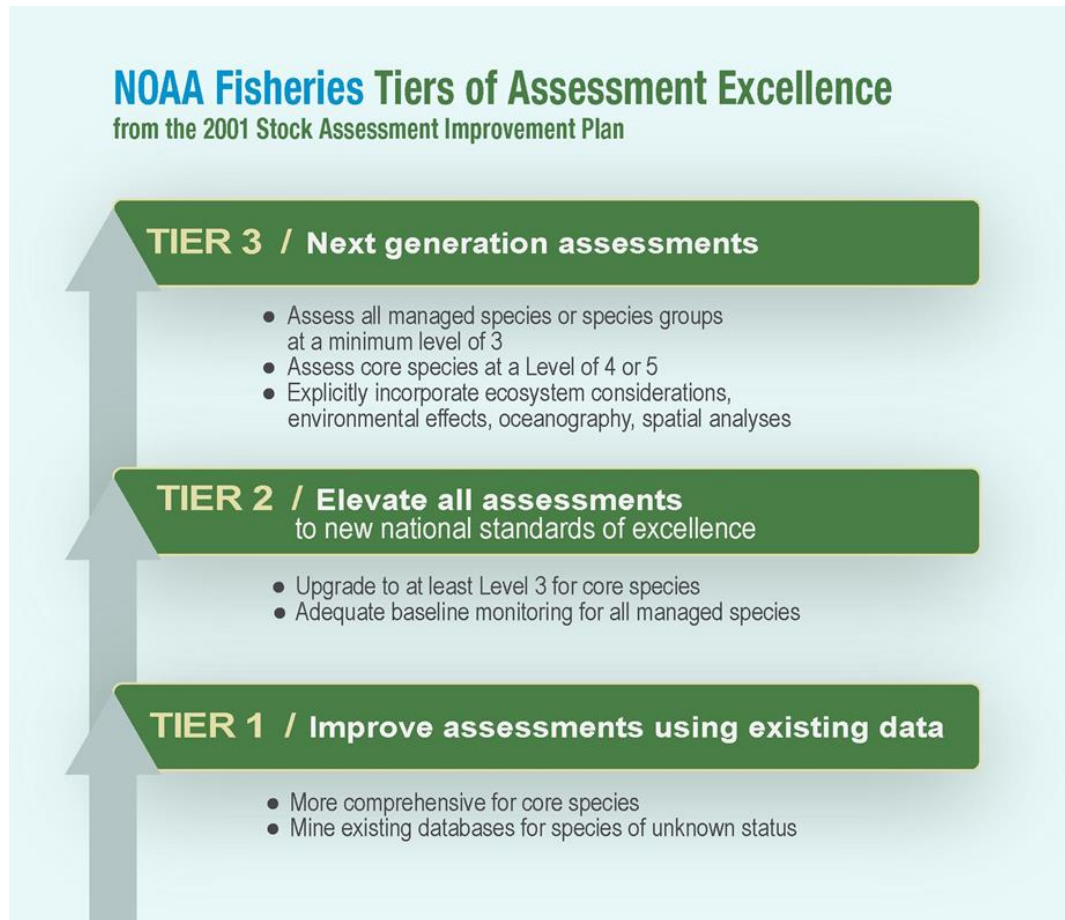
443 **Chapter 2—Accomplishments of NOAA Fisheries' Stock** 444 **Assessment Enterprise**

445 **Chapter highlights:**

- 446 • **An increased quantity and quality of stock assessments in support of strong fishery**
447 **management has greatly reduced overfishing and facilitated rebuilding of many overfished**
448 **stocks.**
- 449 • **Stock assessment program funds have increased in response to the 2001 Stock Assessment**
450 **Improvement Plan (SAIP), expanding the capacity for data collection, monitoring, and**
451 **advancing stock assessment science.**
- 452 • **NOAA Fisheries has a national infrastructure for stock assessment programs.**
- 453 • **More is now known about stock dynamics. The increased attention has highlighted the**
454 **importance of expanding many assessments to consider factors such as changes in the**
455 **ecosystem.**

456 **2.1. The 2001 Stock Assessment Improvement Plan**

457 Generally, U.S. fisheries are recognized around the world as being successfully and sustainably managed
458 (Food and Agriculture Organization (FAO), 2014). This success is due mainly to a scientifically driven
459 management process that relies on the advice from the NOAA Fisheries stock assessment enterprise.
460 Since the release of the SAIP in 2001, the subsequent expansion and advancement of the stock
461 assessment program has drastically improved the quantity and quality of stock assessments being used
462 to support fishery management. The 2001 SAIP defined three Tiers of Assessment Excellence to serve as
463 milestones for NOAA's stock assessment enterprise (Fig. 2.1). The three tiers centered on assessment
464 "levels" that were defined in the 2001 SAIP (not defined or used here), and the 2001 document
465 recommended an initial effort to strive for Tier 2 at a minimum. Meanwhile, the 2001 SAIP also initiated
466 a dialogue on the potential importance of taking more of an ecosystem approach to stock assessments.
467 Although the original strategy was useful for expanding the scope and number of stocks assessed,
468 Section III of this document describes a new strategy that shifts the focus from moving up the tiers for
469 all stocks to setting stock-specific priorities.



470
471 **Fig. 2.1** Summary of the three Tiers of Assessment Excellence, as described in the
472 2001 Stock Assessment Improvement Plan (Mace et al., 2001). **Note:** The “levels”
473 referenced in the figure were defined in the 2001 SAIP, but not defined here to avoid
474 confusion with later chapters.

475 The 2001 SAIP concluded with 10 recommendations that set a strategic direction for NOAA Fisheries’
476 stock assessment enterprise (NMFS, 2001). Those 10 recommendations can be combined into 6 general
477 categories that served as new focus areas for NOAA Fisheries:

- 478 1. Increase overall budget and staff to expand data collection and stock assessment capabilities.
- 479 2. Enhance existing educational and training programs in quantitative fisheries and ecosystem
480 science, fisheries economics, and social sciences to ensure an available pool of new federal
481 fisheries scientists. In addition, develop comprehensive training programs to enhance the
482 scientific skills of current federal scientists.
- 483 3. Improve stock assessments by enhancing partnerships and cooperative programs with other
484 federal and state agencies, private foundations, universities, environmental groups, recreational
485 and commercial fishing organizations, individual fishermen, and other stakeholders with an
486 interest in data collection for stock assessments.

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- 487 4. Increase federal and academic research to advance stock assessment methods.
488 5. Strengthen public awareness and credibility of NOAA Fisheries' stock assessment science by
489 expanding internal and external outreach and communications efforts.
490 6. Create an overall strategic plan that provides comprehensive guidance toward achieving the
491 mission of NOAA Fisheries.
492

493 NOAA Fisheries relied on the strategic direction put forth in the 2001 SAIP to improve the quality and
494 quantity of its stock assessments by supporting advancements in data collection, research, workforce
495 capacity, public messaging, and integrated strategic planning. In addition, a National Research Council
496 report (NRC, 1998) identified gaps in NOAA Fisheries' stock assessment program, with emphasis on data
497 collection, analytical methods, assessment processes, and education and training. To address federal
498 mandates, the 6 focus areas identified from the 2001 SAIP, the 1998 NRC report, and other sources,
499 NOAA Fisheries expanded its efforts toward building a robust and reliable stock assessment enterprise.
500 These advances have created a strong foundation that aids the development and implementation of an
501 NGSA Enterprise.

502 **2.2. Improvements and Impacts of NOAA's Stock Assessments in the 21st** 503 **Century**

504 NOAA Fisheries' stock assessments have directly improved an overall understanding of the state of U.S.
505 fisheries and have enhanced the science needed to manage for sustainability. With knowledge of stock
506 status, fishery managers can make informed decisions to meet their management targets. From 2001 to
507 2014, NOAA Fisheries' capacity for conducting stock assessments increased substantially, with more
508 than 50 assessments conducted in 2001 and almost 190 assessments in 2015, a 217% increase in
509 assessment output (Fig. 2.2). During this period, NOAA Fisheries' assessments provided the information
510 to reduce the number of stocks experiencing overfishing by 30% and reduce the number of overfished
511 stocks by 24% (Fig. 2.3). Thus, NOAA Fisheries' stock assessment enterprise has played a major role in
512 establishing sustainable U.S. fisheries during the past 15 years.

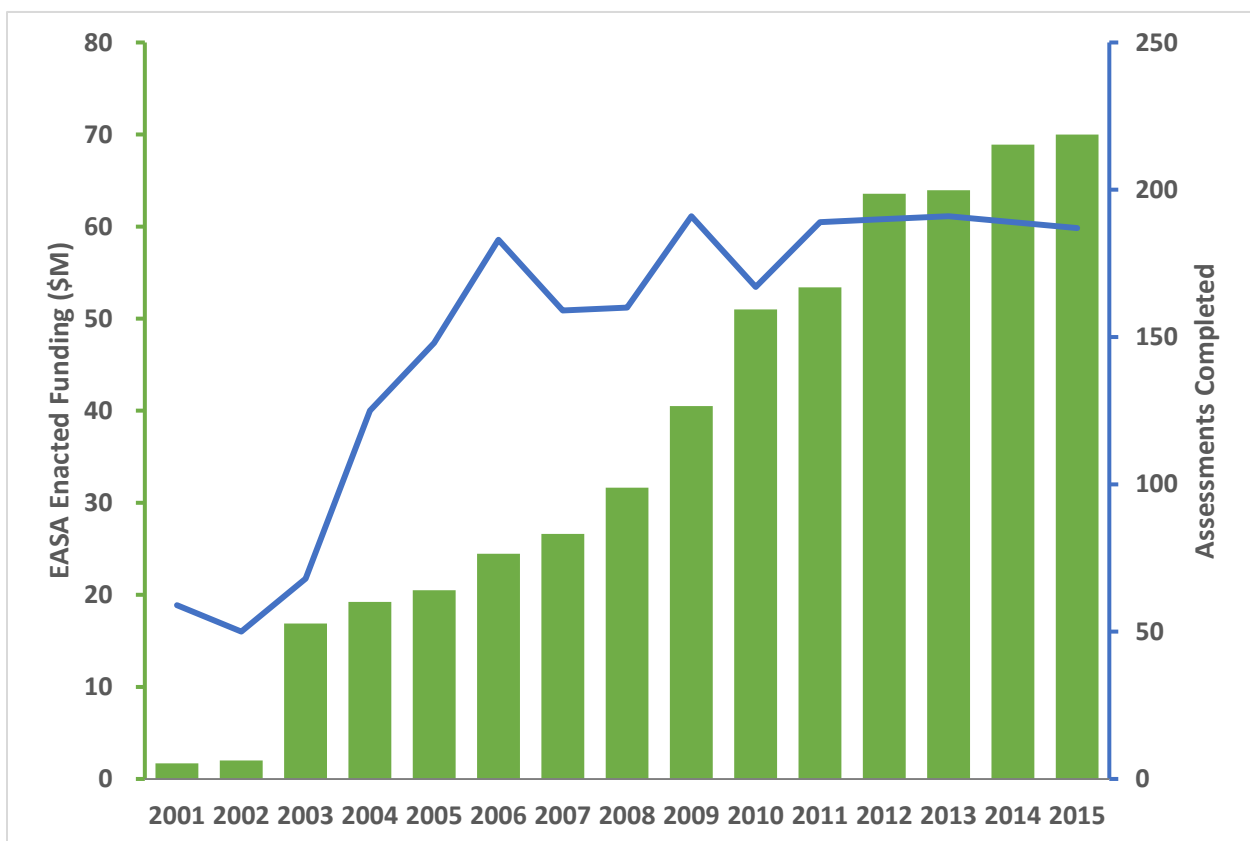
513 In 2005, NOAA Fisheries developed the Fish Stock Sustainability Index (FSSI), a performance measure
514 that tracks the status and assessments of 199 core stocks identified according to regional priorities. Each
515 stock tracked is awarded points if its status is known and if it is not considered overfished or undergoing
516 overfishing. The FSSI combines this information into a single number by totaling the 199 FSSI stocks (the
517 maximum possible value for the FSSI when summed across all categories and all stocks is 1,000).
518 Significant effort has been dedicated toward conducting assessments of FSSI stocks in particular, and
519 toward eliminating overfishing on all stocks. As a result, the FSSI has been steadily increasing since its
520 inception toward its maximum value of 1,000 (Fig. 2.3). This trend is a simple and clear measure that
521 emphasizes the success of a federal fishery management process that manages for sustainability.

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522 The quantity and quality of stock assessments increased because of budget and staffing increases in
523 NOAA Fisheries' core stock assessment budget lines (2001 SAIP, focus area 1). In particular, the 2001
524 SAIP supported growth of the Expand Annual Stock Assessments (EASA) budget line from \$1.7 million in
525 2001 to \$70.0 million in 2015 (Fig. 2.2). This growth in overall capacity enabled a range of investments
526 that improved the national stock assessment program. Broadly, these investments included advances in
527 data collection and monitoring programs, research in advanced sampling technologies and stock
528 assessment methods, workforce capacity, and the stock assessment peer review process. Although the
529 total number of stock assessments conducted each year has stabilized recently, the science behind the
530 assessments has continued to improve.

531

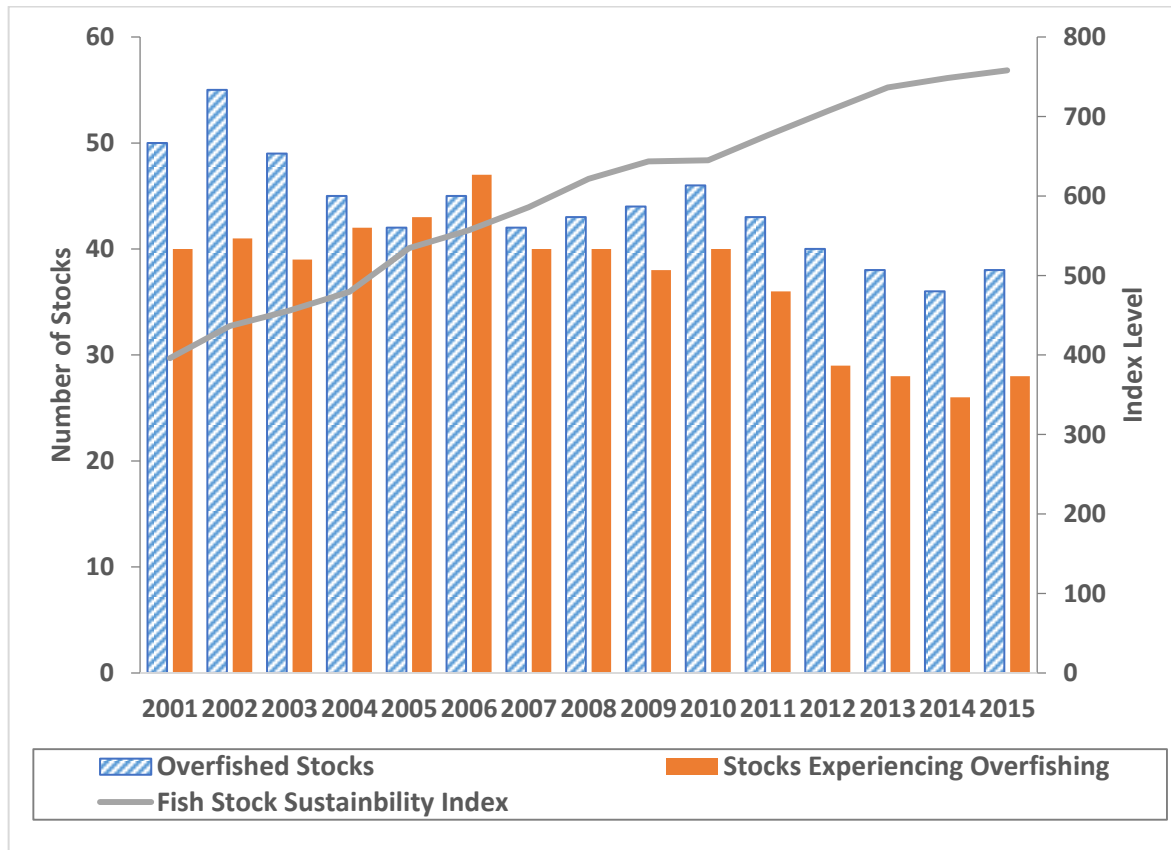


532

533 **Figure 2.2.** Comparison of the total number of stock assessments completed each year for federally
534 managed stocks (right axis, blue line) and growth in the EASA budget line (left axis, green bars), 2001–
535 2015. **Notes:** 1) Tracking of stock assessments before 2005 was less complete; 2) The FSSI was calculated
536 retroactively for 2001–2004; 3) Budget lines other than EASA also contribute to stock assessments.

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538 **Fig. 2.3.** Status of federally managed fish stocks (number of overfished stocks and stocks experiencing
539 overfishing; left axis) over time compared with the NOAA Fisheries' Fish Stock Sustainability Index (right
540 axis), 2001–2015.

541 **2.2.1. Data Collection and Monitoring Capabilities**

542 The data collection and monitoring capabilities of NOAA Fisheries' has expanded substantially.
543 Improvements to catch monitoring programs have resulted in better coordination of data on
544 commercial fishery statistics and better estimation of recreational statistics. The Fisheries Information
545 System (FIS) program was established to coordinate fishery statistics and to facilitate public access to
546 comprehensive, high-quality, and timely fisheries information. Another effort is the Marine Recreational
547 Fisheries Statistics Survey (MRFSS), a long-standing program originating out of the Magnuson Fishery
548 Conservation and Management Act of 1976 that has served as a foundational source of marine
549 recreational fisheries information. With an increasing demand for improved stock assessments, it
550 became clear that improvements to MRFSS were also needed. Therefore, in 2007, MRFSS was revised
551 and renamed the Marine Recreational Information Program (MRIP).

552 Another investment made by NOAA Fisheries was to expand the regional fisheries observer programs
553 that are coordinated under a National Observer Program (NOP). Funding for observers has tripled since

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554 1999, resulting in an increase in the number of fisheries monitored by onboard observers from 17 to 48
555 (including 10 catch share fisheries) and the number of observer days from 55,000 to 80,210. This
556 increase in fishery-dependent data collection has improved the accuracy of NOAA Fisheries' stock
557 assessments, improved the characterization of fishery bycatch, and resulted in better overall fishery
558 management. However, for many fisheries observer coverage remains low. In these cases, without
559 further expansion, stock assessments will be challenging and may provide highly uncertain results.

560 In an effort to expand and improve fishery-dependent sampling, NOAA Fisheries has been evaluating
561 and incorporating electronic monitoring and electronic reporting (EM/ER). Electronic reporting relies on
562 digital data collection interfaces to allow reporting by fishermen, whereas electronic monitoring relies
563 on video cameras to remotely observe fishery operations. These technologies can be used in a variety of
564 fishery monitoring programs, and in fact strategic plans have been developed in each region to identify,
565 evaluate, and prioritize implementation of these technologies⁵.

566 In addition to expanding fishery-dependent data collection, NOAA Fisheries also invested in developing
567 and/or improving scientific (fishery-independent) surveys. For instance, the West Coast Groundfish
568 Bottom Trawl Survey expanded in spatial coverage, improving monitoring of approximately 90
569 commercially fished stocks along the coasts of Washington, Oregon, and California. Also, in
570 collaboration with the South Carolina Department of Natural Resources' Marine Resource Monitoring
571 and Assessment Program (MARMAP), NOAA Fisheries established the Southeast Fishery Independent
572 Survey (SEFIS) program, which uses trap and video surveys to monitor reef fish in South Atlantic waters.
573 This survey increased the accuracy, precision, and usefulness of data available for assessments and
574 facilitated a greater than two-fold increase in the size of annual survey samples. Atlantic sea scallops
575 also benefitted from improved survey capability by creating a habitat camera mapping system (HabCam)
576 to augment the dragged dredge survey. This expansion significantly increased the number of scallops
577 that could be observed by the survey, resulting in more accurate estimates of scallop abundance and
578 habitat. Another example of expanded capacity is the Northeast Area Monitoring and Assessment
579 Program (NEAMAP), a new survey that complements the NOAA Fisheries' bottom trawl survey by
580 sampling shallower inshore habitat.

581 Although the development of new surveys has expanded total data collection capabilities, the overall
582 cost of data collection has continued to increase. Scientific resource surveys are further limited by the
583 availability of NOAA research vessels and funding to support chartering University–National
584 Oceanographic Laboratory System (UNOLS) vessels and commercial industry vessels. Therefore, when
585 considering the capacity required to provide management advice on all stocks under NOAA Fisheries'
586 purview, there is a need to sustain NOAA's fleet infrastructure. Also required is improved survey
587 coverage with integrated ocean observation systems. This coordination will help address information
588 gaps and spatial uncertainties in stock assessments in a changing environment.

⁵ <http://www.st.nmfs.noaa.gov/advanced-technology/electronic-monitoring/index>

**[Implementing a Next Generation Stock Assessment Enterprise:
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DISCUSSION PURPOSES**589 2.2.2. Education and Training of Stock Assessment Scientists**

590 The overall demand for more and improved stock assessments resulted in the realization that there
591 were not enough stock assessment scientists in NOAA Fisheries to meet the growing assessment
592 demand. Furthermore, as indicated by focus area 2 of the 2001 SAIP and NRC (1998), existing university
593 programs were not capable of supplying enough stock assessment scientists to meet the expanding
594 need. This awareness prompted investments in each fisheries science center to support educational
595 efforts and connections among NOAA Fisheries and academia across the regions. One program that
596 resulted from this initial investment is the West Coast Groundfish Stock Assessment Training and
597 Mentoring program at the University of Washington, which is now considered one of the premiere
598 institutions for training stock assessment scientists.. Another example is the Research Training and
599 Recruitment (RTR) program in the southeast region. This program was designed to create a pipeline to
600 introduce undergraduate students to stock assessment science, train graduate students, and recruit
601 stock assessment scientists to NOAA Fisheries. Unfortunately, the RTR program has been discontinued
602 due to budget cuts, but given the value and need for this pipeline, restarting the program could prove
603 beneficial.

604 Following the 2001 SAIP, NOAA Fisheries and NOAA Sea Grant expanded their joint fellowship programs
605 in population dynamics and marine resource economics. Initially supporting approximately 3 fellows per
606 year, the fellowship program grew to fund 6 fellows on average with a maximum of 12 awarded in 1
607 year. Since the program's inception, more than 40% of fellows have gone on to work for NOAA Fisheries.
608 Furthermore, to build capacity in ecosystem modeling, the NOAA Fisheries–Sea Grant fellowship
609 program recently expanded to include quantitative ecology in general. NOAA also supports numerous
610 other academic partnerships to facilitate education and training in mission-critical areas, including the
611 Quantitative Ecology and Socioeconomics Training Program (QUEST), Cooperative Ecosystem Studies
612 Units (CESUs), NOAA's 16 Cooperative Institutes (CIs), the Living Marine Resources Cooperative Science
613 Center (LMRCSC), and many other programs coordinated by NOAA's Office of Education. Overall, the
614 various educational programs have led to significant increases in the number of scientists with the
615 quantitative skills necessary to provide scientific advice to fishery managers.

616 Despite initial investments in education and training, the need for qualified candidates has continued to
617 exceed the number available. The gap in available stock assessment scientists was again illustrated in a
618 2008 report from the Departments of Commerce and Education, "The Shortage in the Number of
619 Individuals with Post-Baccalaureate Degrees in Subjects Related to Fishery Science" (U.S. Dept. of
620 Commerce and U.S. Dept. of Education, 2008). In recognition of the ongoing shortage, NOAA Fisheries
621 continues to expand its QUEST program to increase the number of academic faculty in these disciplines.
622 The QUEST program now provides dedicated support to seven faculty and additional support to three
623 rotating faculty. As NOAA-supported faculties continue to train individuals, the identified gap in qualified
624 candidates will continue to decrease, thereby addressing SAIP focus area 2.

625 2.2.3. Cooperative Research

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627 To comply with focus area 3, cooperative research programs were established at national and regional
628 levels to increase data collection capabilities. These programs also fostered communication,
629 coordination, and mutual respect among NOAA Fisheries and its stakeholders. In addition, cooperative
630 research has been shown to improve associations among fishers, scientists, and managers (Hartley and
631 Robinson, 2006; Johnson and van Densen, 2007; Johnson 2010) by increasing opportunities for
632 successful and sustainable management. Investments in cooperative research have also facilitated the
633 development of innovative approaches to collecting, processing, and reporting information on stocks
634 that were previously unavailable. A number of fishery-independent surveys previously conducted
635 exclusively on NOAA ships were complemented or replaced by surveys from chartered industry vessels.
636 For instance, NOAA Fisheries' Atlantic Surfclam–Ocean Quahog Survey began chartering an industry
637 vessel in 2012. The NOAA-supported Northeast Area Monitoring and Assessment Program (NEAMAP) is
638 also conducted by an industry vessel and augments existing surveys conducted on NOAA ships in the
639 Northwest Atlantic. Additionally, the main groundfish trawl surveys conducted along the U.S. West
640 Coast and Alaska are implemented through industry charters. NOAA Fisheries continues to expand
641 collaborations with industry as well as other partner agencies (e.g., the previously mentioned SEFIS
642 survey) to support sustainable fisheries management that engages stakeholders at all levels.

643 2.2.4. Advancements in Fisheries Science

644 NOAA Fisheries continues to support advancements in fisheries science (SAIP focus area 4) through the
645 creation of several national working groups that focus on specific mission-critical topics. These programs
646 are coordinated at NOAA Fisheries headquarters by the Office of Science and Technology, and many of
647 these working groups manage internal funding to support regional projects that address high-priority
648 issues, including improvements for stock assessments. In addition to supporting research, the funding
649 opportunities foster collaboration and technology distribution throughout NOAA. Although the projects
650 are led by NOAA scientists, collaboration with external groups is encouraged and results in partnerships
651 with academics; commercial and recreational fishers; state, interstate, national, and international
652 agencies; and non-governmental organizations. These partnerships have provided substantial
653 improvements to NOAA Fisheries' stock assessment and monitoring capabilities.

654 Collectively in fiscal year 2015, almost \$14 million in funding was distributed across programs to support
655 innovative research in stock assessments and other aspects of fisheries science. Over time, these
656 investments have resulted in major advancements, resulting in improvements in the science used to
657 support fisheries management. For example, the Assessment Methods Working Group provides national
658 oversight to facilitate direct improvements in the stock assessment enterprise. This group oversees the
659 NOAA Fisheries Toolbox⁶, which provides a suite of standardized interfaces for implementing stock
660 assessment analyses. Several Toolbox techniques were developed or improved through research

⁶ <http://nft.nefsc.noaa.gov/>

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661 projects funded by working groups and are now publicly available and applied in operational stock
662 assessments. The Assessment Methods Working Group also facilitates NOAA's annual support of the AD
663 Model Builder Project⁷. The ongoing support of this project has allowed open access to AD Model
664 Builder, a software package that serves as the basis for a large percentage of NOAA Fisheries' stock
665 assessments as well as stock assessments around the world. Other working groups focus on various
666 aspects of fisheries science, including the incorporation of ecosystem and habitat information in the
667 assessment process; improvements to the efficiency of data collection and survey operations with
668 innovative technologies; and enhancements to cooperative research and international collaborations.

669 2.2.5. Peer Review Approaches

670 Notable improvements to the fishery management process have resulted from establishing rigorous
671 peer review methods for stock assessments. Although various review processes were in place before
672 2001, substantial investments in stock assessment quality assurance have been made since the 2001
673 SAIP. In part, these investments were driven by legislative mandates to ensure that the best scientific
674 information available was provided to fishery managers. Investments were also made to increase the
675 credibility of NOAA Fisheries science products among stakeholders (SAIP focus area 5), and increase
676 transparency and opportunities for public engagement in the fishery management process. A national
677 peer review process, called the Center for Independent Experts (CIE), was established to provide a
678 rigorous independent review of emerging scientific methods and influential science products. Various
679 regional processes were either created or improved since 2001, including the Southeast Data,
680 Assessment, and Review (SEDAR); Stock Assessment Workshop/Stock Assessment Review Committee
681 (SAW/SARC) in the Northeast; Stock Assessment Review (STAR) in the Northwest; Western Pacific Stock
682 Assessment Review (WPSAR); and the Plan Team process in the North Pacific. These regional processes
683 all rely on the CIE when a higher degree of independence is required, particularly in the selection
684 process of highly qualified reviewers. Overall, the level of quality assurance for stock assessments has
685 vastly improved since the 2001 SAIP, resulting in a thorough and transparent fishery management
686 process that uses high-quality advice as the basis for management decisions. Approaches to stock
687 assessment quality assurance and peer reviews are covered in greater detail in Chapter 6.

688 2.2.6. Communication and Outreach

689 In the context of SAIP focus area 5, NOAA Fisheries has made a considerable effort to improve its
690 communication and public outreach about stock assessments. Access to stock assessment reports has
691 vastly improved, and the reports themselves have become comprehensive descriptions of the entire
692 assessment. Although some of these reports can be difficult to understand, they offer a high degree of
693 transparency. To improve access to assessment information, many reports now include upfront
694 summaries of the primary results. NOAA Fisheries is continually improving its outreach and engagement
695 strategy to convey information and maintain ongoing dialogues with a variety of audiences.

⁷ <http://www.admb-project.org/>

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696 Improvements have aimed to provide better information and engagement with stakeholders on the
697 national stock assessment program and its performance, facilitate access to data used in stock
698 assessments, improve communication within the national stock assessment program, and promote
699 transparency in the assessment process and the resulting scientific advice. The Marine Resource
700 Education Program (MREP), which is funded through a grant to the Gulf of Maine Research Institute, is a
701 successful program designed to provide fishery stakeholders with an inside look at fisheries science and
702 the management process.

703 Many new products have been developed to convey fishery stock assessment and management
704 information to a variety of audiences. For instance, FishWatch⁸ is a website designed by NOAA Fisheries
705 to provide scientific information to consumers to encourage sustainable seafood choices. The Species
706 Information System is a national database that stores stock assessment and fishery management
707 information and offers access to summaries and results from assessments through a public portal⁹.
708 NOAA Fisheries also generates several regular reports, such as annual reports to Congress on the status
709 of stocks,¹⁰ national stock assessment summary reports,¹¹ and annual summaries of commercial fishing
710 statistics and economic impacts through Fisheries of the United States¹² and Fisheries Economics of the
711 United States,¹³ respectively. Completing these efforts provide broad access to the science that supports
712 federal fisheries management.

713 Additionally, NOAA Fisheries welcomes opportunities to engage on assessment-related topics with
714 various interested parties. These stakeholders include non-governmental organizations; NOAA and
715 Department of Commerce leadership; Office of Management and Budget staff; Congressional
716 representatives; and regional councils, both individually and nationally, through venues such as New
717 Council Member Training, and the Council Coordination Committee and its Scientific Coordination
718 Subcommittee. The incremental increases in appropriated funds, along with an improved public
719 perception of NOAA Fisheries, suggest that overall expanded outreach and communication efforts have
720 been effective in some areas. Nevertheless, communication and outreach efforts need to be expanded
721 and improved. To achieve that goal, NOAA Fisheries will continue to seek funding and opportunities to
722 improve strategies for communicating to and engaging with stakeholders on the stock assessment
723 process.

724 **2.2.7. Strategic Planning**

725 Focus area 6 from the 2001 SAIP has been addressed through significant expansion of the extent to
726 which NOAA Fisheries conducts and coordinates strategic planning efforts. The SAIP itself represents

⁸ <http://www.fishwatch.gov/about/index.htm>

⁹ <https://www.st.nmfs.noaa.gov/sisPortal/sisPortalMain.jsp>

¹⁰ http://www.nmfs.noaa.gov/sfa/fisheries_eco/status_of_fisheries/

¹¹ <http://www.st.nmfs.noaa.gov/stock-assessment/FishStockReports/index>

¹² <http://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus13/index>

¹³ http://www.st.nmfs.noaa.gov/economics/publications/feus/fisheries_economics_2012

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727 one of many focused efforts that advance or report on a fundamental aspect of NOAA Fisheries'
728 scientific portfolio. As portrayed in Fig. 1.1, other focused strategic efforts include the Marine Fisheries
729 Habitat Assessment Improvement Plan (NMFS, 2010); the National Climate Science Strategy (Link et al.,
730 2015); strategic documents related to assessing protected marine species (NMFS, 2004 and 2013); and
731 annual peer reviews of NOAA Fisheries' scientific programs.¹⁴ Additionally, a number of regular reports
732 provide updates and opportunities for strategic evaluation of specific programs. For instance, the
733 National Bycatch Report¹⁵ provides a species-level accounting of bycatch by U.S. fisheries, and the
734 Fisheries Information System Annual Report¹⁶ describes the status of NOAA Fisheries data collection
735 programs. Together, the various plans and reports are combined under the broad category of
736 Ecosystem-Based Fishery Management (EBFM). Finally, the focused strategic planning efforts are
737 synthesized and funneled through a number of national efforts. Several of these larger efforts include
738 strategic plans and Annual Guidance Memoranda produced at multiple levels (office, agency, and
739 department) and are used to guide agency and program operations.

740 **2.3. Summary of the 2001 SAIP**

741 The 2001 SAIP has been an invaluable strategic planning document that facilitated vast improvements in
742 NOAA fisheries' stock assessment enterprise. Resulting increases in funds for stock assessment science
743 allowed NOAA Fisheries to improve many stock assessments and address the six focus areas of the 2001
744 SAIP to varying degrees. As a result, the stock assessment programs and staff employed by NOAA
745 Fisheries provide world-class scientific advice to resource managers. Despite the need for continuing
746 advancements in the stock assessment enterprise (culminating in this new SAIP), it should not be
747 overlooked that the U.S. fishery management system has been highly successful in achieving resource
748 sustainability and community resiliency.

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¹⁴ <http://www.st.nmfs.noaa.gov/science-program-review/index>

¹⁵ <https://www.st.nmfs.noaa.gov/Assets/Observer-Program/bycatch-report-update-2/NBR%20First%20Edition%20Update%202015%20Final.pdf>

¹⁶ <http://www.st.nmfs.noaa.gov/Assets/FIS/documents/FIS%20Annual%20Report.pdf>

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SECTION II. THE CURRENT STATE OF NOAA FISHERIES' STOCK ASSESSMENT ENTERPRISE

764 **Chapter 3. Overview of NOAA Fisheries' National Stock** 765 **Assessment Programs**

766 **Chapter highlights:**

- 767 • **NOAA Fisheries' stock assessments provide scientific advice for federal fisheries managed by**
768 **regional fishery management councils and other fisheries managed by state, interstate, and**
769 **international organizations.**
- 770 • **Regional assessment programs face diverse issues due to the nature of regional fisheries,**
771 **species, ecosystems, and governances.**
- 772 • **Despite regional differences, patterns have emerged in the methods used to conduct**
773 **assessments for federally managed fisheries.**

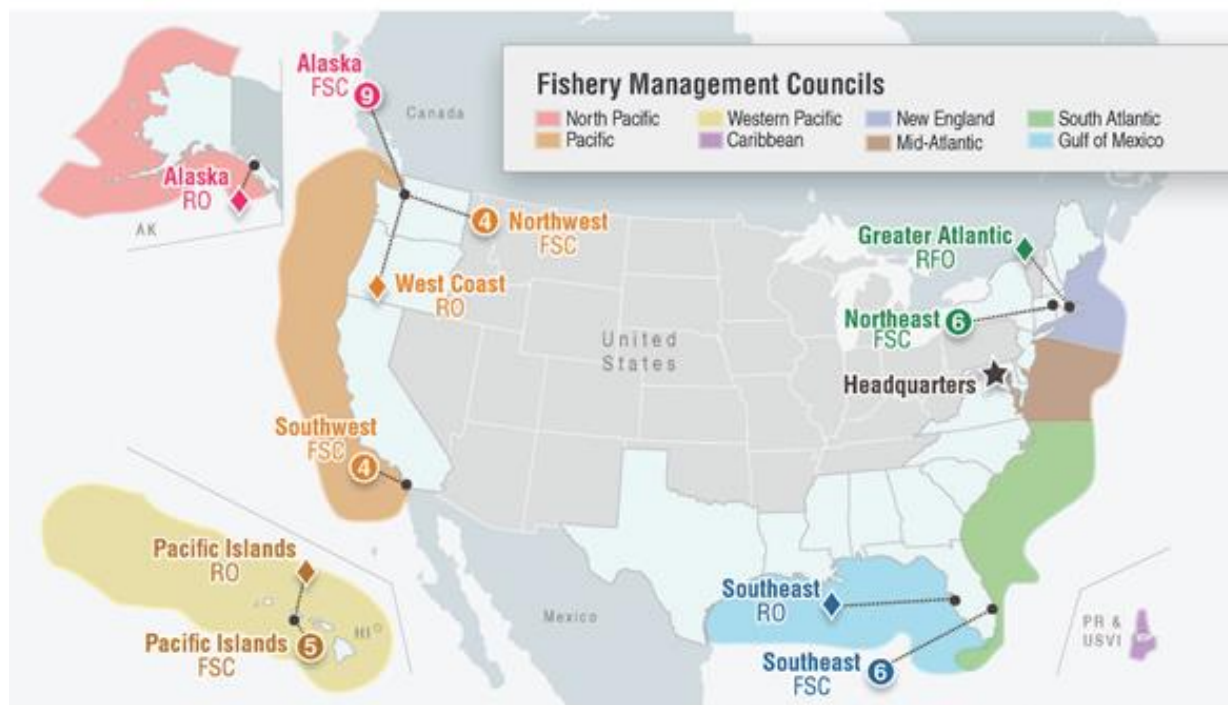
774 NOAA Fisheries' stock assessment programs provide global leadership in stock assessment science. The
775 stock assessment enterprise is a combined system that operates through regional science–management
776 partnerships and coordination, and national initiatives from headquarters offices. As described in
777 Chapter 1, NOAA Fisheries is directed by federal law to provide scientific advice to eight Regional Fishery
778 Management Councils and NOAA Fisheries' Atlantic Highly Migratory Species Division for more than 473
779 federally managed fish stocks, some of which are stock complexes that contain many individual stocks.
780 NOAA Fisheries' science centers coordinate with their respective regional offices to provide scientific
781 advice to federal fishery managers. Further, NOAA creates partnerships with state, interstate, and
782 international fishery management organizations, and NOAA scientists work collaboratively with these
783 groups to conduct or assist with assessments of stocks that do not fall under federal jurisdiction. Figure
784 3.1 shows the organization and responsibilities of NOAA Fisheries' stock assessment enterprise.

785 The types of stocks managed vary across regions. There are notable differences in the types of fisheries;
786 stakeholders affected; jurisdictions and their respective assessment processes supported (see Chapter
787 6); and the natural ecosystems that support the productivity of fisheries. For example, many of the
788 longest-standing and most lucrative commercial fisheries target groundfish and shellfish in temperate
789 and cold waters (e.g., cod, pollock, scallops, crabs, and so on). In addition, several science centers
790 conduct assessments of the nation's most economically and ecologically valuable groundfish and
791 shellfish (especially the Alaska and Northeast Science Centers). Despite these differences, common
792 characteristics among regions can be used to maximum advantage when designing strategies for NOAA's
793 stock assessment programs.

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NOAA Fisheries Science to Support Fisheries Management



□ The Western Pacific FMC manages additional regions not depicted here.

NOAA Fisheries Organization

Regions	Regional Offices (RO)	Fishery Science Centers (FSC) # Number of Fishery Management and/or Advisory Organizations supported by Science Center	Labs / Field Stations / Facilities
Alaska	♦ Alaska RO Juneau, AK	9 Alaska FSC Seattle, WA	AK • Anchorage • Baranof Island • Dutch Harbor • Juneau • Kodiak • Pribilof Islands WA • Seattle OR • Newport
West Coast	♦ West Coast RO Seattle, WA	5 Northwest FSC Seattle, WA	WA • Manchester • Pasco • Seattle • Mukiteo
		4 Southwest FSC La Jolla, CA	CA • Arcata • Granite Canyon • La Jolla • Pacific Grove • Piedras • Santa Cruz Antarctica • King George Isl. • Livingston
Pacific Islands	♦ Pacific Islands RO Honolulu, HI	5 Pacific Islands FSC Honolulu, HI	HI • Honolulu U.S. Territories • American Samoa • Northern Mariana Islands • Guam
Greater Atlantic	♦ Greater Atlantic RFO* Gloucester, MA * Regional Fisheries Office	6 Northeast FSC Woods Hole, MA	ME • Orono MA • Woods Hole RI • Narragansett NJ • Highlands CT • Milford
Southeast	♦ Southeast RO St. Petersburg, FL	6 Southeast FSC Miami, FL	NC • Beaufort FL • Panama City • Miami MS • Pascagoula • Stennis LA • Lafayette TX • Galveston

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Fishery Management & Advisory Organizations

* Advisory (not management) organization.

Organization	Supported by NOAA Fisheries Science Center(s)	Managed Ecosystem	Managed Stocks
ADFG	Alaska Dept. of Fish & Game	Gulf of Alaska & Bering Sea - Sub-Arctic	Numerous Alaska coast stocks
CCAMLR	Commission for the Conservation of Antarctic Living Marine Resources	Antarctic	Toothfishes, Icefish, & Krill
CCSBT	Commission for the Conservation of Southern Bluefin Tuna	Southern Hemisphere Oceans	Southern bluefin tuna
IATTC	Inter-American Tropical Tuna Commission	Eastern Pacific Ocean - Sub-Arctic to Tropical	Tunas, Billfish, Sharks
IPHC	Int'l Pacific Halibut Commission	Pacific Coast - Temperate to Sub-Arctic	Pacific halibut
ISCTTS*	Int'l Scientific Committee for Tuna & Tuna-Like Species in the Northern Pacific Ocean	Northern Pacific Ocean	Tunas, Billfish, Sharks
NPFC	Northern Pacific FC	Northern Pacific Ocean - Sub-Arctic to Sub-Tropical	Numerous groundfish, Pelagics, Invertebrates
NPFMC	Northern Pacific FMC	Gulf of Alaska & Bering Sea - Sub-Arctic	Groundfish, Salmon, Crab, Scallops
PFMC	Pacific FMC	California Current	Salmon, Groundfish, pelagics, HMS
PSC*	Pacific Salmon Commission	Pacific Coast, Bays, Rivers, & Estuaries	Pacific salmon stocks
PSMFC*	Pacific States Marine FC	Pacific Coast, Bays, Rivers, & Estuaries	Numerous Pacific coast stocks
PWS	Pacific Whiting Treaty	California Current - Temperate	Pacific whiting (Pacific hake)
SPRFMO	Southern Pacific Regional FMO	Southern Pacific Ocean	Jack mackerel, Chub mackerel, Squids
WCPFC	Western & Central Pacific FC	Western & Central Pacific Ocean	Tunas, Billfish, Sharks
WPFMC	Western Pacific FMC	Insular Pacific Hawaii - Tropical	Bottomfish, Reef fishes, HMS, Invertebrates
ASMFC	Atlantic States Marine FC	U.S. East Coast, Bays, & Estuaries	Coastal groundfish, Pelagics, Invertebrates, Anadromous fishes
CFMC	Caribbean FMC	Caribbean Sea - Tropical	Reef fishes, Invertebrates, Migratory pelagics
GOMFMC	Gulf of Mexico FMC	Gulf of Mexico - Tropical/Subtropical	Reef fishes, Invertebrates, Migratory pelagics
GSMFC	Gulf States Marine FC	Coastal Gulf of Mexico - Tropical/Subtropical	Gulf menhaden, Blue crab, Many commercial/rec. stocks
ICCAT	Int'l Commission for the Conservation of Atlantic Tunas	Atlantic Ocean - Sub-Arctic to Tropical	Tunas, Billfish, Sharks
MAFMC	Mid-Atlantic FMC	Northeast U.S. Continental Shelf (Mid-Atlantic Bight)	Groundfish, Clams & quahogs, Pelagic fishes & squids
NAFO	Northwest Atlantic FO	Northwest Atlantic Ocean	Groundfish, Squid, Shrimp
NASCO	North Atlantic Salmon Conservation Org.	Northeast U.S. Continental Shelf (Georges Bank) - Temperate Climate	Georges Bank groundfish stocks shared by U.S. & Canada
NEFMC	New England FMC	Northeast U.S. Continental Shelf (New England)	New England groundfish, Sea scallops, Red crab, Atlantic herring, Atlantic salmon
SAFMC	South Atlantic FMC	Southeast U.S. Continental Shelf	Reef fishes, Invertebrates, Migratory pelagics
TMGC	Transboundary Mgmt. Guidance Committee	Northeast U.S. Continental Shelf (Georges Bank) - Temperate Climate	Georges Bank groundfish stocks shared by U.S. & Canada

Science Centers

- Alaska
- Northeast
- Northwest
- Southeast
- Southwest
- Pacific Islands

Geography

- AK - Alaska | CA - California | CT - Connecticut
- FL - Florida | HI - Hawaii | LA - Louisiana
- MA - Massachusetts | ME - Maine | MS - Mississippi
- NC - North Carolina | NJ - New Jersey | NY - New York
- OR - Oregon | PR - Puerto Rico | RI - Rhode Island
- TX - Texas | U.S. - United States
- USVI - U.S. Virgin Islands | WA - Washington

Shorthand / Acronyms

- Dept. Department
- FC Fisheries Commission
- FMC Fisheries Management Council
- FMO Fisheries Management Organization
- FO Fisheries Organization
- HMS Highly Migratory Species
- Int'l International
- Is. Islands
- Mgmt. Management
- Org. Organization
- Rec. Recreational (fisheries)

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796 Figure 3.1. Summary of NOAA Fisheries' scientific programs that support fisheries management,
797 including the location of regional offices, science centers and their associated field offices, and the
798 various management jurisdictions supported.

799 In many cases, funding has supported decades-long survey monitoring programs of groundfish stocks
800 and their fisheries, thus providing large quantities of information to support data-intensive and
801 sophisticated approaches for conducting stock assessments. In contrast, many tropical-reef-associated
802 fishes (e.g., snappers and groupers) that fall under federal jurisdiction have very limited data on which
803 assessments and management decisions can be based; however, recreational fisheries for some of these
804 stocks are among the most important fisheries in the country. The Southeast and Pacific Islands centers
805 are responsible for many of the reef-associated stocks. Some of these stocks are subject to international
806 harvests of unknown scale, further contributing to assessment and management challenges. Situations
807 where there is little data for a fish stock may be due to limited ship time and resources, diverse species
808 and life history patterns, and complex habitats that are not conducive to data collection. These data
809 gaps substantially limit the types of analyses that can be conducted as well as the degree of certainty
810 surrounding the resulting scientific advice. Although there is little data for some groundfish stocks and
811 sufficient data for some tropical species, these species groups provide general "bookends": Most of the
812 remaining categories of federally managed stocks fall along the range of data availability between these
813 extremes.

814 Coastal mid-water (pelagic) stocks (e.g., sardines, hakes, mackerels, and squids) are assessed in nearly all
815 centers, and several centers conduct assessments of anadromous fish that migrate between marine and
816 freshwater systems, such as Pacific and Atlantic salmon. Stocks within these species groups vary greatly
817 regarding the amount of data available for assessments. NOAA Fisheries also conducts assessments of
818 highly migratory species (HMS; e.g., tunas, billfish, and sharks) in collaboration with international
819 partners, although NOAA Fisheries manages U.S. stocks of Atlantic HMS and contributes to management
820 of HMS in other oceans. Generally, assessments of these stocks rely heavily on fishery-dependent data,
821 because scientific surveys that cover the distribution of wide-ranging species are cost-prohibitive.

822 Beyond species groups, other patterns emerge across regions. For instance, commercial catch may
823 represent a high proportion of landings in some regions (e.g., Alaska, Pacific), whereas recreational
824 interests dominate other regions (e.g., Southeast). The stakeholder group dynamics and complexity vary
825 by region, with numerous state partners and diverse fishing interests along the east coast and generally
826 fewer stakeholder groups along the west coast. In addition, each regional ecosystem has unique
827 characteristics, although national similarities emerge in this area. For instance, cold-water and
828 temperate ecosystems are experiencing a higher degree of warming due to climate change, potentially
829 affecting the distribution and productivity of many valuable stocks (Nye et al., 2009; Pinsky et al., 2013).
830 Warming in tropical regions has been less severe, but coral reef systems can be highly sensitive to small
831 temperature fluctuations and ocean acidification, and localized effects on biodiversity have been
832 observed. Although each stock faces many unique challenges within an assessment context, these
833 regional similarities indicate that numerous issues rise to the national level. Consequently, a main

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834 objective of this document is to provide national guidance and potential solutions that may benefit
835 assessments of many stocks across regions.

836 General issues facing the NOAA Fisheries stock assessment enterprise include the following:

- 837 • Centers increasingly require a comprehensive prioritization process to guide assessments and
838 address information gaps. Despite growth in stock assessment capacity, the demand for stock
839 assessments and scientific advice to guide fisheries management exceeds the capacity to meet
840 that demand.
- 841 • After samples and data are collected, additional work is needed before they can be incorporated
842 into assessments. These tasks include quality assurance, processing, and formatting to comply
843 with assessment model requirements. These steps constitute significant bottlenecks that limit
844 assessment throughput in many regions, especially where the input data for the assessment
845 models must be compiled from diverse data sources.
- 846 • Historical stock depletions in U.S. fisheries resulted in many stocks being listed as overfished.
847 Rebuilding an overfished stock takes time, and while a stock is on a rebuilding plan, frequent
848 assessments are required. As a result, past actions have created a bottleneck in the assessment
849 process, increasing the current demand for stock assessments.
- 850 • For certain stocks, the assessment and management process does not meet expectations. For
851 instance, an increase in stock biomass might not be observed despite harvest reductions, or an
852 assessment model may exhibit instability (Chapter 5). These issues can impact the credibility of
853 the science, stakeholder engagement, and overall ability to manage for sustainable fisheries.
- 854 • NOAA Fisheries is responsible for providing scientific advice on numerous stocks for which there
855 is little data. Although annual catch limits are required for all federally managed stocks, a high
856 level of uncertainty exists around estimates of sustainable harvest levels when catches
857 themselves are unknown.
- 858 • Due to their quantitative skills and familiarity with managed stocks, many NOAA assessment
859 scientists are tasked with analyses to support evaluation of management alternatives, resulting
860 in less time to devote to assessment research.
- 861 • The historical investment in fisheries and fishery-independent data has generally been lowest in
862 regions with the highest diversity of fisheries and species. In many cases, the primary data
863 collection programs began after certain target species were already overfished. Data from these
864 programs are therefore highly uncertain and often contentious, and extensive investigations are
865 often requested. As a result, more time, staff, and resources are required to complete
866 assessments in these regions.

867 NOAA Fisheries; stock assessment enterprise successfully supports federal mandates and provides the
868 scientific basis on which most U.S. fisheries have achieved sustainability. This science has helped support
869 millions of jobs and generate hundreds of billions of dollars in economic activity annually. Although
870 NOAA's current stock assessment enterprise functions well, challenges highlighted in this and

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871 subsequent chapters warrant attention to further improve long-term sustainability and opportunity for
872 U.S. fisheries.

873 To that end, the remaining chapters in this section identify the primary issues facing NOAA Fisheries'
874 stock assessment enterprise. These chapters describe the current status and challenges associated with
875 the following specific aspects of the stock assessment process:

- 876 • Data collection (Chapter 4)
- 877 • Assessment modeling (Chapter 5)
- 878 • Quality assurance (Chapter 6)

879 This comprehensive evaluation is necessary for determining the highest priority issues.

880 ***References***

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886 **Chapter 4. Data collection to support stock assessments**

887

888 **Chapter highlights:**

- 889 • Data collection for stock assessments is conducted in partnership with numerous management
890 organizations, academic institutions, and stakeholders.
- 891 • Scientific surveys (also called “fishery-independent” surveys) use data collection methods that
892 are tailored to the habitats and biological features of the species.
- 893 • Data collected in cooperation with commercial, recreational, and other fisheries (called fishery-
894 dependent data) are used to monitor catch, effort, incidental catch (called “bycatch”), numbers
895 of fish returned to the sea either dead or alive (called “discards”), and other stock and fishery
896 dynamics.
- 897 • Fundamental data for stock assessments include abundance, biology, and catch (explained later
898 in this chapter).
- 899 • Assessments can also be informed and improved using other data sources, such as ecosystem
900 and socioeconomic data.

901

902 **4.1. Data types and collection methods**

903

904 NOAA Fisheries' stock assessments are conducted using a wide variety of data that are collected by
905 numerous sources, including federal and state agencies; commercial, recreational, and other fisheries;
906 academic partners; and other stakeholders. All data, regardless of the source, can be considered for
907 inclusion in stock assessments (see Chapter 5 for information about how data are analyzed). As part of
908 the stock assessment review process (Chapter 6), all data and their sources are evaluated to ensure that
909 they are appropriate for an assessment model and were collected using a scientifically sound method.

910

911 Most contemporary stock assessments strive to include three main data types (Mace et al., 2001):

912

913 **Abundance**—changes in relative or absolute numbers or biomass over time

914 **Biology**—demographics and life history

915 **Catch**— fishing effort, bycatch, and discards

916

917 Increasingly, there is an effort to include other data in the stock assessment process: ecosystem data,
918 such as environmental forcing factors and predator–prey dynamics; and socioeconomic data, such as
919 market dynamics and human behavior)

920

921 Data for stock assessments are collected according to two primary strategies: fishery-dependent and
922 fishery-independent. Fishery-dependent data, as the name implies, is collected as part of commercial,
923 recreational, or subsistence/cultural/tribal fisheries. These data provide information on the landings and

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924 bycatch of the fishery as well as the biological make-up of the catch (i.e., age, size, sex). Fishery-
925 independent data provide information on the abundance, distribution, and demographics of fish stocks
926 in their natural environments. These data are collected using standardized scientific surveys, which use
927 consistent methods over space and time to maintain objectivity and obtain an accurate perception of
928 wild fish stock dynamics. Fishery-independent data can be collected in cooperation with the fishery and
929 its vessels, but not during normal fishing operations.

930

931 The remainder of this chapter provides an overview of the specific types of data that are collected for
932 and used in stock assessments of federally managed species, as well as challenges associated with the
933 collection and use of those data. This information provides a baseline assessment to help identify data
934 gaps and potential strategies for improved data collection (covered in detail in Chapter 8). A summary of
935 the types of data used by NOAA Fisheries to support stock assessments is presented in Table 4.1, which
936 is categorized by the geographic areas managed by the eight Fishery Management Councils (refer to Fig.
937 3.1).

938

939 Table 4.1. Summary of stock assessment data collection by regional fishery management council, source,
940 and type of data collected. Fishery-dependent data is categorized into commercial and non-commercial
941 sources, while fishery-independent data is categorized into extractive and non-extractive sources. Catch
942 and effort data is typically compiled from all sources, and biological data is obtained from certain
943 sources, including information on length (L), weight (W), age (A), reproduction (R), and genetics (G). An
944 "X" indicates the collection of catch information only.

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Summary Table		North Pacific	Pacific	Western Pacific	Gulf of Mexico	South Atlantic	Caribbean	Mid-Atlantic	New England	
Fishery Dependent	Commercial	Port/Trip/Weighmaster Data	L,W,A,R	L,W	L,A	L,A	L	L,W,A	L,W,A	
		Observer Data	L,W,A,R,G	L,W,A	L,W,A,R	L,W	L,W		L,W,A	L,W,A,R
		Market Data			L,W,A,R,G					
		Vessel Monitoring System	X		X	X	X	X	X	X
		Other (Aerial, Acoustic)	X		X					
	Self-Reported (Logbook, Trip Ticket, Cannery Reports, etc.)	X	X	L,W	X	X	X	W	W	
	Non-Commercial	Intercept	W	L,W	L,W	L,W,A,R,G	L,W,A,R,G		L,W	L,W
		Observers		L,W					L,W	L,W
		Other (Tournament)				X	X	X		
		Self-Reported (Logbook, Phone or Mail survey, etc.)	X	X	X	X	X		X	X
Fishery Independent	Extractive	Trawl	L,W,A,R,G	L,W,A,R,G	X	L,W,R		L,W,A,R	L,W,A,R	
		Longline	L,W,A,R,G	L,W,A,R,G	L,W	L,W,A,R	X		L,W,A,R	
		Dredge							L,W,A,R	L,W,A,R
		Handline, Rod & Reel		L,W,A,R,G	L,W		L,W,A,R			
		Other (Trap, Gillnet)	X			L,W,A,R	X		L,W,A,R	
	Non-extractive	Acoustic	L,W,A,R,G	X	X				X	X
		Camera (stationary)			L	X				
		Camera (mobile)	X	L	L				L	L
		Other (Aerial, Diver, Mark-Recapture)	L		L	X	X	X		

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4.1.1 Catch data

Catch refers to the removals due to fishing and, in some cases, research of all fish of a given stock (or stock complex). Catch includes the fish brought to shore for sale or consumption (i.e., landed) as well as fish released at sea that are either already dead or subsequently die (i.e., dead discards). Total catch is an important component of all stock assessments because it indicates the scale of fishing mortality imposed on a stock by commercial, recreational, or tribal fishing efforts. Approaches to estimating the different components of catch vary depending on the type of fishery, with landings typically more easily estimated than discards. The two main types of catch data are commercial and recreational (Table 4.1), although subsistence and tribal fisheries can also contribute to total removals for some stocks. NOAA Fisheries' relies on data from commercial fisheries collected through self-reporting by fishermen, permit holders, or fish dealers, and through data collection and observer programs conducted by NOAA Fisheries, state agencies, tribes, and international partners. Through fishermen's logbooks, the commercial sector self-reports certain data related to catch, such as the total amount of a given species caught (typically in units of weight); catch locations (often following regional reporting areas or grids); and information on fishing techniques (e.g., fishing gear and vessel characteristics, and approaches used in fishing operations). Data on fishing techniques (e.g., gear measurements, fishing location, depth, time, and so on) can be used to estimate and standardize fishing effort across various fishing strategies. Tracking landings for many stocks can be relatively straightforward (e.g., a sum across all sales records), while tracking discards requires estimation.

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966 An important approach for collecting fishery-dependent data is through the use of fishery observers,
967 who are deployed on commercial fishing and processing vessels to monitor fishing activities. Fishery
968 observers are crucial for tracking catch and discards, because they are placed on specific fishing vessels
969 to record catch and discard rates by species and gear type. Those discard rates are expanded by the
970 total amount of fishing effort within each gear type to generate total discard estimates. Fishery observer
971 data are also used to validate self-reported discard rates from the commercial fleets. Studies can be
972 conducted to determine the survival rate of discarded fish, with dead discards being added to the catch
973 to determine the total. Observers may also sample the landings and discards to collect biological
974 information, such as the size and age distribution of the catch.

975

976 Recreational fisheries can contribute a substantial portion of the total catch of certain stocks when there
977 are large numbers of recreational fishermen, the recreational sector is allocated a large portion of the
978 catch, and there are high levels of fishing effort. This is particularly the case in warmer regions of the
979 U.S. and its territories, such as the southeast where landings from year-round recreational fishing often
980 exceed commercial landings. The recreational sector is divided into three main subsectors: headboat,
981 charter vessels, and individual private anglers. Both self-reporting and government programs collect
982 data from all three subsectors.

983

984 The Marine Recreational Information Program (MRIP) is the national data collection program for
985 recreational data (except in Alaska where the Alaska Department of Fish & Game coordinates this
986 effort). To estimate the amount of recreational fishing effort in a region, MRIP conducts a telephone-
987 based survey of registered recreational fishermen (although this survey is transitioning to a mail-based
988 approach). Additionally, in-person shoreside surveys (called "intercept surveys") are conducted to
989 estimate the catch and effort associated with individual trips. Finally, multiplying total effort estimated
990 from the phone/mail surveys by the estimated average catch/effort for each trip provides estimates of
991 the total recreational catch. Similar to the commercial sector, both landed and discarded fish are
992 considered, with survival rates of the discarded fish applied to determine the total catch. Further
993 sampling is also conducted to evaluate the biological characteristics of the fish caught in recreational
994 fisheries.

995

996 When programs are in place, subsistence, cultural, and tribal data are incorporated through either
997 standard reporting requirements or through specialized data collection systems. The amount of fish
998 caught in this sector is often small compared with the commercial and recreational sectors. However,
999 accounting for all catch is important to ensure accuracy in stock assessments. For some stocks, the
1000 subsistence, cultural, and tribal sectors are not sufficiently monitored; in these cases, the data are not
1001 used in assessments.

1002

1003 4.1.2 Abundance data

1004 Data on stock abundance over time are important for evaluating a stock's response to fishing and effects
1005 due to other factors. Thus, abundance data directly influences estimates of stock productivity. With the

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1006 exception of stocks for which little data are available (called “data-limited” stocks), abundance data are
1007 used in nearly all stock assessments. Abundance data may be relative (e.g., percentage changes in stock
1008 size over time) or absolute (total) abundance (e.g., measures of stock size in terms of total numbers or
1009 weight). When available, absolute abundance estimates are preferred, mainly because they provide a
1010 solid foundation for stock assessment analyses by anchoring the assessment model at a scale that
1011 reflects actual stock biomass. Trends in relative abundance are useful for characterizing fishing effects.
1012 However, estimating the actual scale of the stock can be challenging when using relative abundance,
1013 which can be quantified using numbers of fish as well as weight. Unfortunately, data on absolute
1014 abundance is uncommon because the approach used for calculating it requires information that is
1015 difficult to obtain (e.g., a stock’s total habitat volume, proportion of a stock available to sampling gear,
1016 and the efficiency with which a survey samples the available stock). Despite these challenges, there are
1017 examples of surveys that provide absolute abundance estimates, including bottom trawl surveys for
1018 certain flatfish stocks in the Bering Sea, the yelloweye rockfish survey off southeast Alaska that uses
1019 observations from a remotely operated vehicle, and the sea scallop survey off New England that uses a
1020 towed camera system (HabCam).

1021
1022 Ideally, abundance trends or indices of relative abundance are obtained from scientific surveys.
1023 However, when survey observations are unavailable, fishery-dependent sources can be used. In a
1024 fishery-dependent survey, catch rates such as annual catch per unit of effort (CPUE) serve as
1025 substitutions for relative abundance. For example, catch rates in southeastern headboat fisheries¹⁷ are
1026 used in assessments for multiple reef fish species managed by the South Atlantic Fishery Management
1027 Council (SAFMC) and Gulf of Mexico Fishery Management Council (GOMFMC). Also, because it is cost-
1028 prohibitive to conduct scientific surveys over the distribution of most highly migratory species,
1029 assessments of these stocks rely almost exclusively on fishery-dependent data. Although fishery-
1030 dependent data tends to be readily available as part of routine fishery monitoring, extra caution is
1031 needed when using these data because they are influenced by changes in fishing practices and therefore
1032 may not be objective. To remove potential biases, fishery-dependent CPUE trends are typically
1033 corrected or “standardized” (Maunder and Punt, 2003) before they are used as substitutes for stock
1034 abundance in an assessment.

1035
1036 Abundance trends generated from fishery-independent surveys are preferable to those from fishery-
1037 dependent sources. Fishery-independent surveys are standardized, using consistent methods over time
1038 and space that optimally cover the range of the stock, including areas of lower abundance. These
1039 surveys can be designed such that they balance sampling effort in accordance with regional stock
1040 density (e.g., via adaptive, data-guided approaches that distribute sampling by depth, longitude,
1041 latitude, and/or habitat type). As a result, changes over time in measures of stock abundance or density
1042 from well-designed scientific surveys are assumed to be proportional to changes in stock size.

¹⁷ <http://www.sefsc.noaa.gov/labs/beaufort/sustainable/headboat/>

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1043 Nevertheless, scientific surveys do not provide a perfect depiction of stock dynamics: They often target
1044 multiple species and therefore may not follow a design that is ideal for certain species; they may have
1045 fixed designs that do not adapt to changing ecosystems; and they may be affected by changing
1046 priorities, resources, or unforeseen events (e.g., weather and mechanical delays). As a result, to
1047 maximize available resources and provide high-quality abundance data, NOAA Fisheries uses multiple
1048 fishery-independent survey techniques described in Table 4.1.

1049

1050 4.1.3 Biological data

1051

1052 Samples of fish collected to support stock assessments can provide information on age, length, weight,
1053 sex, reproduction (e.g., maturity and fertility or fecundity), genetic information, and natural mortality
1054 (i.e., not caused by fishing). Age and length data are used mainly to characterize growth, as well as the
1055 age and size distributions of the assessed stock (including the catch). Weight, sex, and reproductive data
1056 are used to calculate reproductive potential, which may include aspects of egg production and/or total
1057 weight of mature fish (i.e., fish that can breed). Genetic data typically are not used directly in stock
1058 assessments, but can be used to determine stock structure (i.e., the spatial boundaries of a stock) and
1059 evaluate whether the definition for a managed stock is consistent with the biological stock. Finally,
1060 natural mortality, which is difficult to estimate, can be informed by scientific research, such as tag-and-
1061 recapture studies. These studies can be done in advance to provide an estimate of natural mortality, or
1062 the data from the studies can be incorporated into a stock assessment model to help scientists estimate
1063 natural mortality within the assessment. In fact, for most of the biological information listed above, the
1064 samples collected require substantial processing and analysis before these data can be analyzed in a
1065 stock assessment. This step can actually be one of the major bottlenecks in the assessment process.

1066

1067 Fish samples are collected from both fishery-dependent and -independent sources (see Table 4.1).
1068 Samples from fishery-dependent sources are primarily collected by port samplers (intercept surveys at
1069 fishing ports) and at-sea observers. Age, length, and weight are the most common information collected
1070 from both fishery-dependent and -independent sources, with reproductive samples, genetic analyses,
1071 and natural mortality studies occurring less frequently.

1072

1073 It is relatively straightforward to measure a fish's size (length and weight), and these measurements can
1074 be taken at sea or wherever sampling is conducted (e.g., ports). There are multiple approaches to
1075 determining a fish's age, each of which requires substantial processing time in a laboratory. Most
1076 methods involve counting yearly rings found by examining hard parts extracted from fish, such as bones
1077 in the inner ear (otoliths) or, less commonly, fin spines, vertebrae, scales, or other structures.

1078

1079 Reproductive data can be collected from a visual examination, but there is also a need for microscopic
1080 tissue analyses to obtain detailed information on fertility and maturity. Genetic samples are collected
1081 mainly for research studies on fish stock structure than as routine samples collected for stock
1082 assessments. However, genetic studies occur periodically to determine whether management stocks are

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1083 appropriately defined and whether data are being collected and analyzed accordingly (e.g., whether
1084 data from separate areas should be analyzed separately or in combination).

1085
1086 Similarly, natural mortality rates are often assumed in stock assessments rather than being influenced or
1087 estimated using assessment data. Thus, research studies that estimate natural mortality of managed
1088 stocks are another important activity that helps structure an assessment, but may only need to be
1089 conducted periodically rather than for every assessment. Within stock assessments, natural mortality is
1090 a simple but important parameter that captures many complex ecological processes that affect survival,
1091 such as predator–prey, disease, toxins, habitat, and other dynamics (except fishing). In fact, all biological
1092 parameters referenced here are affected by ecological processes. As a result, a strong connection exists
1093 between the collection and use of biological data and ecosystem data. In addition, there is a strong need
1094 to conduct research to better understand these relationships, particularly in ecosystems experiencing
1095 rapid change.

1096
1097 **4.1.4. Ecosystem and socioeconomic data**

1098
1099 Not only are there connections between stock biology, productivity, and ecological processes, but stock
1100 abundance data, and even fishery data, are affected by ecosystem and socioeconomic dynamics. For
1101 instance, the proportion of a stock sampled by a survey may be affected by environmental conditions.
1102 Similarly, the location and effectiveness of fishing may be influenced by changing ecosystems, market
1103 dynamics, and fishing strategies. Thus, as we continue to improve our understanding of the connections
1104 between fish, fisheries, and their ecosystems, a clear need emerges to improve assessments by
1105 expanding their scope to incorporate important ecosystem and socioeconomic connections. Our
1106 understanding of these connections is furthered through direct experience and studies that mimic actual
1107 conditions, both of which are based on observations (data) from marine ecosystems and communities.
1108 Although these environments are complex, dynamic, and often difficult to define, substantial progress
1109 has been made in recent decades to understand and describe the marine ecosystems that support
1110 federal fisheries. Nevertheless, significant work still needs to be done to fully characterize these
1111 ecosystems and communities and how they change over time; the data demand required to accomplish
1112 this work is large. Although additional data and research are needed to obtain a more complete
1113 understanding of how ecosystem and socioeconomic drivers affect fish and fisheries, the stock
1114 assessment process is flexible enough to adapt to include new features and data as they become
1115 available. In fact, certain stock assessments conducted by NOAA Fisheries already routinely incorporate
1116 ecosystem information (Chapter 5).

1117
1118 Because there is an increasing need and desire to include additional drivers in stock assessments, the
1119 necessary data are collected to both support routine use in existing assessments and to conduct
1120 research that expands overall knowledge and improves assessments in the future. The primary
1121 ecosystem data being collected (and projected) include diet information to capture predator–prey
1122 dynamics, and physical and chemical ecosystem properties such as temperature, salinity, oxygen

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1123 concentration, pH, and seafloor structure. In many cases, existing surveys and research cruises have
1124 been expanded to include ecosystem data collection, thereby maximizing data collection opportunities.
1125 In other cases, cruises dedicated to ecosystem monitoring are conducted to collect key information. A
1126 wide range of data are being collected as part of the Global Ocean Observing System, both by NOAA and
1127 external partners, and these data can serve as key variables in stock assessments. In fact, the
1128 combination of ocean observation systems with survey designs will become increasingly important to
1129 better understand ecosystem and stock dynamics. Another source of ecosystem information that can be
1130 used in stock assessments is an ecosystem model that integrates data and draws conclusions from those
1131 observations to estimate ecosystem-level dynamics. Actually, aspects of ecosystem-level models are
1132 often constructed using the results from analyses of single stock dynamics (e.g., stock assessments).
1133 Therefore, a two-way connection between stock assessment and ecosystem modeling is occurring and is
1134 necessary to develop the science that supports fisheries management.

1135

1136 4.2.0. Strengths and challenges

1137

1138 Data collection for U.S. fish stock assessments has evolved into a far-reaching partnership that collects a
1139 high volume of a wide variety of data. Formal programs exist for collecting, processing, and preparing
1140 these data for analysis in stock assessment models. The use of these data in stock assessments is
1141 evaluated in a public forum (see Chapter 6) where all data, including those collected by stakeholders,
1142 are considered for inclusion in assessment models. Thus, the overall data collection process for stock
1143 assessments is sophisticated, transparent, and effective. However, several challenges remain that
1144 require attention:

1145

1146 • It can be difficult to obtain accurate and timely catch data.

1147 The accuracy and uncertainty surrounding catch and effort data varies considerably from stock
1148 to stock. Assessment models analyze historical catches to understand the impacts of fishing over
1149 time, and for stocks with fisheries that have been monitored since their beginning, catch
1150 histories may be fairly accurate. However, catch monitoring was commonly incomplete or
1151 nonexistent during a fishery's early years. Where historical data are lacking, reconstructions of
1152 catch time series can allow estimation of the full development of some fisheries, especially on
1153 the west coast, but reconstructions are difficult where fishing effort has been high for centuries.
1154 Even today, challenges exist in collecting accurate catch information. Monitoring of stocks that
1155 are harvested internationally can be hindered by jurisdictional issues. In addition, low observer
1156 coverage and lack of knowledge surrounding release mortality in some fisheries create
1157 challenges for characterizing bycatch and whether discarded fish survived. Fishery observer data
1158 are expensive to collect, but need to be increased in some regions of the country (e.g., observer
1159 coverage is approximately 2% for some fisheries in the southeast region). Recreational,
1160 subsistence, and artisanal fisheries are difficult to monitor because they are dispersed and have
1161 limited resources for reporting their catches (Cummins et al., 2015). Further, self-reported data
1162 from fisheries can contain errors, both unintentional and intentional, that require improvements

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1163 in the data validation programs and quality assurance/quality control (QA/QC) systems.

1164

1165 Most stock assessment models treat catch information with a high degree of confidence, and
1166 inaccurate catch histories add uncertainty and bias to stock assessments. For fisheries with
1167 mandatory catch reporting that dates to the start of the fishery, it may be safe to assume that
1168 catch histories are fairly accurate. However, there are many instances where uncertainty
1169 surrounds catch estimates, so every effort is made to estimate the full extent of fishery
1170 removals. Where there is substantial uncertainty surrounding catch histories, assessment
1171 models may need enhanced functionality to account for this uncertainty.

1172

1173 One of the largest bottlenecks for assessments in almost every region of the country is related
1174 to the processing and delivery of fishery data to assessment modelers. These challenges extend
1175 the time required to conduct stock assessments, and may result in large gaps between the final
1176 year of data used in the assessment and when the assessment is completed. Increased
1177 electronic reporting by commercial fisheries could help create more efficient data access and
1178 potentially improve QA/QC. Similarly, the development of automated tools, such as video-based
1179 counting of discards by species, could improve the availability and accuracy of data in certain
1180 situations.

1181

1182 • **Abundance data is expensive to collect and challenging to extract from fishery catch rates.**

1183 Although fishery-independent surveys are preferred over fishery-dependent data sources for
1184 providing estimates of stock abundance, challenges also exist in the implementation and use of
1185 fishery-independent surveys. First, scientific surveys are often relatively expensive to conduct
1186 and require significant ship time, with vessel days typically ranging from approximately \$2,500
1187 per day for smaller, contracted vessels to more than \$15-30,000 per day for larger NOAA ships.
1188 In addition to vessel costs, resources are also needed for equipment and supplies, and field,
1189 laboratory, and analytical personnel. As a result, annual costs for surveys often range from
1190 hundreds of thousands to millions of dollars per year when all costs are considered. Second, the
1191 efficiency of gear types used in fishery-independent surveys may vary with the size or age of
1192 specimens being caught (e.g., older and larger fish may be better at avoiding capture by trawls
1193 due to increased swimming ability or speed with size), or by habitat type (e.g., trawls may be
1194 more likely to collect fish over unstructured versus structured habitat). These differences in gear
1195 effectiveness, unless known and corrected for, increase the uncertainty around abundance
1196 estimates. Thus, to maximize the usefulness of fishery-independent data, gear-specific
1197 efficiencies must be assessed—potentially a time-consuming and costly undertaking. Third,
1198 surveys can be designed to make the most of information collected on specific species (e.g.,
1199 dredge surveys for scallops, acoustic surveys for midwater schooling fish); however, most
1200 surveys capitalize on the opportunity to collect information on a group of species. This multi-
1201 species sampling approach means that data are collected on many more species than under a
1202 single-species approach, thereby allowing many more stock assessments to be conducted with

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1203 minimal increases in resources. However, additional considerations are associated with multi-
1204 species surveys. For instance, the stocks collected may have different distributions, habitat
1205 preferences, daytime patterns, and/or availability to fishing gear. For such surveys, establishing
1206 a survey design that reduces uncertainty surrounding abundance estimates for certain target
1207 species may increase the uncertainty surrounding the abundance of other species. In other
1208 words, because distributions, habitat use patterns, and behaviors vary by species, it is
1209 impossible to design surveys that are ideal for all species sampled. Thus, choices will have to be
1210 made based on species-specific management importance, cost, and logistical considerations.

1211
1212 The primary challenge related to the use of fishery-dependent data for generating estimates of
1213 relative stock abundance is that multiple factors unrelated to stock abundance can affect fishery
1214 catch rates. For instance, changing management actions may alter catch rates due to varying
1215 harvest quotas, size restrictions, temporal and spatial management, and so on. Catch rates are
1216 also affected by fishery-driven changes in practices, such as changes in market prices, fuel
1217 prices, and so on; improvements in fishing strategies and techniques, such as new technologies
1218 that improve catch efficiency; and target species preferences, such as certain stocks may be
1219 targeted after quotas for other stocks are met. Additionally, changes in the completeness of
1220 reporting (e.g., enforcement and compliance with reporting requirements) will affect the data
1221 available on catch rates. Issues related to estimating abundance trends from fishery-dependent
1222 data require considerable attention, because fisheries can adapt their practices to maintain
1223 catch rates, and therefore profits, when stocks decline (e.g., if stock density declines in certain
1224 areas, fishing can be redirected to higher-density areas to maintain efficiency).

- 1225
1226 • **Research is needed to improve biological data.**
1227 Because the types of biological data collected for stock assessments are diverse, so are the
1228 challenges associated with those data. Optimally, all biological data used in stock assessments
1229 should be collected to represent managed stocks as a whole. When only a portion of a stock's
1230 spatial distribution (or ages, sizes, or sexes) are sampled, the biological data must be interpreted
1231 with caution because it may not represent the entire stock. To avoid biased biological data, it is
1232 important to sample the entire stock as much as possible, and to research sampling strategies
1233 and efficiencies to understand which portions of the stock are represented by the data. In some
1234 cases, stock distributions extend across jurisdictional—state, federal, and international—
1235 boundaries, creating sampling and management challenges. However, if a managed stock is not
1236 consistent with a biological stock, then estimates of productivity, stock status, and harvest
1237 recommendations may be inaccurate.

1238
1239 When collecting biological data, it is important to understand the minimum number of samples
1240 needed to sufficiently estimate life history factors. For many stocks, studies to address sampling
1241 intensity have not been conducted, but this research is important for determining and
1242 prioritizing resources needed for data collection in stock assessments. There are potentially

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1243 numerous cases of both under- and over-sampling of biological data, affecting not just the time
1244 and resources dedicated to collect the data, but also the time and resources assigned to
1245 processing the samples. In fact, due to limited capacity and substantial processing requirements,
1246 biological sample processing (e.g., counting age rings) is a primary bottleneck in the stock
1247 assessment process.

1248
1249 For aging analyses, species-specific studies are necessary to validate assigned ages; however,
1250 these studies are lacking for many managed stocks. Even when validation studies have occurred,
1251 the determination of an individual fish's age can be challenging, as is often the case for older
1252 individuals of long-lived species. As such, fish are typically aged by multiple analysts with a goal
1253 of reaching high levels (e.g., greater than 90% agreement) among analysts before data are
1254 judged useful for assessments (Campana, 2001).

1255
1256 For reproductive data, there are multiple areas where additional research could improve stock
1257 assessments. For example, more detailed understanding of reproductive capacity by size and
1258 age could result in more accurate assessment models and therefore biological reference points.
1259 Additionally, studies are needed to better understand the timing and duration of spawning
1260 seasons, as well as spawning frequency, particularly for stocks with individuals that spawn
1261 multiple times during a season, and stocks with individuals that do not spawn each season
1262 (Secor, 2008; Rideout and Tomkiewicz, 2011; Fitzhugh et al., 2012). Numerous species,
1263 especially tropical reef fishes, have both male and female reproductive organs (called
1264 "hermaphroditic"), often reaching maturity as one sex and then transitioning to the other. These
1265 species pose unique challenges to modeling reproductive dynamics, and more studies are
1266 needed to develop assessment methods and better understand ratios of males to females in the
1267 stock and how those ratios relate to productivity (Shepherd et al., 2013).

1268
1269 Natural mortality is a critical, although understudied, component of stock assessments. In fact,
1270 many assessments are conducted without any direct measures of natural mortality. Rather,
1271 natural mortality rates often emerge from using data and relationships with other life history
1272 data, other species, or without any supporting information. Thus, there is a clear need for more
1273 tagging studies and tag-and-recapture data to improve natural mortality estimates, as well as a
1274 link to predation and other sources of known, measurable mortality.

- 1275
1276 • **More ecosystem and socioeconomic data and research are needed.**
1277 Ultimately, to expand the scope of stock assessments, it is not enough that additional data are
1278 available. Scientists also need to understand more fully how fish stocks and fishery dynamics are
1279 affected by ecosystem and socioeconomic factors. For instance, because biological processes
1280 combine a number of ecosystem processes, more research on predator-prey, disease, toxins,
1281 and habitat dynamics would improve understanding of factors that affect stock productivity.
1282 Similarly, research into human and market dynamics is valuable to help understand and predict

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1283 fisheries. Even without including ecosystem or socioeconomic data, many assessments already
1284 account for change caused by these drivers, such as through variability in weight by age or
1285 changing fishing practices (e.g., selectivity patterns). However, further research will help
1286 improve an understanding of the key drivers to improve assessments and the resulting advice.
1287 Improving prediction skills is particularly important in the context of climate change, because a
1288 stock's historical responses to fishing, which are evaluated in an assessment, may not reflect
1289 future responses.

1290
1291 To expand assessments to be more holistic, researchers need to increase their collection of
1292 ecosystem and socioeconomic data. Although beneficial partnerships are in place, and many
1293 existing data collection efforts are being leveraged to collect these additional data, there simply
1294 is not enough data to fully characterize complex and multifaceted ecosystems and communities.
1295 Thus, additional data collection and research efforts are needed. However, the information
1296 currently available can be used and is being used in assessments now. With innovative science
1297 (Chapter 9) and strategic prioritization (Chapter 10), ecosystem and socioeconomic data can be
1298 incorporated where most needed.

1299

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1383

1384 Chapter 5. Analytical tools

1385 Chapter highlights

- 1386 • **Stock assessment models are specifically designed to produce results needed by fishery managers.**
- 1387 • **A range of models is available to suit the diversity in available data for each stock.**
- 1388 • **Models that use limited data produce management advice by making strong assumptions; models**
- 1389 **that use more types of data can estimate the effects of more factors on a given fish population.**
- 1390 • **Characterizing the uncertainty in model outputs is important for evaluating the risk associated**
- 1391 **with various management strategies.**

1392 5.1. Introduction

1393 This chapter provides an overview of the analytical tools used in NOAA's fish stock assessments. Many of
1394 these tools are highly technical, and therefore, this information is intended for those already familiar
1395 with these methods, or for those interested in an introduction to the mechanics of stock assessment
1396 modeling. The analytical work conducted by stock assessment scientists is designed to translate data
1397 from fisheries, surveys, and biological studies to characterize the status of a fish stock and to provide
1398 catch forecasts needed by fishery managers. These analyses consist of three principal stages:

- 1399 1. Data preparation
- 1400 2. Modeling and forecasting of fishery and population dynamics
- 1401 3. Risk analysis and decision support

1402 In stage one, the many samples collected each year from fisheries and surveys need to be processed and
1403 summarized by a few values (e.g., the age composition of the catch for a given year) that are input to a
1404 stock assessment model. During the second stage, development, calibration, application, and
1405 forecasting of these models are major activities for the stock assessment programs. Then, in the third
1406 stage, the uncertainty surrounding stock assessment results is explored to calculate tradeoffs and risks
1407 and communicate them to fishery managers and the affected public. In addition to these three stages of
1408 assessment analyses, which are described in more detail in this chapter, stock assessment modelers also
1409 conduct a wide range of research and perform management support activities that use their analytical
1410 skills. These activities range from investigations of ecosystem and habitat factors affecting fish stock
1411 dynamics, to analyzing bycatch patterns in fisheries. Opportunities to conduct research allow stock
1412 assessment scientists to remain creative, innovative, and at the forefront of stock assessment science.
1413 The distinction between stock assessments and general scientific research and investigations into fish
1414 population dynamics is that the results of stock assessment analyses are tailored for delivery to fishery
1415 managers. Thus, NOAA Fisheries' stock assessment scientists conduct world-class fisheries research
1416 while also participating in operational science (i.e., stock assessments) that deliver quality scientific
1417 advice to fishery managers.

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DISCUSSION PURPOSES**1418 5.2. Preparing stock assessment input data**

1419 As described in Chapter 4, a variety of data (i.e., samples) are collected to support stock assessments.
1420 However, the samples collected by these various programs may not be available as input into stock
1421 assessment models until they have been processed. This processing includes laboratory analysis of
1422 samples and organizing the data so they are appropriate for use in assessment models. For example,
1423 catch information recorded from thousands of fishing trips is combined into a measure of total (usually
1424 annual) catch by each fleet. Similarly, survey observations from hundreds of locations are totaled into a
1425 measure of stock abundance, again usually annual, throughout the range of the survey. This
1426 combination typically involves sophisticated statistical models often designed and implemented by stock
1427 assessment scientists (see review by Maunder and Punt, 2004).

1428 Processing data for generating catch-age compositions (and catch-length compositions) requires
1429 analytical thoroughness and an incorporation of the sampling process (Kimura, 1989; Dorn, 1992). The
1430 fishery data on catch and its size and age composition can come from many sources including NOAA,
1431 commission or state-specific landings receipts, NOAA fishery observer programs, state-specific biological
1432 sampling, diverse recreational fishery sectors, and so on. Merging these raw data into statistically sound
1433 estimates of fleet-specific catch statistics can be difficult and time-consuming for stock assessment
1434 scientists and data analysts. The need to improve the efficiency of this process so that data are readily
1435 (and publicly) available for assessments was a major finding of NOAA's stock assessment program
1436 reviews in 2013¹⁸. In certain scenarios, standardized, immediately usable data systems could help relieve
1437 this drain on the assessment process and potentially result in more timely assessments for more stocks.
1438 However, frequent changes in fishery management and fishermen's behavior hinder the development of
1439 automated collection systems for fishery data.

1440 Another major effort is developing methods to create a measure of stock abundance from raw fishery
1441 logbook or survey sample data. Here, statistical methods such as generalized linear models have been
1442 useful (Maunder and Punt, 2004), and the next wave of innovation in this area may be fully geostatistical
1443 methods (Thorson et al., 2015). Pre-processing data before using it in models also requires consideration
1444 of the appropriate observation uncertainties (Francis, 2011). Finally, statistical methods are used for
1445 estimating or reconstructing historical catches. The reliability of these methods can vary over time and
1446 by region (e.g., if the catch accounting method involves data collections at different spatial scales,
1447 assumptions about distributing can be critical).

1448 5.3. Stock Assessment Models**1449 5.3.1. Principles**

1450 Population dynamics models produce the main stock assessment results. Information fed into these
1451 models is obtained from the pre-processing models discussed earlier. Population dynamics models are

¹⁸ <https://www.st.nmfs.noaa.gov/science-program-review/program-review-reports/index>

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1452 based on realistic, but simplified, representations of the factors affecting the productivity and mortality
1453 of fish stocks. In addition, these models are designed to produce estimates of current, historical, and
1454 future fish abundance and fishing mortality.

1455 Population dynamics models are standardized using the time series of abundance, biological, and catch
1456 data. The quantity and quality of these data and the amount of variation (contrast) they show over time
1457 influences the types of models that are used and how well they can be expected to perform (Maunder
1458 and Piner, 2014). Each stock provides unique data for an assessment, including the research conducted
1459 to support assumptions underlying stock and fishery dynamics. Thus, the choice of stock assessment
1460 model and model configuration within the assessment framework is governed by a stock-specific,
1461 scientific, decision-making process that attempts to identify the most appropriate analytical approach.
1462 Implementing this process requires strong technical expertise and is a fundamental role of the stock
1463 assessment analyst. Numerous choices are available to assessment analysts, and Table 5.1 provides a
1464 general summary of the range of options.

1465 Most stock assessment analyses are statistically based, so the general conceptual approach to running
1466 or “fitting” an assessment model follows basic statistical modeling practices. This process involves the
1467 following general steps:

- 1468 1. Specifying mathematical equations (models) that are assumed to represent stock and fishery
1469 dynamics
- 1470 2. Inputting relevant data pertaining to stock and fishery dynamics
- 1471 3. Applying statistical methods that calibrate the mathematical models by comparing the
1472 processes defined by the equations to the patterns observed in the data.

1473 The specific details about each step of the modeling process vary with the amount and type of data
1474 available for an assessment (Figure 5.1). For instance, most data-rich assessments are age (or length)
1475 based, and therefore provide a more detailed evaluation of the effects of fishing and other factors on
1476 the stock. To achieve this level of detail, the mathematical models need to be created to track cohorts
1477 (or length classes) over time, which results in a relatively large number of model parameters that need
1478 to be estimated (informed by data) or specified (i.e., assumed). This type of configuration requires age-
1479 (or length-) specific data, as well as relatively complex statistical methods capable of calibrating models
1480 with many parameters. One benefit of a more detailed model is that generally, there are fewer strong
1481 assumptions about stock dynamics required. With data-moderate assessments, there are typically
1482 observations of total catch as well as changes in abundance, but the data are aggregated across ages
1483 (sizes), so these assessments inherently assume that the dynamics apply to all ages and sizes of
1484 individuals in the stock equally. However, the benefits of a simple model include easier understanding,
1485 generally simpler statistical methods which can result in fewer complications during application (i.e.,
1486 models that are easier fit), and often a straightforward calculation of key results. For instance, solutions
1487 for maximum sustainable yield (MSY) reference points which form the basis for stock status
1488 determinations and setting sustainable catch limits can be directly calculated with biomass dynamics

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1489 models (see Section 5.3.2). With data-rich assessments, these reference points are often determined in
1490 a secondary step that involves simulation analyses based on the results obtained from fitting the
1491 assessment model.

1492 Data-limited approaches are used for many U.S. stocks and may be used for a variety of reasons. The
1493 most common reason is when there is not enough data for more complete assessments. However, data-
1494 limited methods are also employed as a stop-gap for setting catch limits between more complete
1495 assessments and as a default approach when a more complete assessment has issues and is not deemed
1496 appropriate for management. There are numerous data-limited methods available that differ in their
1497 data requirements and underlying assumptions (Newman et al., 2014). Several methods rely only on
1498 catch data, while others incorporate life-history information or apply multipliers to trends in biomass. All
1499 data-limited approaches rely on fairly strong assumptions about stock dynamics (e.g., the amount that a
1500 stock has depleted over time) and therefore should not be considered a long-term approach to support
1501 sustainable management of important stocks.

1502 **5.3.2. Outputs and uses**

1503 Stock assessment models are designed to give fishery managers numerical estimates of relevant fishery
1504 management quantities. Common outputs and their uses include the following:

- 1505 1) Reference Points:
 - 1506 a) F_{MSY} —The average fishing rate, or suitable proxy (e.g., $F_{40\%}$), that would produce the maximum
1507 sustainable yield. This serves as the limit beyond which overfishing is considered to occur.
 - 1508 b) B_{MSY} —The average stock abundance when fishing at F_{MSY} (the associated Minimum Stock Size
1509 Threshold (MSST) below which the stock is considered overfished is often a specified fraction of
1510 B_{MSY} or its proxies).
- 1511 2) Stock Status Determination—The comparison of current stock abundance and fishing rates
1512 produced by an assessment model with the associated fishing and biomass reference points.
- 1513 3) Harvest Control Rule—A formula that calculates a limit or target catch level and is based on a stock's
1514 abundance and other factors (e.g., scientific uncertainty, risk policy). Many control rules strive to
1515 attain a large fraction of MSY while keeping the risk of overfishing at an agreed level. National
1516 Standard 1 Guidelines require that scientific uncertainty be taken into account when calculating
1517 target harvest policies.
- 1518 4) Harvest Recommendation—Level of catch recommended for achieving the objectives of the harvest
1519 policy, typically based on forecasts of abundance trends. For federal fishery managers, this value
1520 provides the technical input needed by a council's Scientific and Statistical Committee to
1521 recommend an acceptable biological catch (ABC) to its council.

1522 As described in more detail in Section 5.4, the uncertainties surrounding outputs 1 through 4 should be
1523 characterized and measured as completely as possible to support effective and robust management
1524 decisions. Because stock assessment models are the foundation for determining stock status and setting

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1525 catch limits, there is a high level of public scrutiny and strong peer review requirements (see Chapter 6).
1526 Additionally, assessment models and their outputs have broader applications (Section 1.2).

1527 Many demands are placed on the stock assessment modeling community. Some managers and
1528 stakeholders want simpler methods that are quick to implement and transparent to a wider community,
1529 while others want methods that are more comprehensive and/or more heavily evaluated during each
1530 application. There is also interest in more spatial resolution to better match the on-the-water
1531 observations of local fishermen. Ideally, there is a preference for more complete measures of
1532 uncertainty to better implement precautionary approaches and avoid surprises as estimates change
1533 over time. No one modeling approach will satisfy all these demands, but progress is being made in
1534 several areas highlighted next and in chapter 9.

1535 5.3.3. Categories

1536 A range of stock assessment models has been designed to provide tools across a variety of scenarios,
1537 mainly related to data availability (Table 5.1). Where data are limited, or when simple analyses are used
1538 for monitoring between more comprehensive assessments, modeling approaches tend to be relatively
1539 simple and rely on fairly rigid assumptions about stock and fishery dynamics (Categories 1 and 2 from
1540 Table 5.1). In these cases, assumptions about important factors are often based on knowledge from
1541 stocks with similar attributes, so scenarios with limited data can still produce stock-specific results.
1542 Many stocks in U.S. managed fisheries do not have sufficient data for conducting stock assessments that
1543 provide typical management advice (i.e., stock status and catch limits/targets). However, the U.S.
1544 requirement to establish annual catch limits (ACLs) in all fisheries has forced a rapid response by stock
1545 assessment scientists to develop and advance methodology for data-limited stocks (Cummings et al.,
1546 2014; "Data-Limited" methods in Table 5.1). A study of methods for determining ACLs in the U.S.
1547 (Berkson and Thorson, 2015) indicated that 52% rely on methods that consider only catch data to
1548 provide management advice.

1549 When a moderate amount of historical data are available, such as catches over time and an indicator of
1550 changes in stock abundance (or relative abundance) over time, then aggregate biomass dynamics
1551 models can be used (category 3 from Table 5.1). These models calculate how large the stock must have
1552 been to have exhibited the trends observed in the abundance data while the observed catch was being
1553 removed. These estimates are conditioned on population turnover rates indicated by available biological
1554 data.

1555 Moving up the data availability spectrum, a third class of stage-based approaches uses the distributions
1556 of ages or lengths in the fishery harvests and/or surveys (categories 4 through 6 in Table 5.1). Age
1557 and/or size data are particularly useful because they facilitate estimates of total mortality rates for fish
1558 stocks (i.e., the proportional decline in fish abundance with age indicates the magnitude of fishing plus
1559 natural mortality). When eras of high and low mortality coincide with eras of higher and lower levels of
1560 catch, these methods can infer the size of the stock from which the catches were taken. When historical

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1561 time series of age/size data are available, the models can also calculate, by age/size, the degree to which
1562 fish are available to (selected by) a fishery or survey. Further, age/size time series also allow for
1563 calculation of annual fluctuations in the amount of young fish entering the stock (i.e., recruitment) as
1564 well as annual fluctuations in body growth. Additional expansions and information, such as spatial
1565 model configurations and inclusion of ecosystem data, can be considered for any assessment model
1566 framework.

1567 **Table 5.1.** Categories of stock assessment models with focus on the population dynamics
1568 structure (e.g., growth rates, mortality, reproductive characteristics), data requirements
1569 (minimum and data typically used), and types of management advice that can be provided
1570 with associated limitations. "Catch" refers to total catch (including discards to the extent
1571 feasible) in biomass or numbers but without information on age and/or length structure.
1572 "Abundance index" generally refers to a relative index assumed to be proportional to the
1573 abundance of a fish stock as modified by the assumed or estimated size and age selectivity of
1574 the fishery or survey that is the source of the data.
1575

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1. Data-Limited

- **Example methods:** Depletion-Based Stock Reduction Analysis (DBSRA; Dick and MacCall, 2011); Depletion Corrected Average Catch (DCAC; * MacCall, 2009); Surplus Production MSY (Martell and Froese, 2013); Egg-Escapement, Mean Length Estimation (Gedamke and Hoenig, 2006)
- **Population dynamics:** Typically not modeled, but some methods include basic assumptions and expert opinion on natural mortality, stock depletion, sustainability of recent catch, and others
- **Data requirements:** Total catch and/or other biological information as available
- **Management advice:** Catch recommendations and sustainability of recent average catch
- **Limitations:** Results are a placeholder for management advice until direct information on stock status and/or trends can be obtained

2. Index-Based

- **Example methods:** Basic linear models and time series analyses, An Index Method (AIM; NOAA Fisheries Toolbox*)
- **Population dynamics:** Typically not modeled
- **Data requirements:** Time series of total catch and/or stock abundance
- **Management advice:** Mostly qualitative advice about stock trends and whether management action is triggered as part of a harvest control rule (e.g., abundance index goes below a prespecified threshold)
- **Limitations:** Does not provide estimates of stock biomass

3. Aggregate Biomass Dynamics

- **Example methods:** Schaefer or Pella-Tomlinson Production Models (ASPIC; * Prager, 1994); delay-difference models (Collie and Sissenwine, 1983; Deriso, 1990)
- **Population dynamics:** Aggregate biomass dynamics with minimal parameters (carrying capacity— K , intrinsic population growth rate— r , initial biomass— B_0 , and a catchability coefficient— q , related to fishing mortality or survey abundance index); delay-difference models expand on this to include at least two life stages and assumptions about growth and natural mortality
- **Data requirements:** Time series of total catch and at least one index of stock abundance; delay-difference models typically have abundance indices for each life stage, and information on growth and natural mortality
- **Management advice:** Estimates of maximum sustainable yield (MSY), current biomass (B) relative to B_{MSY} , current fishing rate (F) relative to F_{MSY} , and the current catch that corresponds to F_{MSY}
- **Limitations:** Requires contrast in the data (i.e., periods of high and low catch and biomass, as well as variability in the abundance index over time); typically ignores biological information regarding individual body growth, maturity, and natural mortality rate; provides more detailed population dynamics but still aggregates dynamics within life stages

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4. Virtual Population Analysis (VPA)

- **Example methods:** VPA and Dual Zone VPA (ADAPT & VPA-2BOX; NOAA Fisheries Toolbox*)
- **Population dynamics:** Starting from the last year in the data and the oldest age for each cohort in that year, abundance-at-age is calculated backwards in time using catch-at-age and natural mortality; models are often tuned by fitting to age-specific abundance indices
- **Data requirements:** Complete, high-quality catch-at-age and weight-at-age data for every time step and at least one abundance index for calibration ("tuning" in a VPA context); age-specific abundance indices are often used
- **Management advice:** Time series of biomass and fishing rates are primary sources of advice; however, model output can be analyzed separately to evaluate stock-recruitment relationships; these additional analyses help provide complete advice on stock status and forecasts of catch limits and targets
- **Limitations:** Obtaining complete catch-at-age data that can be considered known without error at every time step is not realistic for many stocks; estimation techniques often use specific approaches that create challenges for characterizing uncertainty (e.g., confidence intervals); method performs best when the fishery is the dominant source of mortality (i.e., fishing mortality > natural mortality)

5. Statistical Catch-at-Length (SCAL)

- **Example methods:** Statistical Catch-At-Length (SCALE; NOAA Fisheries Toolbox*); Stock Synthesis (SS;* Methot and Wetzel, 2013); MultifanCL (Fournier et al., 1990); crustacean models (Zheng et al., 1995; Chen et al., 2005)
- **Population dynamics:** Length-structured, with a length-based transition matrix to update the stock's length composition between consecutive time steps; can incorporate natural mortality, growth, recruitment, and fishing mortality at length; the inclusion of size data from fishery or survey catches allows for the estimation of size selectivity patterns by fleets/surveys and the time sequence of recruitments
- **Data requirements:** Total catch by fleet, at least one abundance index, length composition data from fleets/surveys (some missing data allowed); may allow the catch data to be separated into landings and discards
- **Management advice:** Stock status and forecasts of catch limits and targets relative to management reference points (if stock-recruitment dynamics are embedded); otherwise advice is limited to estimated time series of biomass and fishing rates
- **Limitations:** Typically less informative about recruitment and mortality of older individuals than when age data are available

6. Statistical Catch-at-Age (SCAA)

- **Example methods:** Stock Synthesis (SS;* Methot and Wetzel, 2013); Age-Structured Assessment Program (ASAP;* Legault and Restrepo, 1999); Assessment Model for Alaska (AMAK#), Beaufort Assessment Model (BAM; Craig, 2012); MultifanCL (Fournier and Archibald, 1992; Fournier et al., 1990); C++ Algorithmic Stock Assessment Library (CASAL; Bull et al., 2012)
- **Population dynamics:** Age-structured, incorporating natural mortality, growth, recruitment and recruitment variability, fishing mortality, and selectivity
- **Data requirements:** Total catch by fleet, at least one abundance index, samples of age compositions by fleet/survey; missing data are allowed (in contrast to VPA); some implementations allow the catch data to be separated into landings and discards
- **Management advice:** Stock status and forecasts of catch limits and targets relative to management reference points (if stock-recruitment dynamics are embedded); otherwise advice is limited to estimated time series of biomass and fishing rates
- **Limitations:** Flexibility of software package to include additional factors is highly diverse and difficult to categorize; direct estimates of MSY-based quantities depend on whether stock-recruitment dynamics are included

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DISCUSSION PURPOSES1578 *<http://nft.nefsc.noaa.gov/index.html>1579 #<https://github.com/NMFS-toolbox/AMAK>1580 **5.3.4. Application and choice**

1581 Assessment models use advanced statistical and computational methods to enable estimation of the
1582 parameters of the model, which can be as many as thousands in the most data-rich and flexible cases.
1583 When detailed, flexible models are applied to relatively simple data sets, some factors in the models
1584 need to be specified as constants or the models will need extra constraints/penalties on parameters for
1585 those factors to prevent the results from becoming highly uncertain or illogical. Conversely, when
1586 simpler model configurations are confronted with more detailed data, they may not adequately
1587 represent the processes that created some of the detailed patterns in the data. Therefore, they can
1588 produce biased results. In general, model choice is governed by data availability, but another important
1589 consideration relates to the *principal of parsimony*. The level of detail in the assessment relates to the
1590 scale of investment in data collection; thus, to maximize limited resources, assessments should be as
1591 simple as possible while achieving the management objectives. In many cases, age-structured data and
1592 other information are important for achieving optimum yield from fish stocks. However, for less
1593 important stocks, it may not be worth the investment to collect such detailed data.

1594 Integrated analysis models, such as Stock Synthesis (Methot and Wetzel, 2013), provide flexibility to
1595 combine aspects of both age-structured and biomass dynamics models. These methods are frequently
1596 used in stock assessments because they can be adjusted to match a variety of data availability scenarios.
1597 Integrated analysis here refers to the ability to simultaneously include length and age, tag–recapture,
1598 and other data. Because these are flexible models, programs such as Stock Synthesis support a variety of
1599 configurations to implement many of the model categories in Table 5.1, particularly the SCAA and SCAL
1600 models. One potential drawback of integrated analysis models is that the flexibility may result in
1601 implementation errors or configurations that are too detailed given the data available. Drawbacks such
1602 as these emphasize the importance of documentation, best practices, and user guides for stock
1603 assessment methodology.

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1605

1606 5.4.1. Characterizing scientific uncertainty

1607

1608 It is not possible to observe every process affecting every individual fish in a stock (without error);
1609 therefore, there will always be some degree of uncertainty surrounding stock assessment results. This
1610 uncertainty can be reduced by improving and expanding observing systems and by conducting research
1611 to understand processes. However, acknowledging and characterizing uncertainty is an integral part of
1612 fisheries management. Because information is not perfect and complete, the advice that results from
1613 analyzing that information may not be perfect either. Therefore, uncertainty is characterized and
1614 adjustments are made to buffer against negative outcomes, such as overfishing, when information is not
1615 perfect (Methot et al., 2014).

1616

1617 Six types of uncertainty that commonly receive attention in fisheries (Peterman, 2004; Link et al., 2012)
1618 include the following:

- 1619 1. Process error (or uncertainty due to natural variability)
- 1620 2. Observation error (or measurement or estimation uncertainty)
- 1621 3. Structural complexity (or model uncertainty)
- 1622 4. Communication uncertainty (issues related to interpretation and use of results)
- 1623 5. Objective uncertainty (or lack of clarity on goals and objectives, often included with outcome
1624 uncertainty)
- 1625 6. Outcome uncertainty (or management performance uncertainty)

1626

1627 From this list, 1–3 may be accounted for within stock assessments, where 4–6 are not typically
1628 addressed during analyses. For process and observation error, approaches that are likely to characterize
1629 uncertainty most appropriately are models that are explicitly statistical that allow for sufficient flexibility
1630 to capture both sources of error at the same time as. However, simpler models can provide reliable
1631 fisheries management advice, especially if they have been evaluated through simulation testing and/or
1632 decision support analyses (see Section 5.4.2).

1633 Several statistical methods that are used frequently can help address and measure uncertainty in stock
1634 assessments. For instance, Bayesian statistics provide an opportunity to use prior knowledge about a
1635 certain process or model parameter to help with estimation in the assessment model. This method is
1636 especially useful when there is not enough information in the input data to estimate assessment
1637 parameters, and previous analyses do not provide enough certainty to specify the exact value of the
1638 parameters at the start of the assessment. The combined use of prior knowledge and information in the
1639 data supports an appropriate treatment of uncertainty in many assessments.

1640 Another statistical approach that is becoming more common in stock assessments is the use of random
1641 effects, or state–space models. With this technique, assessment processes and parameters can be
1642 treated not only as fixed estimates, but also as parameters that change over time and/or space

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1643 according to a random process. Previously, state–space techniques were too cumbersome to implement
1644 in relatively complex stock assessment models; however, recent developments in computing power and
1645 statistical software have made it possible to do so. Assessments can now account for shifts in population
1646 and/or fishery dynamics without a detailed understanding of the cause of those shifts. Thus, state–space
1647 models offer a sophisticated approach to addressing uncertainty that accounts for both observation and
1648 process errors and balances total uncertainty between these two components. Although full state–space
1649 stock assessments are not yet commonly used in the United States, these assessments provide a very
1650 active area of research and development.

1651 A commonly used approach to account for process error in U.S. stock assessments is model sensitivity
1652 analyses. This technique evaluates the structural uncertainty of models. In other words, this approach
1653 tests to see how the results compare when other mathematical equations are used, data are added to
1654 or eliminated from the assessment, different values of parameters are selected, or different
1655 assumptions about model parameters are considered. Commonly this approach narrows the choice to
1656 one or a small set of plausible model configurations, thus arriving at what is considered a good model.
1657 However, resting on a single “base” model ignores the total uncertainty across the set of plausible
1658 models. In some cases, assessments try to average results across the suite of models, but more technical
1659 guidance is needed on how to do this in a stock assessment context. Although climate and weather
1660 forecasts rely heavily on ensemble modeling techniques, there are enough differences in the data and
1661 modeling approaches that the scientific basis behind their methods does not directly translate to a stock
1662 assessment application. Essentially, weather forecasts can evaluate model skill by direct comparison
1663 with observed events, but in stock assessments, the true occurrence (e.g., last year’s total biomass)
1664 cannot be observed without uncertainty. Nevertheless, there is a growing preference to use multimodel
1665 inference for characterizing process errors in stock assessments, and quantitative approaches are
1666 currently being used for some stocks (Stewart and Martell, 2015).

1667 Within a single assessment model configuration, several diagnostic tools can be used to evaluate the
1668 consistency and stability of a model. Retrospective analyses (such as Mohn, 1999) test for systematic
1669 inconsistencies, or patterns in the results, when the model excludes data year-by-year going back in
1670 time. If models do not perform well according to this diagnostic, then there is an issue with the
1671 assessment and alternative model configurations may be evaluated. Thus, retrospective analysis is
1672 useful for evaluating the extent of model mis-specification (Hanselman et al., 2013), which may help
1673 address process error. However, detecting and accounting for retrospective patterns is not
1674 straightforward and remains an area of active research (Deroba, 2014; Hurtado-Ferro et al., 2015;
1675 Brooks and Legault, 2016; Miller and Legault, 2017). Although other diagnostic tools can evaluate model
1676 stability, retrospective analyses are commonly used because when a model shows a pattern, researchers
1677 tend to be skeptical about the assessment results.

1678

1679 5.4.2. Decision support

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1680 Decision support analyses use the uncertainty surrounding the outputs of stock assessment models and
1681 other components of the management process to evaluate tradeoffs among options. The need to
1682 quantify uncertainty was reinforced under the National Standard 1 (NS1) Guidelines, which specify the
1683 requirement apply a risk policy that accounts for scientific uncertainty when setting catch limits (Methot
1684 et al., 2014). Assessment scientists from NOAA Fisheries provided important technical guidance for
1685 applying this aspect of the NS1 Guidelines (Shertzer et al., 2009) where they showed how the probability
1686 range (i.e., uncertainty) around an estimated overfishing level (OFL) could be used to set a catch target
1687 below the OFL that had a specified probability, P^* , of allowing overfishing to occur. According to the NS1
1688 Guidelines, the chance of exceeding the true OFL must not exceed 50%, and the approach from Shertzer
1689 et al. allows managers to specify the level of risk they are willing to tolerate (up to a 50% chance of
1690 overfishing). There are other acceptable approaches to account for uncertainty in catch
1691 recommendations, and these are typically more generic than P^* . For example, the Pacific Fishery
1692 Management Council relies on a meta-analysis of the performance of past assessments to develop an
1693 overall level of assessment uncertainty to feed into the P^* approach (Ralston et al., 2011).

1694 Decision tables are another tool increasingly being used in stock assessments to show managers a range
1695 of outcomes if errors occur in certain aspects of the assessment. Decision tables contrast the effects of a
1696 range of possible management decisions (e.g., harvest levels) with a range of stock assessment
1697 scenarios. For example, this approach can show how a higher quota could quickly deplete a stock if the
1698 stock size is actually lower than the current estimate. Conversely, the table could show how a lower
1699 quota may result in missed fishing opportunity if stock biomass is actually higher than estimated.

1700 Another, more comprehensive decision-support tool is termed Management Strategy Evaluation (MSE;
1701 de la Mare, 1986; Smith et al., 1999; Punt et al., 2014). An MSE takes the basic concept of the decision
1702 table and plays it out in computer simulations many times to reveal the performance characteristics of
1703 the entire fishery–science–management system. MSEs contribute to a transparent decision-making
1704 process because they include stakeholders in the earliest stages where objectives are defined. This
1705 approach helps improve management decisions, from data collection, to modeling approaches, to
1706 harvest control rules that have the most needed properties. Essentially, any decision point in the
1707 science–management process can be evaluated using MSE, such as optimizing between fishery-
1708 independent versus fishery-dependent data collection (Cummings et al., 2016). Because of the variety of
1709 uncertainties that can be addressed using the MSE technique, NOAA Fisheries has been expanding its
1710 capacity in this rapidly growing field by supporting projects and hiring staff dedicated to conducting
1711 MSEs.

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1712 5.5. Strengths and challenges

1713

1714 NOAA Fisheries is a world leader in the science of stock assessment modeling. With substantial modeling
1715 expertise and sophisticated software, the assessment models used by NOAA Fisheries are accurate and
1716 efficient and can accommodate a variety of stocks with different types and qualities of data. These
1717 models provide the quantitative advice that has supported a successful and sustainable U.S. fisheries
1718 management system. However, despite many decades of assessment model evolution, old challenges
1719 remain unresolved (Maunder and Piner, 2014), and new issues have come to the forefront.

- 1720 • **More stock assessments should be linked to ecosystem or socioeconomic drivers.**

1721 All stock assessment models are simplifications of nature. They operate on less detailed spatial
1722 scales than the scale on which fish interact with fishing operations and their local habitats. The
1723 models tend to assume constant or randomly fluctuating rate processes that are rarely linked to
1724 specific ecosystem or socioeconomic causal factors. The standard assumption is that average,
1725 although variable, processes have been operating for the past decades, and these processes will
1726 continue to fluctuate around that same average in the future. However, as climate change and
1727 other mechanisms cause ecosystems to shift from recent average conditions, it may not be safe
1728 to assume that past conditions reflect the future. In fact, process errors (Section 5.4.1) may
1729 occur in some stock assessments when an assessment does not include important ecosystem
1730 effects.

1731

1732 Thus, the scopes of certain stock assessments need to be expanded to incorporate factors other
1733 than fishing that influence the status and likely future direction of harvested stocks. Many
1734 important processes and dynamics operate within an ecosystem; consequently, there is a
1735 variety of approaches to account for ecosystem dynamics within assessments. For instance,
1736 assessment models are generally flexible enough to incorporate factors related to climate
1737 change, predator–prey dynamics, habitat effects, species distributions and movements, and
1738 others in a variety of ways. The primary challenges to expanding assessments are in
1739 understanding the relationship between ecosystems and fish stocks and obtaining data that
1740 capture these relationships. Through ongoing research efforts and advanced techniques, NOAA
1741 Fisheries has made good progress in expanding the scope of certain assessments. As described
1742 in Box 5.1, NOAA Fisheries incorporates ecosystem factors into assessments where there is a
1743 strong case for doing so and the appropriate data are available.

1744

1745 Another important detail to consider regarding ecosystem and socioeconomic data and their
1746 incorporation in stock assessments is the ability to project those dynamics. Assessment models
1747 are used to develop forecasts of stock and fishery dynamics and predict future catches and stock
1748 status. These forecasts serve as the basis for developing recommendations regarding
1749 sustainable harvest levels. If features of the assessment model are linked to ecosystem or
1750 socioeconomic factors, then projections of those factors are needed. Certain ecosystem

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1751 dynamics can be forecasted with much higher skill than others, and the resolution of the
1752 forecasts needs to match that of the assessment forecasts. Thus, in addition to increasing
1753 ecosystem data collection and process studies, there is a need to improve forecast skill for
1754 important ecosystem dynamics on time and space scales that are relevant to fisheries
1755 management. Although Box 5.1 demonstrates progress in this area, there is a definite need for
1756 continued advancement, and increased use of additional data and drivers in stock assessments
1757 will be contingent on three important factors:

- 1758
- 1759 1. Continued research to understand linkages between stock dynamics and
1760 ecosystem/socioeconomic drivers
- 1761 2. Availability of relevant ecosystem/socioeconomic data (see Chapter 9)
1762
- 1763 3. Priority and capability for implementing expanded stock assessment models and forecasts (see
1764 Chapter 9 for a discussion of modeling capability and Chapter 10 for a prioritized approach to
1765 determining which assessments should be expanded) .
1766

- 1767 • **Guidance is needed for appropriately characterizing process errors.**

1768 There is a long history in stock assessments of exploring a variety of model configurations and
1769 model types within assessments although, historically, scientific advice has typically been based
1770 on the results from one “best” model run. However, scientists and managers are becoming less
1771 comfortable with relying on a single model and are increasingly interested in capturing multiple
1772 theories about stock and fishery dynamics to form the basis for quantitative advice. Using a
1773 range of models offers appropriate treatment of the true process error and uncertainty
1774 surrounding the advice, but there are several important considerations in need of research and
1775 guidance:

- 1776
- 1777 1. How should results from multiple stock assessment models be communicated and/or
1778 combined to provide advice to managers?
- 1779 2. What diagnostics and measures of model skill should be used when evaluating a suite of
1780 assessment models and selecting one or more model as the basis for management
1781 advice?
- 1782 3. How should the total uncertainty from a group of assessment models be appropriately
1783 characterized and used in the management process?
1784

- 1785 • **Research is still needed to inform basic stock assessment decisions.**

1786 The current stock assessment process works well in most cases. However, stock assessment
1787 models are complex and diverse, so despite decades of development and application, continued
1788 work is still needed to address the basic features and assumptions of these models. For
1789 instance, there are often requests to use new data sources (or all available data) within
1790 assessments. Yet, not all data are necessarily appropriate for assessments because they may not

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1791 adequately represent stock dynamics, they may not be in a format that is compatible with a
1792 particular assessment model, or they are made available too late in the assessment process to
1793 be evaluated sufficiently. Assessment models tend to perform better when there is strong
1794 contrast in the data; that is, the observations cover a range of conditions from high to low stock
1795 abundance and from high to low levels of fishing. Unfortunately, most sampling programs were
1796 not in place throughout the several decades in which fisheries have impacted fish stocks. As a
1797 result, the data are more informative about recent trends but not about the absolute condition
1798 of the stock relative to historical conditions that predate fishing. Where fish abundance data can
1799 be adjusted to provide assessments with measures of absolute abundance, the assessment then
1800 contains a strong anchor point regarding total biomass. The availability of absolute abundance is
1801 a major step forward in knowledge for stock assessments. Unfortunately, fish are difficult to
1802 sample in a fully calibrated way, so most surveys and fishery-dependent indices of abundance
1803 reflect relative changes over time but not absolute measures of fish abundance.

1804
1805 Stock assessment teams, review panels, and management groups (e.g., council SSCs) play an
1806 important role in determining which data sources should be incorporated into specific
1807 assessments. After data are selected and prepared for a particular assessment model there still
1808 may be issues to resolve. For example, more than one data set may capture particular aspects of
1809 the stock, but conflict in the information being passed to the model. This conflict can inflate
1810 uncertainty or create instability with the assessment model and therefore can result in a debate
1811 about how to statistically “weight” various data sources. The following list highlights several
1812 areas where further research and development are needed to provide objective, standardized,
1813 and quantitative approaches to help guide several basic decisions within stock assessments:

- 1814
- 1815 1. Selection and processing of a variety of data sources for use in assessments
 - 1816 2. Weighting of data sources within assessments
 - 1817 3. Dealing with conflicting information and correlated or confounded model components
- 1818

- 1819 • **Data-limited stock assessment methods do not provide complete information to managers.**
1820 With limited information, researchers cannot obtain the same results or certainty available in
1821 stock assessments that use more complete data. Unfortunately, filling these gaps by collecting
1822 more data is not the only answer, because for many stocks, data collection is technically difficult
1823 or cost prohibitive. Data-limited methods give us tools to prioritize stocks into those for which
1824 full assessments appear unnecessary, and those for which relevant data needs to be collected to
1825 conduct a more complete assessment. Thus, there is a need to manage expectations with data-
1826 limited stock assessments (Cummings et al., 2014) and a need to develop strategies for
1827 addressing fishery management needs and mandates when data are not available to do so.

1828

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1830 Box 5.1. NOAA Fisheries' stock assessments with ecosystem information

1831 NOAA Fisheries conducts stock assessments to produce scientific advice for fishery managers. The main
1832 objectives of fishery stock assessments are to evaluate stock status relative to defined limits, and to
1833 recommend harvest levels that optimize yield, prevent overfishing, and rebuild depleted stocks as
1834 necessary. In most cases, assessments are conducted from a single-species perspective, where ecosystem
1835 and environmental factors are not drivers of stock
1836 dynamics, but are assumed to either be constant or to
1837 contribute to unexplained variation in stock abundance or
1838 biology. However, for a number of stocks, ecosystem
1839 information has been directly incorporated into
1840 assessment models, thereby providing fishery managers
1841 with stock-specific advice that accounts for changes in
1842 the ecosystem. Some West Coast salmon forecasts are
1843 incorporate numerous ocean and ecosystem indicators.
1844 Assessments of certain North Pacific groundfish stocks
1845 and West Coast small pelagic stocks incorporate water
1846 temperature, because this variable affects the number of
1847 fish encountered by abundance surveys. The assessment
1848 of the butterfish stock in the northeast Atlantic also
1849 accounts for habitat effects on availability to abundance
1850 surveys. In addition, for Atlantic herring, northern
1851 shrimp, and Gulf of Mexico groupers, the numbers of fish
1852 that die due to natural causes (i.e., natural mortality) are
1853 modeled using ecosystem indices. With herring, an
1854 important prey species in the northeast Atlantic, predator
1855 dynamics are incorporated into the stock assessment, and
1856 for groupers, fishermen and scientists have observed events where large numbers of fish die when
1857 substantial red tides occur (i.e., harmful algal blooms). Thus, a red tide index is incorporated in the
1858 grouper stock assessments.



1859 The examples highlighted here refer to assessments that incorporated ecosystem data directly as drivers in
1860 the actual assessment models. However, ecosystem data can also be effectively considered when
1861 preparing assessment input data (or during other steps of the process not summarized here). The number
1862 of assessments that incorporate ecosystem data has continued to increase over time. In 2005, 4% of the
1863 stock assessments conducted by NOAA Fisheries included ecosystem factors, and by 2015 that number
1864 increased to 8%. As research and monitoring of stock and ecosystem dynamics continues to expand, the
1865 number of stock assessments and management measures that consider ecosystem variability and change
1866 will continue to increase.

1867

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- 2047

2048 Chapter 6. Quality Assurance in the Stock Assessment Process

2049

2050 Chapter highlights

- 2051 • **Objective peer reviews of stock assessments are necessary to help determine that the best**
- 2052 **scientific information available is used as the basis for fisheries management.**
- 2053 • **Independent regional peer review processes improve the integrity, reliability, and credibility**
- 2054 **of scientific information used for fishery management.**
- 2055 • **Stock assessment reviews vary in their extent in accordance with the “terms of reference”**
- 2056 **that guide a particular assessment peer review.**
- 2057 • **The review process provides transparency and opportunities for stakeholder input.**
- 2058 • **There is a trade-off between maintaining high standards for peer reviews and increasing the**
- 2059 **number of completed assessments.**

2060

2061 6.1.0. National guidance on science quality assurance

2062

2063 National Standard 2 (NS2) of the 2007 MSA specifies that conservation and management measures for
2064 federally managed fisheries should be based upon the best scientific information available (BSIA). The
2065 NS2 Guidelines were developed to ensure that the BSIA is used when providing advice to fishery
2066 management councils (NOAA, 2013; NOAA, 2016). This guidance includes the following criteria for
2067 evaluating BSIA: relevance, inclusiveness, objectivity, transparency and openness, timeliness,
2068 verification and validation, and peer review as appropriate. Scientific peer review is described as an
2069 important criterion in determining the BSIA, and for situations where rigorous, independent peer review
2070 is necessary, the NS2 Guidelines adopt many of the Office of Management and Budget (OMB) peer
2071 review standards (OMB 2004). These standards include balance in expertise, knowledge, and bias; lack
2072 of conflicts of interest; independence from the work being reviewed; and transparency of the peer
2073 review process. The NS2 Guidelines recognize that varying degrees of independence may be required for
2074 various reviews depending on the novelty, controversy, and complexity of the review. For example, an
2075 assessment update may be sufficiently reviewed with only regional expertise, while a review of
2076 emerging methods or controversial topics may require a more rigorous, independent peer review
2077 process. Deciding on an appropriate scope for the review is linked with how best to balance the need for
2078 a high quantity of assessments for timely management decisions with the need for rigorous peer
2079 reviews when necessary.

2080

2081 The NS2 Guidelines indicate that regional science centers and their respective councils have the
2082 discretion to determine the appropriate form of peer review needed for each stock assessment. The
2083 guidelines also clarify the role of the Fishery Management Councils' Science and Statistical Committees
2084 (SSCs) in the scientific review process. A peer review process is not a substitute for an SSC, but should

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2085 work in conjunction with the SSC. The NS2 Guidelines also clarified the contents of the Stock Assessment
2086 and Fishery Evaluation (SAFE) report, which can consist of a set of documents that a council uses to
2087 make decisions. The overall objectives of the NS2 Guidelines are to ensure the highest level of integrity
2088 and strengthen public confidence in the quality, validity, and reliability of scientific information
2089 distributed by NOAA Fisheries to support fishery management actions.

2090

2091 **6.2.0. Overview of the stock assessment review process for fisheries** 2092 **management**

2093

2094 Well-established peer review processes are in place in each region (NOAA, 2016). Each peer review can
2095 vary based on the different stages of the review (e.g., review of the data collection, modeling methods,
2096 and assessment results); the form of the review; or the degree of thoroughness needed. Throughout
2097 these stages, reviews may be conducted internally by regional experts or they may be conducted by
2098 independent reviewers as coordinated by the Center for Independent Experts (CIE). Most often, review
2099 panels consist of a range of expertise including experts with regional knowledge and independent
2100 experts selected through the CIE process. NOAA Fisheries' Office of Science and Technology administers
2101 a contract for the CIE process but the deliverables of the CIE are handled independently. The CIE process
2102 autonomously selects highly qualified peer reviewers, and this rigorous CIE peer review process is most
2103 often used to evaluate benchmark assessments, emerging methods and science, or other potentially
2104 controversial topics (e.g., biological opinions or recovery plans). Typically, CIE reviews are conducted in
2105 person, but "desktop" reviews are also conducted when time and expenses need to be minimized, and
2106 the limitations of a remotely conducted review are acceptable.

2107

2108 The decision to establish a peer review, according to MSA section 302(g)(1)(E), is made jointly by the
2109 Secretary of NOAA Fisheries and a regional council (NOAA, 2016; NOAA 2013). Therefore, the scope of
2110 the review as defined by the review terms of reference (ToR) is established jointly among the pertinent
2111 NOAA Fisheries science center and relevant council(s). Accordingly, councils and science centers are
2112 given discretion to determine the form of peer review used for each stock assessment. For example, a
2113 science center and the relevant council(s) may determine the form of review needed (e.g., panel or desk
2114 review), establish the ToR for the review, and request the combination of expertise required, and
2115 whether independent CIE reviewers will participate on the review panel. Each regional peer review
2116 process incorporates this partnership among the science center and its respective council(s), and each
2117 process complies with the NS2 Guidelines (NOAA, 2016).

2118

2119 The overall review process and the NS2 guidelines provide sufficient flexibility for the science centers
2120 and their respective councils to determine when a peer review is needed, the form of review, and the
2121 degree of rigor needed in the peer review. However, these decisions must also consider the need to
2122 maintain a relatively high rate of completion of stock assessments to support timely management
2123 decisions. To meet this need, rigorous peer reviews should be reserved for products such as benchmark

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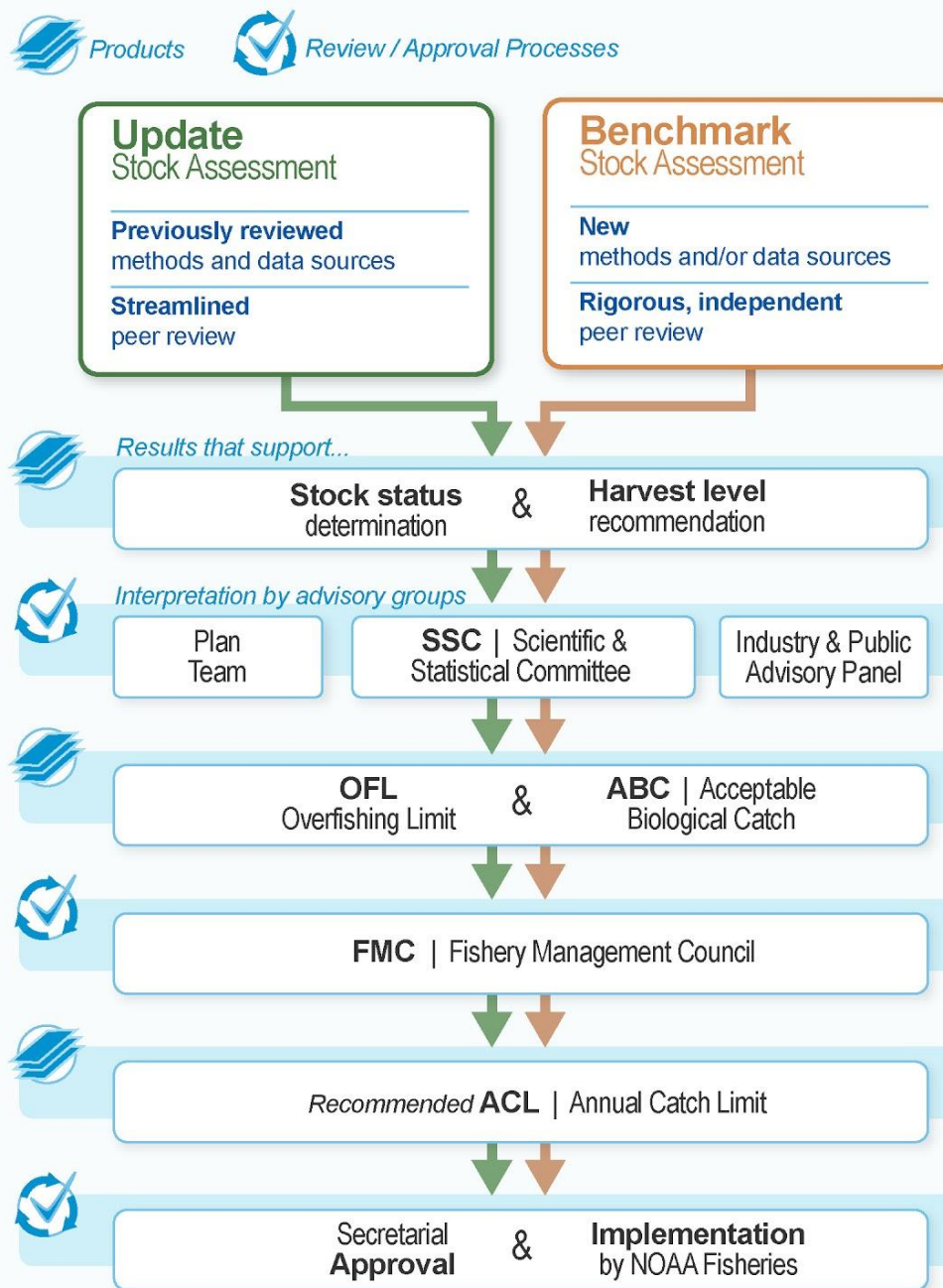
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2124 assessments, emerging methods, or potentially controversial topics (e.g., biological opinions and
2125 recovery plans). For these products, review panels are often balanced with both regional and
2126 independent perspectives in the review process, and stock assessments are often subject to a series of
2127 reviews involving NOAA Fisheries, SSCs, and external CIE review before the scientific information (e.g.,
2128 SAFE report and peer review reports) is sent to the council's SSC advisory panel for its evaluation and
2129 recommendations. Other reviews, such as routine update assessments, do not require a high degree of
2130 independence, allowing for a more streamlined review process by regional experts and the council's
2131 SSC. NS2 Guidelines provide clarification that participation by the SSC in the peer review process is
2132 acceptable as long as their participation is compliant with the peer review standards and does not
2133 interfere with their primary role of providing an evaluation and recommendations to their council.
2134

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NOAA Fisheries Generic Stock Assessment to Management Process



2135
2136 **Figure 6.1.** Generic overview of the process from a draft stock assessment to management decisions,
2137 including independent review, advisory bodies, council decisions, and final approval by NOAA Fisheries.
2138 While fishery management councils are responsible for recommending annual catch limits, NOAA
2139 Fisheries determines stock status for federally managed stocks and this action occurs in parallel to the

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2140 process depicted in this figure. (Note: This figure does not provide a detailed representation of each
2141 regional process.)

2142

2143 Overall, NOAA Fisheries' stock assessments are subject to appropriate levels of peer review before they
2144 are used as a basis for fishery management decisions. Figure 6.1 provides a generic representation of
2145 the process by which a stock assessment supports fishery management and is used to develop and
2146 implement catch limits. The details of the actual regional peer review processes vary across regions and
2147 do not strictly adhere to Figure 6.1. For federally managed (and certain interstate commission-managed
2148 stocks), the regional review processes are managed under regional entities, such as Southeast Data
2149 Assessment and Review (SEDAR), the Stock Assessment Workshop/Stock Assessment Review Committee
2150 (SAW/SARC), Stock Assessment Review (STAR), the Western Pacific Stock Assessment Review (WPSAR),
2151 and the North Pacific Plan Team stock assessment review process. Fishery Management Councils, in
2152 partnership with the science centers, use these regional processes in combination with their internal
2153 reviews and the independent CIE reviews. In all cases, review meetings are announced publicly and open
2154 to the public.

2155

2156 **6.3. Regional stock assessment review processes**

2157

2158 Each current regional review process is described briefly in the following sections and compared in Table
2159 6.1. Although these processes encompass many federally managed stocks, NOAA Fisheries participates
2160 in a variety of other stock assessment review processes, particularly for stocks managed under
2161 transboundary and international agreements (i.e., authorities other than the MSA). Because these
2162 processes are quite diverse, and typically established through international partnerships, this section
2163 focuses on the review processes specific to federally managed stocks.

2164

2165 **6.3.1. Southeast Data, Assessment, and Review (SEDAR)**

2166

2167 The SEDAR process was jointly established in 2002 by the NOAA Fisheries' Southeast Fisheries Center
2168 (SEFSC) and Southeast Regional Office (SERO), Southeast Atlantic Fishery Management Council (SAFMC),
2169 Gulf of Mexico Fishery Management Council (GMFMC), and Caribbean Fishery Management Council
2170 (CFMC). The SEDAR process has improved the quality and transparency of fishery stock assessments in
2171 the Atlantic, Gulf of Mexico, and U.S. Caribbean regions. The SEDAR process also works in partnership
2172 with the Atlantic and Gulf States Marine Fisheries Commissions. The SEDAR Steering Committee, which
2173 consists of members from the SEFSC, councils, and Atlantic and Gulf States Marine Fisheries
2174 Commissions, determines the stocks that will be assessed and reviewed in a given year. Many stocks are
2175 assessed on a 3- to 5-year cycle, although higher priority stocks may be assessed more frequently. The
2176 SEDAR Steering Committee also determines the scope for each stock assessment (such as standard,
2177 benchmark, and update assessment). Stock assessment ToR are developed and reviewed by SSCs and
2178 SEFSC analytical staff prior to finalization, ensuring the ToR are appropriate for the species assessed.

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2180 The SEDAR process is organized around a series of workshops. In data workshops, datasets are
2181 documented, analyzed, and reviewed, and data for conducting assessment analyses are compiled. In
2182 assessment workshops, quantitative population analyses are developed and refined and stock
2183 assessment parameters are estimated. Finally, in review workshops, a panel of independent experts
2184 reviews the data and assessment analyses and recommends the most appropriate values of critical
2185 population and management quantities. The review workshops typically include a panel composed of
2186 CIE reviewers as well as council SSC appointees. The process takes approximately 6 to 9 months for a
2187 benchmark assessment and 3 to 5 months for an update. Current staffing levels at the SEFSC allow a
2188 total of five to seven SEDAR benchmark assessments per year in across the Gulf of Mexico, Atlantic, and
2189 U.S. Caribbean regions. Additional assessments are then possible if they are conducted as updates. All
2190 SEDAR workshops are open to the public, and SEDAR emphasizes constituent and stakeholder
2191 participation in assessment development, transparency in the assessment process, and a rigorous and
2192 independent scientific review of completed stock assessments. The relatively elaborate review process
2193 implemented by SEDAR, a high level of transparency at each step, and a typical need for compiling data
2194 from a wide variety of sources in the Southeast region creates several bottlenecks that limit the number
2195 of assessments produced in the Southeast.

2196

2197 6.3.2. Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC)

2198

2199 Beginning in 1985, the SAW/SARC process was jointly established by the NOAA Fisheries' Northeast
2200 Fisheries Science Center (NEFSC), Greater Atlantic Regional Fisheries Office (GARFO), New England
2201 Fishery Management Council (NEFMC), Mid-Atlantic Fishery Management Council (MAFMC), and
2202 Atlantic States Marine Fisheries Commission (ASMFC). The SAW is a formal protocol designed to prepare
2203 and review assessments of fish and invertebrate stocks in the offshore U.S. waters of the northwest
2204 Atlantic, and facilitates federally led stock assessments for the New England and Mid-Atlantic Fishery
2205 Management Councils as well as state-led assessments for the Atlantic States Maine Fisheries
2206 Commission. Within the SAW, assessments are peer reviewed by an independent panel of stock
2207 assessment experts called the Stock Assessment Review Committee (SARC). The SAW/SARC process is
2208 overseen by the Northeast Regional Coordinating Council (NRCC), which includes directors and chairs of
2209 leading partner organizations. These committee members are responsible for developing a 2-year
2210 schedule for stock assessments and helping to develop and approve the stock assessment ToR with the
2211 councils and their SSCs. The SAW/SARC was primarily established for benchmark stock assessments, but
2212 other efforts such as update assessments, operational assessments, and data-limited evaluations are
2213 also facilitated.

2214

2215 The SAW/SARC process includes a series of meetings that are fully open to the public. There are industry
2216 meetings, data meetings, model meetings, and finally peer review meetings where the SARC is asked to
2217 determine the adequacy of the assessments in providing a scientific basis for management. The SARC
2218 panel may accept or reject an assessment, and each SARC panelist provides a written review
2219 approximately 5 weeks after the peer review meeting. The panel also provides an overall written

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2220 summary of the proceedings. There are approximately two SARC meetings per year and within each,
2221 two or three stock assessments are typically reviewed. Additional assessments are conducted on stocks
2222 in the northwest Atlantic, but these are reviewed through other processes, such as internally through
2223 the council's SSC. Similar to SEDAR, the SAW/SARC process for benchmark assessments is relatively
2224 time-intensive and therefore limits the number of assessments produced. However, to improve the
2225 number of assessments conducted, the northeast region also produces update or "operational"
2226 assessments that rely on the council's SSC to offer a more streamlined review.

2227

2228 6.3.3. Stock Assessment Review (STAR)

2229

2230 The STAR process was established in 1998 to provide peer review of the scientific information (primarily
2231 stock assessments) used for management of Pacific groundfish and coastal midwater species. Thus, the
2232 STAR process is coordinated by the Pacific Fishery Management Council (PFMC), NOAA Fisheries'
2233 Northwest Fisheries Science Center (NWFSC), Southwest Fisheries Science Center (SWFSC), and West
2234 Coast Region (WCR). The PFMC oversees the process and involves its standing advisory bodies,
2235 particularly their SSC. Together, NOAA Fisheries and the PFMC consult with all interested parties to plan
2236 and prepare the ToR and develop a calendar of events with a list of deliverables for final approval by the
2237 council. NOAA Fisheries and the council share fiscal and logistical responsibilities and both strive to
2238 ensure that there are no conflicts of interest in the STAR process.

2239

2240 STAR panels include a chair appointed from the relevant SSC subcommittee (i.e., groundfish or coastal
2241 pelagic species) and three other experienced stock assessment analysts with knowledge of the specific
2242 modeling approaches being reviewed. Of these three members, at least one is typically appointed from
2243 the CIE and at least one should be familiar with west coast stock assessment practices. For groundfish,
2244 an attempt is made to identify one reviewer who can consistently attend all STAR panel meetings in an
2245 assessment cycle. Given these constraints, the pool of qualified technical reviewers is limited, and it can
2246 be difficult to meet all conditions when staffing STAR panels. Groundfish STAR panel meetings occur
2247 every 2 years, whereas reviews of Pacific sardine occur every 3 years and reviews of Pacific mackerel
2248 every 4. The resulting "off years" allow time for conducting research and improving stock assessments.
2249 Typically, three to five STAR panel meetings for groundfish are held during each assessment cycle ("on
2250 year") and one meeting for a coastal pelagic species (either Pacific sardine or Pacific Mackerel). The
2251 panels normally meet for 1 week, and the number of assessments reviewed per panel typically does not
2252 exceed two, except in extraordinary circumstances when the SSC and NOAA Fisheries agree that it is
2253 advisable, feasible, and necessary. For groundfish species, the SSC reviews the STAR panel report and
2254 recommends whether an assessment should be further reviewed at the so-called "mop-up" panel
2255 meeting, a meeting of the SSC's groundfish subcommittee that occurs after all of the STAR panels,
2256 primarily to review rebuilding analyses for overfished stocks. If an assessment is found unacceptable for
2257 use in managing coastal pelagic species, a full assessment would be conducted the following year. The
2258 entire STAR process is fully transparent, and all documents and meetings are open to the public with
2259 opportunity for public comment.

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2260

2261 6.3.4. Western Pacific Stock Assessment Review (WPSAR)

2262

2263 The WPSAR process was established in 2010 to improve the quality and reliability of stock assessments
2264 for fishery resources in the Pacific Islands region. This region encompasses a range of fisheries and
2265 ecosystems, including the American Samoa Archipelago, Hawaii Archipelago, Mariana Archipelago,
2266 Pacific Remote Island Areas, and Pacific pelagic stocks. The Western Pacific Regional Fishery
2267 Management Council (WPRFMC), Pacific Islands Fisheries Science Center (PIFSC), and Pacific Islands
2268 Regional Office (PIRO) share responsibilities in implementing the WPSAR process. The WPRFMC, PIFSC,
2269 and PIRO provide a coordinator to work together to oversee and facilitate the review process, with
2270 direction from the WPSAR Steering Committee that consists of the directors (or their designees) of the
2271 science center, regional office, and council. The three coordinators work under the direction of the
2272 Steering Committee to plan and organize reviews, prepare ToR, and develop a schedule according to a
2273 multi-year planning cycle. Fiscal and logistical responsibilities are shared among the science center,
2274 regional office, and the council.

2275

2276 The WPSAR framework has been modified over time and currently uses two different approaches for
2277 the review and acceptance of stock assessment research products in the Pacific Islands region. For
2278 benchmark reviews, new stock assessment methods not previously used for management consideration
2279 and any major changes to a previous assessment (beyond inclusion of additional years of data) will
2280 undergo a panel review, most likely in person. This panel will have a chair who will also be a member of
2281 the council's SSC, and all other panel members will be external independent experts who will provide a
2282 review. For update reviews, where assessments have changed only by the addition of recent years of
2283 data, one to three experts will provide a review, most likely by desktop. These experts may consist of all
2284 PIFSC or SSC personnel. For any review, the WPSAR Steering Committee can decide to use CIE as the
2285 review mechanism. Any in-person reviews are open to the public to encourage constituent/stakeholder
2286 participation and ensure rigorous, transparent, and independent scientific review of completed
2287 assessments.

2288

2289 6.3.5. North Pacific Plan Team Stock Assessment Review Process

2290

2291 A variety of stocks fall under the jurisdiction of the North Pacific Fishery Management Council (NPFMC),
2292 including groundfish and invertebrates in the Gulf of Alaska (GOA), Bering Sea (BS), and the Aleutian
2293 Islands (AI). NOAA Fisheries' Alaska Fisheries Science Center (AFSC) is responsible for stock assessments
2294 for 22 species or species groups under the groundfish fishery management plan (FMP) for the Gulf of
2295 Alaska (GOA) and approximately 26 species or species groups under the Bering Sea/Aleutian Islands
2296 BS/AI Groundfish FMP. The Alaska Department of Fish and Game (ADF&G) is responsible for one stock
2297 assessment in the GOA groundfish FMP. The AFSC and ADF&G share assessment responsibilities for the
2298 10 species in the BS/AI King and Tanner Crab FMP, and the ADF&G has responsibility for assessing
2299 scallops. The NPFMC, AFSC, Alaska Regional Office (AKRO), and the ADF&G collaborate on the

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2300 preparation and conduct of the review of North Pacific stock assessments. The stock assessments and
2301 reviews are guided by generic ToR¹⁹ rather than ToR specific to particular stocks. The review process in
2302 this region includes partnerships with federal and state agencies and academic institutions who
2303 participate in the stock assessment review and advisory process, such as the Council's Plan Teams, SSC,
2304 and Advisory Panel. Separate teams are appointed for the BSAI and GOA, comprising 12 members each.
2305 The teams meet twice a year (3 ½ days in September and 5 days in November). They meet jointly for 1½
2306 days on issues of common interest, including information related to ecosystems, economics,
2307 management, research priorities, and so on. The teams meet separately to review survey data reports
2308 and stock assessments. Their recommendations on the stock assessments, overfishing limits (OFLs), and
2309 acceptable biological catch (ABC) levels are reviewed by the Council's SSC.

2310
2311 The review process has evolved over the past 2 ½ decades to become more streamlined than most
2312 regional processes. Essentially, all stocks managed by the NPFMC are evaluated and reviewed according
2313 to the frequency of the scientific survey upon which the assessment is based. The groundfish trawl
2314 survey in the Eastern Bering Sea (EBS) is conducted annually; therefore, most EBS stocks are assessed
2315 each year. Groundfish trawl surveys in the Gulf of Alaska (GOA) and Aleutian Islands (AI) alternate years
2316 (surveys in the GOA conducted during odd numbered years, and surveys in the AI during even numbered
2317 years). Despite this general schedule, certain stocks (e.g., walleye pollock, Pacific cod, and Atka
2318 mackerel) are assessed annually to prevent these groundfish fisheries from causing jeopardy of
2319 extinction of Stellar sea lions or adverse modification of their critical habitat. A combined GOA/EBS/AI
2320 assessment of sablefish occurs each year, timed with the annual frequency of the sablefish longline
2321 survey in the GOA, and alternating surveys for EBS and AI in odd and even years, respectively..

2322
2323 Typically, update assessments (termed "full assessments") are conducted for developing harvest advice
2324 for the following 2 years. The 2-year cycle allows for the use of the most recent biological information in
2325 the stock assessment while eliminating potential delays or gaps in setting the second year's limits. In the
2326 off years, partial update assessments ("executive summaries") are performed to reevaluate the scientific
2327 advice without conducting a full assessment. The stock assessment updates are compiled in a Stock
2328 Assessment and Fishery Evaluation (SAFE) report. After review and revision, the draft SAFE reports are
2329 released by the science center for pre-dissemination to the council's Plan Teams for review. Plan Teams
2330 review the SAFE reports and make recommendations to the SSC. The SSC then reviews the SAFE reports
2331 as well as the Plan Team recommendations and provides the NPFMC with an ABC and OFL
2332 recommendation for each stock. The council provides public notice of the meetings of its Plan Teams
2333 and SSC and when SAFE reviews are being conducted; procedures are in place to allow for public
2334 comment at these meetings. Although routine updates are necessary for a streamlined annual
2335 assessment and review cycle, recommendations for improving assessments are made and reviewed by
2336 the SSC during the year to allow for improvements without requiring a more comprehensive review

¹⁹ http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Groundfish/GPT_TOR.pdf

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2337 process. However, in addition to the normal schedule of assessment updates and reviews, a separate
2338 review schedule is maintained, with the goal of obtaining an independent CIE review of each stock
2339 assessment about once every 5 years. These more involved reviews are scheduled so that they do not
2340 affect the relatively efficient annual cycle.

2341
2342 Table 6.1. Comparison of regional stock assessment and peer review processes used in the management
2343 of U.S. fisheries.

	Peer review process				
	SEDAR	SAW/SARC	STAR	WPSAR	North Pacific Plan Teams
Year initiated	2002	1985	1998	2010	1989
Region(s) covered	Southeast coast, Gulf of Mexico, Caribbean	Northeast coast	West coast	Pacific Islands	Gulf of Alaska, Bering Sea, Aleutian Islands
Council(s) supported	SAFMC, GMFMC, CFMC	NEFMC, MAFMC	PFMC	WPFMC	NPFMC
Other entities supported	ASMFC, GSMFC, HMS Sharks	ASMFC	-	-	-
Science center(s) participating	SEFSC	NEFSC	NWFSC, SWFSC	PIFSC	AFSC
Typical review panel	CIE and SSC	CIE and SSC	SSC, CIE, and other	SSC, PIFSC, CIE, and other	SSC, CIE (roughly every 5 years per stock)

2344
2345 **6.4. Quality assurance of stock assessments for partner organizations**
2346

2347 The United States has interests in numerous fisheries, not just the federally managed stocks that fall
2348 under the MSA. As a result, NOAA Fisheries contributes to assessments of many stocks managed by
2349 partner organizations, such as interstate commissions, state agencies, tribal organizations, international
2350 regional fishery management organizations (RFMOs), and organizations related to a variety of
2351 international treaties and agreements (Figure 3.1). The processes by which these assessments are
2352 reviewed are under the discretion of each partner organization. NOAA Fisheries works with these groups
2353 to comply with their respective review processes, but the processes are not bound to MSA mandates. In

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2354 some cases, CIE reviewers are used, and NOAA Fisheries helps to facilitate these reviews. Also, certain
2355 partner organizations rely on the regional processes described in Sections 6.3.1 to 6.3.5. For example,
2356 the Atlantic States Marine Fisheries Commission uses the SEDAR and SAW/SARC processes for many of
2357 its stock assessments.

2358

2359 6.5. Strengths and challenges

2360

2361 NOAA Fisheries, the Fishery Management Councils, and many other partners and stakeholders ensure
2362 that high-quality scientific advice (i.e., BSIA) is provided to fishery managers by strictly adhering to MSA
2363 mandates and related guidance. The NS2 Guidelines of the MSA, which emphasize the importance of
2364 peer review, have helped to build confidence and trust among managers and stakeholders that the BSIA
2365 is used in the fishery management process. However, the peer review process presents strengths and
2366 challenges that must be considered to meet the increasing demand to provide timely assessments for
2367 management decisions. For this reason, more careful prioritization is needed when balancing reviews
2368 that require a more rigorous a peer review process (e.g., CIE peer review) and reviews that can be
2369 conducted in a more streamlined manner. Further, NOAA Fisheries facilitates and helps to improve stock
2370 assessment peer reviews through partnerships with numerous management agencies that are not
2371 governed by the MSA. Collectively, a substantial amount of attention is being dedicated toward quality
2372 assurance for stock assessments. These efforts have improved the credibility of the fishery management
2373 process and increased the quality and transparency of fishery management decisions. For federally
2374 managed fisheries, these improvements have contributed to nearly eliminating overfishing, rebuilding
2375 many important stocks, and ensuring the long-term sustainability of marine resources and resiliency of
2376 fishing communities. However, many challenges and tradeoffs associated with the current assessment
2377 review process remain that warrant consideration. The following list briefly describes these issues.

2378

- 2379 • **Comprehensive peer reviews create a bottleneck that affects the rate at which assessments**
2380 **can be completed.**

2381 Conducting an exhaustive independent peer review of a stock assessment requires substantial
2382 time, effort, and resources and should be used when appropriate. Thus, there is a tradeoff
2383 between the level of rigor dedicated to reviews and the number of assessments that can be
2384 conducted. The regional processes vary in how they prioritize assessment quantity versus review
2385 thoroughness. For example, the NPFMC conducts internal reviews of many assessment updates
2386 each year using council committees, whereas SEDAR coordinates fewer reviews that use a
2387 comprehensive process, particularly for "benchmark" assessments, that relies on the CIE. The
2388 actual review workshop organized by SEDAR lasts only 1 week, and that alone is not a
2389 bottleneck in the assessment completion rate. However, the assessment process coordinated by
2390 SEDAR for benchmark assessments involves multiple workshops (data, assessment, and review)
2391 with public participation and review at each. This multi-step process does limit the number of
2392 assessments completed in this region.

2393

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2394 Whether the reviews are comprehensive and independent, internal and smaller scale, or some
2395 combination of each, all current approaches comply with MSA mandates. Therefore, it is up to
2396 the various regional partners to determine what is most needed for successful fishery
2397 management in their region. Generally, comprehensive CIE reviews are not necessary when a
2398 stock assessment is not substantially different from an assessment that was previously deemed
2399 sufficient for management purposes (for a particular stock). A desktop CIE review is available
2400 when there is a need for fully independent peer review and a desire to minimize time and
2401 expenses dedicated to the review. However, desktop reviews can be challenging for reviewers
2402 to fully understand the scope and context of the review. Further, due to strict conflict of interest
2403 regulations and limited availability of independent CIE experts, considerable lead time is
2404 required for contracting and arranging travel for CIE reviewers (approximately 80% tend to be
2405 foreign nationals). Therefore, more rigorous reviews that require a high degree of independence
2406 (i.e., panel review with CIE reviewers) should be used sparingly. For example, these reviews
2407 could be reserved for benchmark assessments that are substantially different from a stock's
2408 previous assessment, assessments that include new or emerging methods, or for scientific
2409 information on potentially controversial issues.

2410

2411 • **Fully independent reviews may not always provide the best evaluation of the science.**

2412 NS2 provides guidance on balancing the perspectives of peer reviewers and the varying degree
2413 of independence needed for a review. Although the CIE tends to provide the highest degree of
2414 independence, there are drawbacks to using a CIE panel in addition to increased cost and time.
2415 Reviewers with a higher degree of independence (e.g., CIE reviewers) most often have little to
2416 no prior experience with the regional ecosystem or stock being assessed, and in certain
2417 instances, this might result in erroneous interpretation of the information under review due to
2418 the lack of familiarity with regional issues. Balancing a panel of reviewers with regional expertise
2419 may have benefits in this regard. Given variation in familiarity and the limited pool of CIE
2420 panelists, there also can be a lack of consistency across reviews. This inconsistency may cause
2421 some researchers to feel that the nature of the criticisms and potentially the rejection or
2422 acceptance of a particular assessment is driven more by the composition of the review panel
2423 than the quality of the science. This perception can create instability in the management
2424 process. The STAR process addresses this inconsistency by using a primary reviewer who
2425 participates in all its panel reviews during each review cycle (as well as reviewers with regional
2426 expertise such as SSC members).

2427

2428 • **There is a need for consistent documentation and transparent results in the peer review
2429 process.**

2430 Although the stock assessment peer review process offers a high degree of transparency and
2431 provides ample opportunity for stakeholder engagement, further improvements in the
2432 consistency and transparency can be made regarding the information used in the peer review
2433 process (e.g., SAFE reports) and the peer review results. All meetings are open to the public, and

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2434 relevant documents, including assessment and reviewer reports, are generally provided and
2435 made available on publicly accessible websites. The CIE peer review reports are also made
2436 publicly available. However, there are instances where it is unclear in the final stock assessment
2437 report just how the peer review influenced the final product and improved the overall
2438 management advice. Because there is not a standard format across regions for reporting the
2439 conclusions of the review panel—and what, if any, adjustments or additional analyses were
2440 performed to address reviewer comments—this information can be difficult to locate or
2441 inconsistently reported. When stakeholders cannot find this information, they may perceive the
2442 process as less transparent than intended.

2443

2444 • **Well-defined ToR are critical for successful stock assessment reviews.**

2445 Establishing well-defined ToR can provide an appropriate scope for the review, define
2446 appropriate levels of expertise and independence for reviewers, ensure that reviewers focus on
2447 the key elements of the assessment, and describe how to document and respond to reviewer
2448 comments. Thus, the ToR for each regional peer review process and CIE review are established
2449 before the peer review is conducted (NOAA, 2016). To maintain successful peer review
2450 processes, improvements may be needed to ensure that future reviews are conducted
2451 appropriately and are most beneficial to the fishery management process. For this reason, it is
2452 beneficial for the science centers and their respective councils to jointly establish the ToR. In
2453 certain instances, reviewers have focused on aspects of the assessment that are less critical to
2454 ensuring high-quality advice. For example, reviewers may be tempted to focus on reviewing
2455 previously established methods, or previously reviewed data sets, rather than the way in which
2456 assessment methods were applied given the available data. Also, in some cases the number of
2457 additional analyses that can be requested by reviewers is unlimited. Issues such as these can
2458 result in a burdensome review process that may not improve the resulting scientific advice. The
2459 success of the review also depends on the chair who serves in the impartial facilitation of a
2460 panel review based on the ToR.

2461

2462 • **Externally provided stock assessments must be subject to the regional peer review process.**

2463 On occasion, entities other than NOAA Fisheries conduct assessments of federally managed
2464 stocks. These assessments may be well integrated into the management process or outside
2465 normal procedures. Typically, external assessments are commissioned by a stakeholder either to
2466 fill a data gap that is not being addressed or to provide an alternative perspective in an ongoing
2467 assessment. External assessments can be helpful when they provide advice for stocks that
2468 cannot be assessed in a timely fashion, thereby assisting with the assessment workload, or when
2469 they contribute additional analyses for consideration in an ongoing assessment. However,
2470 external assessments can also be disruptive, especially when they are provided late in the
2471 management process or without sufficient documentation to critically evaluate the approach. In
2472 these cases, the assessment tends to compete or conflict with the federal stock assessment
2473 without being subject to an equivalent level of peer review. Establishing well-defined ToR for

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2474 peer review of externally provided stock assessments, as described earlier, helps to mitigate
2475 some potential concerns. Unless the alternative analyses are contributed early in the
2476 assessment process and included in the peer review, these analyses should not have a strong
2477 influence on management decisions. As the contribution of external assessments continues to
2478 increase, many councils have developed or are developing protocols for including these
2479 assessments in the management process.

2480

2481 Although current approaches to stock assessment quality assurance address MSA mandates and result
2482 in high-quality scientific advice being provided to managers, there is room for improvement as discussed
2483 earlier, and recommendations for addressing these issues are provided in Section III. In particular,
2484 Chapter 10 describes a stock assessment process that strives to be timely and efficient while also
2485 maintaining thoroughness and transparency. These improvements rely on an objective approach to
2486 stock assessment prioritization that will optimize the completion rates of assessments by determining
2487 which stocks need assessments and the level at which those assessments should be conducted.

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2491

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2497

2498 **Chapter 7—An Introduction to the Future of NOAA Fisheries'**
2499 **Stock Assessments**

2500 **Chapter highlights:**

- 2501 • **Three primary objectives make up NOAA Fisheries' next generation stock assessment (NGSA)**
2502 **enterprise:**
 - 2503 1. **Expand the scope of many stock assessments and support harvest policies that are**
2504 **more holistic and ecosystem-linked following a strategic approach that makes best use**
2505 **of available resources.**
 - 2506 2. **Use innovative science and technological advancements to improve assessments and**
2507 **establish robust harvest policies to manage stocks between assessments.**
 - 2508 3. **Create a more timely, efficient, and effective stock assessment process that prioritizes**
2509 **stock-specific goals and objectives.**

2510 **7.1. Summary of challenges and the need for improvement**

2511 NOAA Fisheries' stock assessment enterprise faces numerous demands from federal operations, fishery
2512 managers, and interested parties. There are conflicting requests to make stock assessments simpler,
2513 more comprehensive, based on better data, ecosystem-linked, more transparent to affected parties,
2514 prioritized, updated using the latest data and model advancements, quicker to produce, and other
2515 demands. Many aspects of these demands are difficult to satisfy and some are mutually exclusive, as
2516 described in the following examples:

- 2517 • Assessments could be simpler if they had access to reliable, basic data streams regarding the
2518 abundance of fish stocks. Much of the complexity of assessments is due to the advanced
2519 statistical efforts used to overcome various shortcomings in the data.
- 2520 • Assessments could be updated more quickly if they used standardized, streamlined data
2521 systems and standard modeling methods. Improvements to assessment data and models could
2522 then be made by conducting research outside the normal management process, rather than
2523 attempting to develop new operational methods during a constrained management process.
- 2524 • Assessments could be more comprehensive given that data and procedures to build in broader
2525 system-level mechanisms are available. Most assessments incorporate environmental and
2526 ecosystem changes indirectly and without including the actual mechanism driving the changes;
2527 hence, they have very little ability to project changes in future stock conditions that may occur
2528 as a result of future environmental and ecosystem changes.
- 2529 • The effort to include all possible data in an assessment expands the assessment's complexity,
2530 obscures transparency, and reduces efficiency in the process because all data in an assessment
2531 require proper documentation, analysis, and review. Thus, this reduced efficiency is
2532 compounded by the preference for full transparency and comprehensive public review.

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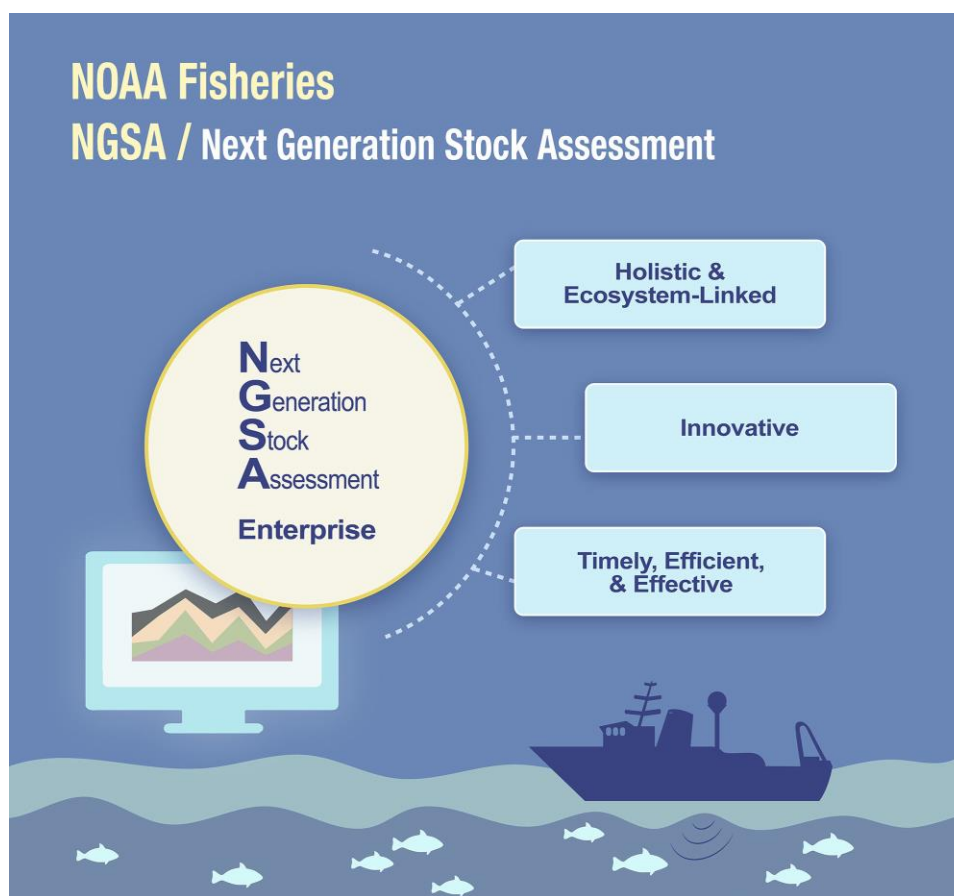
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2533 The NGSAs framework is designed as a roadmap to address and balance the various demands on the
2534 stock assessment enterprise. There are three main themes to this framework (Figure 7.1):

- 2535 a. Expanding the scope of stock assessments to be more holistic and ecosystem-linked
2536 (Chapter 8)
2537 b. Using innovative science and advanced technologies to improve data and analytical
2538 methods (Chapter 9)
2539 c. Establishing a timely, efficient, and effective stock assessment process (Chapter 10)

2540

2541 **Figure 7.1.** The three primary objectives that comprise NOAA Fisheries' NGSAs.



2542

2543 **7.2. Holistic and ecosystem-linked stock assessments**

2544 Today, fishery assessments are mainly designed to analyze a dynamic system in which fishing is the
2545 dominant force and ecosystem factors produce random changes that can be dealt with statistically. This
2546 approach has successfully guided fishery management toward preventing overfishing and rebuilding
2547 depleted fish stocks, but it lacks the ability to provide advice that directly accounts for expected changes
2548 in ecosystems. When faced with ecosystems that are shifting into previously unobserved states, which

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2549 is an expected result of climate change, the quasi-equilibrium paradigm of contemporary stock
2550 assessments is ill-prepared to deal with shifts in stock productivity. Also, the single-species approach
2551 fails to account for the cumulative effects of fishing on multiple stocks in a regional ecosystem. Further,
2552 contemporary assessments do not account for socioeconomic drivers. Although fishery managers
2553 certainly address socioeconomic considerations when setting catch limits, this information may also be
2554 useful in configuring the sub-models of fishery dynamics within assessments.

2555 Assessments can provide more accurate and comprehensive advice if they expand their scope. However,
2556 it is important to consider potential tradeoffs between expanding the scope of an assessment and the
2557 degree of uncertainty around assessment results. These expansions should be thoroughly vetted by
2558 conducting thoughtful research that facilitates the development and evaluation of expanded methods.
2559 There is a consequence to expanding assessments within the operational assessment process, because
2560 additional data sets can mean additional uncertainty that affects the final assessment results. Moreover,
2561 an expanded assessment scope may require increased resources to maintain the additional data inputs.
2562 Nevertheless, expansions should be routinely considered, and a prioritized approach should be used to
2563 determine which stock assessments should expand in scope and how expansive those assessments
2564 should be. Stock assessments should not necessarily expand to be as inclusive as Integrated Ecosystem
2565 Assessments,²⁰ which address all ocean uses in an ecosystem and take a much broader look at multiple
2566 forcing factors on an ecosystem and at multiple services provided by that ecosystem. However, stock
2567 assessments do serve a function within ecosystem-based fishery management (EBFM) by taking an
2568 ecosystem approach to fishery management to the extent feasible. For instance, assessments can
2569 incorporate ecosystem drivers of dynamic processes in the assessment model. Also, stock assessments
2570 provide important information regarding changes in major ecosystem components and processes, so
2571 these products are useful in the development of system-level advice. Chapter 8 provides a broader
2572 discussion and clearer pathway to achieving more holistic and ecosystem-linked stock assessments.

2573 **7.3. Innovative science**

2574 In general, stock assessments need to produce results with higher accuracy and precision. One way to
2575 achieve this goal is to strive for more highly calibrated data; that is, to “fine tune” a data series so it
2576 better represents true dynamics. This fine-tuning can be achieved through data calibration experiments,
2577 where more complete evaluations of certain assessment inputs are conducted so that the full data
2578 series of those inputs can then be adjusted to better reflect true dynamics over time. This approach may
2579 substantially improve assessments, such as those conducted with relatively simple assessment models
2580 that incorporate only the total catch history over time, and one or more time series of an indicator of
2581 stock abundance (see Table 5.1—Aggregate biomass dynamics models). These models are effective only
2582 if input data accurately capture stock and fishery dynamics, and when there is contrast in the data (i.e.,
2583 high and low levels of fishing and abundance over time). In many cases, stock abundance indicators do

²⁰ <http://www.noaa.gov/iea/>

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2584 not perfectly represent stock dynamics, especially when they are based on fishery catch rates, which are
2585 particularly difficult to calibrate over time. Even the absolute knowledge of total catch is challenged as
2586 catch histories are being revisited using new approaches (recreational catches in particular), and as
2587 there is increased awareness of illegal, unreported, and unregulated (IUU) fishing. Contrast in the data is
2588 needed to understand how stocks respond to fishing and how they rebuild from low biomass levels.
2589 However, today's successful fishery management achieves stability, so relatively little contrast is being
2590 realized in recent time periods.

2591 Advanced assessment models (e.g., statistical catch-at-age, see Table 5.1) provide a more complete
2592 description of the effects of fishing on a fish stock, but there are even more concerns about data
2593 calibration in addition to those associated with simpler methods. Advanced assessments incorporate
2594 information on individual growth and the sizes and ages represented in the catch to: 1) ascribe the catch
2595 to the actual age ranges of fish that are affected by the fisheries; 2) account for year-to-year fluctuations
2596 in body growth and the number of young fish entering the stock (i.e., recruitment); and 3) provide direct
2597 evidence of the level of total mortality as represented by the rate of decline in the numbers of older fish.
2598 With additional types of data, the assessment model contains more moving parts that interact and need
2599 simultaneous adjustment (e.g., accurate age, length, maturity, and other biological data is important).
2600 Further, these models also depend on external knowledge of the level of natural mortality and the
2601 possibility that older fish are not as available to fisheries and surveys. Finally, whether simple or
2602 advanced, all models are challenged by major shifts and high year-to-year fluctuations in fish
2603 productivity.

2604 Given these challenges to the performance of modern assessment models, there is a clear need for
2605 more direct calibration of assessment data and more research to better understand and describe fish
2606 stock dynamics and the processes that drive those dynamics.

2607 Chapter 9 describes new scientific and technological developments that may help advance stock
2608 assessments. In particular, there is a focus on achieving a higher calibration of stock abundance data, an
2609 expansion of the data collection and data delivery systems, and utilization of new statistical and
2610 mathematical modeling techniques. Collective investments in these promising areas could result in
2611 measurable improvements in the scientific advice being provided to fishery managers.

2612 **7.4.0 Timely, efficient, and effective stock assessment processes**

2613 To meet many of the increasing demands on NOAA Fisheries' stock assessment programs, there is a
2614 need to improve efficiency in the stock assessment process. Although increased efficiency would result
2615 in more timely advice, it is important that each assessment maintain an appropriate level of detail,
2616 transparency, and review. Each stock assessment should be conducted at a prescribed frequency and
2617 level (data and model richness) in a way that reduces as much as possible the time from data collection
2618 to management adjustment and is sufficiently transparent so that stakeholders have a high level of trust
2619 in the assessment results.

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2620 A data-rich assessment that is timely and transparent and occurs for as many stocks as needed is a
2621 substantial challenge. Fortunately, there are potential process-oriented changes that can help guide
2622 NOAA Fisheries' stock assessment programs to best meet the demands associated with each stock. In
2623 particular, NOAA can improve the tracking of the types of data being used in each assessment; can use
2624 and expand the national stock assessment prioritization process to set goals for each stock; and can
2625 evaluate current assessment levels relative to target assessment levels to help identify stock assessment
2626 gaps and meet realistic expectations for each stock. Further, the process of conducting a stock
2627 assessment can be more streamlined. However, this approach should follow a simplified operational
2628 assessment track that relies on standard, reviewed, tested, and documented approaches to to generate
2629 scientific advice for fishery managers. Improvements to assessment data and methods can then be
2630 considered via a parallel research track that allows time for developing, testing, and reviewing new
2631 approaches before they are applied in a management setting. The level of review along the operational
2632 assessment track can be streamlined, allowing improvements to be fully vetted in the research track.
2633 Finally, standardized and streamlined reporting templates can be used to improve transparency in
2634 assessment results while reducing the time required to communicate those results. Chapter 10
2635 describes proposed changes to the way stock assessments are tracked, conducted, and prioritized to
2636 improve the timeliness, efficiency, and effectiveness of stock assessments.

2637

2638 **Chapter 8—Holistic and Ecosystem-Linked Stock Assessments**

2639 **Chapter highlights:**

- 2640 • **The stock assessment approach should routinely consider ecosystem and socioeconomic**
- 2641 **drivers, and these drivers should be addressed as appropriate with a goal of improved**
- 2642 **understanding of stock dynamics and improved management advice.**
- 2643 • **Stock assessment terms of reference (ToR), particularly those for research assessments that**
- 2644 **intend to improve an assessment, should formally consider ecosystem and socioeconomic**
- 2645 **information.**
- 2646 • **Stock assessments should include multidisciplinary teams and coordinated access to**
- 2647 **ecosystem and socioeconomic reports and research.**
- 2648 • **A general decision process is provided to guide the consideration of ecosystem and**
- 2649 **socioeconomic information in the stock assessment and fishery management process.**
- 2650 • **There is a need for advancing the decision process and developing comprehensive criteria for**
- 2651 **determining the extent of qualitative and quantitative inclusion of ecosystem and**
- 2652 **socioeconomic linkages into the stock assessment and management processes.**

2653 **8.1 Introduction**

2654 Fishery scientists, managers, and stakeholders increasingly want to expand the scope of stock
2655 assessments to be informed by ecosystem drivers as well as the social and economic dynamics affecting
2656 fisheries. Stock assessments tend to account for these factors by either assuming that their effects occur
2657 at some constant average level over time, or to allow random variation in stock dynamics that is not
2658 directly guided by specific ecosystem or socioeconomic mechanisms. In many cases, these approaches
2659 are sufficient for achieving fishery management objectives; thus, it is not necessary to expand the scope
2660 of all stock assessments. However, there are stocks for which ecosystem and/or socioeconomic
2661 information may significantly improve the accuracy and precision of assessment results. For these
2662 priority stocks, expansion of the assessments should be supported by research as well as observations
2663 (e.g., ecosystem or socioeconomic data) available at scales appropriate for including in a stock
2664 assessment model. In most cases, substantial resources are required to conduct the research and data
2665 collection necessary to expand an assessment. Therefore, it is important that this work initially be
2666 directed to address the highest priority cases, while simpler approaches to dealing with ecosystem and
2667 socioeconomic factors can be explored for lower priority stocks.

2668 There is no reason to “force” ecosystem or socioeconomic drivers into stock assessments when there is
2669 not clear evidence to support their inclusion. In fact, identifying drivers in such complex systems is very
2670 challenging. The purpose of these expansions is to improve the assessment and account for the major
2671 factors that drive productivity, but if there is not strong evidence for the expansion, the accuracy and
2672 precision of the assessment results may actually decrease. Regardless of whether ecosystem or
2673 socioeconomic information is included in the assessment, there are many options available to account

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2674 for these additional drivers in fisheries management. In fact, evaluating ecosystem-level tradeoffs is a
2675 core feature of ecosystem-based fisheries management (EBFM).²¹ This evaluation may best be
2676 accomplished through system-level simulation studies, such as management strategy evaluations
2677 (MSEs), and not stock assessments. However, system-level MSEs rely upon stock assessment results, so
2678 improved stock assessments remain fundamental to improving fisheries management. This chapter,
2679 with chapter 10, provides the context and vision for expanding the scope of more stock assessments to
2680 be linked to ecosystem and socioeconomic factors. Examples of stock assessments that incorporate
2681 ecosystem linkages are presented to demonstrate how understanding and advice are improved.

2682 **8.2 Why stock assessments should be expanded**

2683 The fishery stock assessment process uses biological reference points to support stock status
2684 determinations and the application of harvest control rules to support the development of short-term
2685 catch recommendations. In most cases, stock assessments use an historical analysis to determine
2686 biological reference points and then project models based on historical data to determine future
2687 catches. With climate change and other processes affecting marine ecosystems, a primary challenge
2688 facing stock assessment science is how to establish biological reference points and apply harvest control
2689 rules in complex environments that are experiencing constant change. In some cases, long-term
2690 sustainability may be fully understood and achieved by directly incorporating ecosystem and
2691 socioeconomic considerations into the process of determining stock status and developing catch
2692 recommendations. In other cases, it may be sufficient to ensure that robust control rules are in place
2693 and that they are adaptable to variations, such as those caused by climate change and ecosystem
2694 variability.

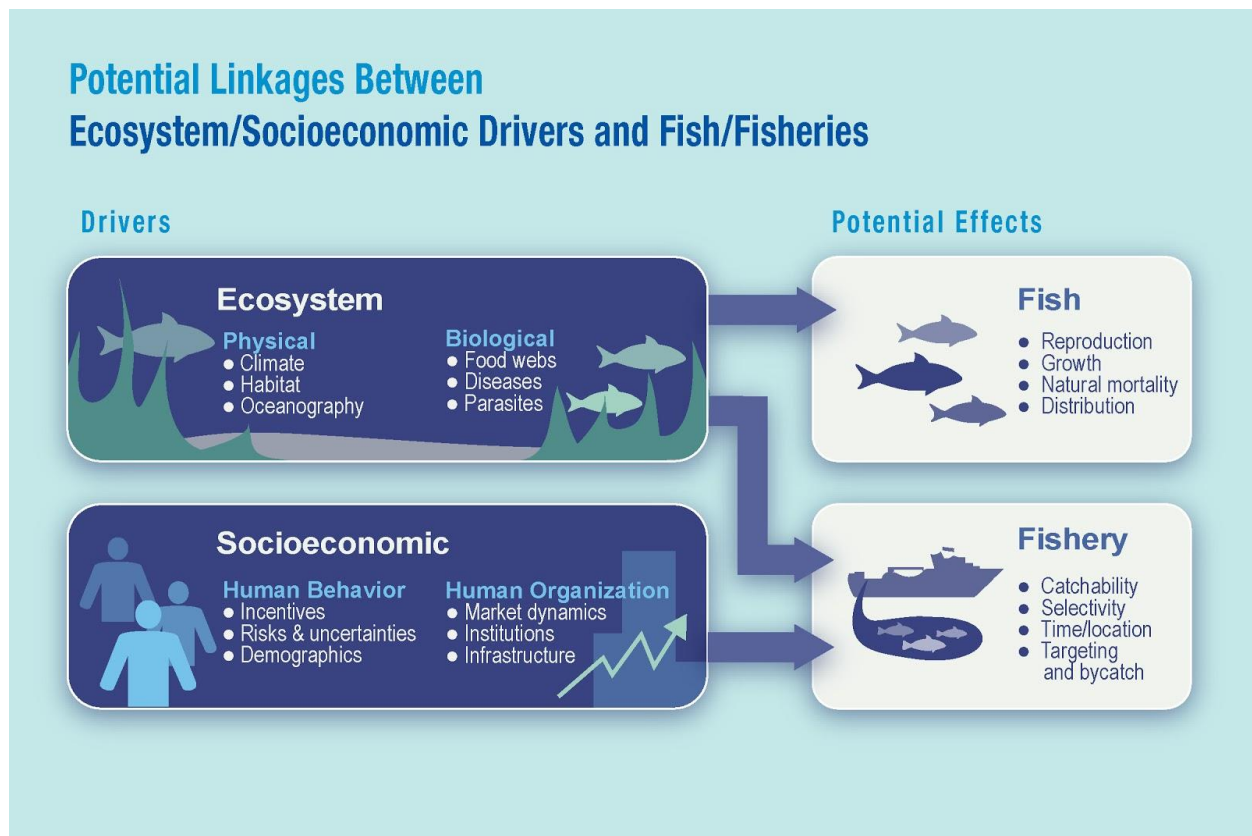
2695 There are many features of an ecosystem and many socioeconomic factors that can affect both fish
2696 stock productivity and fishery dynamics (Figure 8.1). For example, predation mortality alone can
2697 considerably alter the status of a stock (Tyrrell et al., 2011), and changing thermal conditions impact the
2698 distribution, growth, recruitment, and productivity of numerous stocks (Keyl and Wolff, 2008). In some
2699 cases, these factors can be the dominant drivers of stock dynamics, especially as fishery management
2700 has reduced fishing pressure to sustainable levels. Yet those considerations are not often included in
2701 stock assessment models, assumed to be encapsulated in typical assessment model parameters, or
2702 included as random variation. Thus, in many instances, better incorporating these ecosystem linkages
2703 into the stock assessment process is warranted. Although assessment analysts are open and willing to
2704 include additional factors into the assessments, there can be hesitation when relationships with stock
2705 or fishery dynamics is not well understood, when data are not readily available in appropriate formats,
2706 or when it is unclear how best to include the information in an assessment model. These challenges
2707 emphasize the need for investing in research to support more holistic stock assessments.

²¹ <http://www.nmfs.noaa.gov/op/pds/index.html>

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2708 **Figure 8.1.** Ecosystem and socioeconomic processes affecting fish and fisheries.



2709

2710 Part of the stock assessment process involves the use of diagnostic tools to evaluate how well a stock
 2711 assessment model is configured. When assessment models exhibit poor diagnostics, one or more factors
 2712 may be the cause. For example, an assumption about the population dynamics may be incorrect, a key
 2713 factor may be missing from the model, or there may be unaddressed problems with the input data. If
 2714 unresolved, poor diagnostics indicate that the model is not performing appropriately, and therefore the
 2715 quality of the resulting scientific advice is questionable. Although models with questionable skill can still
 2716 be used in a management context, the scientific uncertainty in the results should be characterized in a
 2717 way that accounts for the poor model skill. Further, poor model diagnostics warrant a full investigation
 2718 into the cause. In some cases, a simple fix within the assessment process can improve model
 2719 diagnostics; in other cases, research studies are necessary to improve models outside the operational
 2720 process (see Chapter 10 for more on research and operational assessment tracks). Regardless of the
 2721 time and resources required for investigation, often poor model diagnostics are due to an assumption
 2722 that some process is constant over time when in actuality the process changes appreciably. Thus, one
 2723 common area that may improve model diagnostics is to more broadly explore ecosystem linkages in
 2724 stock assessments models. However, because stock assessments are a simplification of very complex
 2725 dynamics, the challenge lies in determining an appropriate level of linking assessments to the ecosystem
 2726 without making the model too complex for the current goal.

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DISCUSSION PURPOSES**2727 8.3 When to expand stock assessments**

2728 Adding ecosystem or socioeconomic linkages to stock assessment models is not necessary in all cases.
2729 Doing so may not improve model diagnostics, may not provide a better representation of stock or
2730 ecosystem dynamics, and may not improve the management advice resulting from the modeling process
2731 (e.g., Punt et al., 2013). Yet a systematic, structured, decision-criteria approach based on first principles
2732 may help identify those situations that generally warrant closer examination of ecosystem or
2733 socioeconomic considerations and potential inclusion of such linkages in the stock assessment process.

2734 Ideally, the decision to expand a stock assessment should be supported by thorough research into the
2735 drivers affecting a stock's dynamics combined with a full investigation (e.g., management strategy
2736 evaluation) of the costs and benefits of expanding the assessment. However, resources are not sufficient
2737 to support such a methodical approach for all stocks. Thus, a standard, cross-cutting triage exercise is
2738 needed to support the decision process for all stocks in a region. Conducting such exercises would not
2739 only serve to improve single-species assessments, but would also accomplish essential steps in the
2740 transition to EBFM. A relatively simple triage approach that integrates with the stock assessment
2741 prioritization process is described in Chapter 10. Numerous other methods have been developed (Levin
2742 et al., 2009; Link, 2010; Hobday et al., 2011) and examples have been applied in a fisheries context.
2743 These approaches are often termed "ecological risk assessment" and they serve to identify the major
2744 pressures and threats facing a group of species relative to their individual vulnerabilities to multiple
2745 threats. Any number of these methods could be used to inform decisions about the scope of a stock
2746 assessment as well as support the prioritization effort described in Chapter 10.

2747 A stock's natural mortality is one component of a stock assessment that is inherently connected to
2748 ecosystem drivers. This value is challenging to estimate in stock assessments and is often estimated or
2749 assumed by including as a fixed input to an assessment model. Although it is often accepted that natural
2750 mortality varies over time and by age, it is common to assign it a constant value because there may not
2751 be enough data available to estimate the change, and typically there are not obvious theoretical or
2752 mechanistic linkages to ecological processes. In essence, natural mortality in a stock assessment model
2753 represents an integration of numerous complex and interacting processes. However, natural mortality
2754 of fishes that make up a substantial forage base for predators may be driven by the biomass of the key
2755 predator species. These stocks in particular represent good candidates for additional examination and
2756 exploration of predation mortality. Focusing on predator dynamics for forage species' natural mortality
2757 is an example of a simple triage approach to identify one important ecological process for a subset of
2758 stocks while eliminating species that do not experience significant predation mortality. The approach to
2759 examining predation mortality for a given stock could vary (see Section 8.5), but knowing that it could be
2760 an issue from the triage exercise would help highlight and prioritize the research.

2761 Natural mortality represents one of many aspects to consider when triaging stocks to determine which
2762 assessments should be expanded to include ecosystem and/or socioeconomic factors. Figure 8.1
2763 provides an overview of the many factors and effects that should be considered when constructing stock

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2764 assessments. Although Figure 8.1 is a relatively simple diagram, there are numerous variations of
2765 potential interactions between drivers and stock and fishery dynamics. From these triage exercises,
2766 development of decision trees and recommended practices would naturally follow to delineate those
2767 conditions when ecosystem and/or socioeconomic linkages are high priority and which factors should be
2768 considered. Using criteria related to data availability, model diagnostics, model skill, model structure,
2769 known or hypothesized mechanisms, key processes and dynamics, key model parameterizations, and
2770 risk minimization would all be formulated to suggest particular approaches that could be used in the
2771 stock assessment process. For instance, decisions on creating ecosystem linkages in stock assessments
2772 are made in the context of several considerations:

- 2773 1. Based on the stock's value, status, and biology, is there an incentive to expand its
2774 assessment to include ecosystem or socioeconomic factors?
- 2775 2. Is there evidence to suggest that stock or fishery dynamics are tightly coupled with some
2776 variable ecosystem or socioeconomic feature?
- 2777 3. Are data available to model this relationship within the assessment framework?
- 2778 4. Can ecosystem or socioeconomic dynamics be incorporated in a way that maintains a
2779 manageable assessment model?
- 2780 5. Can the relationship between stock, fishery, and ecosystem or socioeconomic dynamics be
2781 forecasted with at least a moderate degree of certainty?

2782 Here, it is recommended that the stock assessment process include two steps:

- 2783 1. Use Figure 8.1 as a framework for conducting a simple qualitative evaluation of potential
2784 ecosystem or socioeconomic linkages.
- 2785 2. Evaluate the results of the target setting process described in Chapter 10 in combination with
2786 the previous considerations list to determine whether it is technically feasible, and worth the
2787 effort, to expand a particular assessment.

2788 This systematic approach does not likely fit well into the operational stock assessment cycle, but
2789 should be developed in a parallel research assessment track (see Chapter 10) that is designed to
2790 improve operational assessments. Simply, research assessments should be guided by relatively
2791 generic, nationally consistent, standing terms of reference that include attention to ecosystem and
2792 socioeconomic considerations. The decision to expand assessments should not be based solely on
2793 the detection of correlations between factors, but rather through thoughtful consideration at each
2794 step and connection outlined earlier. Even if it is not deemed appropriate to expand an assessment
2795 to include ecosystem or socioeconomic linkages, the process of evaluating stock and fishery
2796 dynamics from a broader system-level perspective is generally beneficial. These evaluations should
2797 be well-coordinated with the implementation of EBFM. In particular, management councils will be
2798 developing more Fishery Ecosystem Plans (FEPs) and this process may provide a good opportunity to
2799 assemble an interdisciplinary group that evaluates various ecosystem processes and their effects on

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2800 fish and fisheries. Thus, the FEP development process could provide direct guidance for research
2801 assessments.

2802 **8.4 How to expand stock assessments**

2803 The manner in which ecosystem and socioeconomic considerations can be included into the stock
2804 assessment process is broad and varied. This information can be used to provide context for interpreting
2805 stock assessment results and evaluating system-level effects of harvest recommendations; for
2806 diagnosing issues with stock assessment models; for forming hypotheses of how stock assessments
2807 could be improved; as leading indicators of potential change to prioritize assessment research and
2808 activities; or for adjusting or scaling the harvest advice that derives from a stock assessment. Finally, the
2809 information can be directly incorporated into stock assessment models as covariates and/or as new
2810 model components that describe ecosystem or socioeconomic mechanisms. Table 8.1 expands upon the
2811 processes described in Figure 8.1 to provide additional details on how stock assessments can include
2812 ecosystem or socioeconomic information. Thus, there are several ways in which additional information
2813 can be included in the stock assessment process, but what is appropriate for any given stock, ecosystem,
2814 or management plan depends on several factors.

2815 At one end of this spectrum are purely qualitative approaches. These include the strategic use of
2816 additional documents and information, including ecosystem status reports, ecosystem considerations
2817 already in stock assessments, socioeconomic reports, and relevant research products. This
2818 supplementary information can help shape management advice, such as guide the establishment of
2819 harvest rates that are responsive to changing conditions rather than assume equilibrium conditions;
2820 suggest the current productivity state of the environment, which is useful in guiding approaches to
2821 forecasting catch advice; and highlight possible upcoming changes that may warrant a reconsideration
2822 of future harvest levels or the frequency and approach by which assessments will be conducted. These
2823 qualitative approaches represent simple acknowledgments that changing ecosystems and
2824 socioeconomics affect fish and fisheries. They also fit well within current management approaches by
2825 helping to communicate uncertainty in stock assessment results and providing guidance on how harvest
2826 recommendations may be adjusted to account for this uncertainty.

2827 At the other end of the spectrum are more formalized, quantitative approaches. Quantitative
2828 approaches generally seek to link stock assessment models to ecosystem and/or socioeconomic factors.
2829 This task can be completed either by directly adjusting selected model parameters or structures, or by
2830 providing an index that informs the model's estimation of particular parameters or trends in stock
2831 dynamics. The qualitative and quantitative methods are not mutually exclusive, and neither is superior
2832 to the other, but rather their appropriateness is situation specific.

2833 It is not necessary to force ecosystem or socioeconomic information into every stock assessment. The
2834 important point in this chapter is that the stock assessment process should include a systematic
2835 approach to considering how stocks and fisheries are affected by changes related to ecosystems and

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2836 socioeconomics, and where/how appropriate, those considerations should be included. Chapter 10
2837 describes a simple approach to evaluating, across stocks, assessments that should be expanded to
2838 include ecosystem information. Then, Figure 8.1 combined with Table 8.1 and the considerations listed
2839 earlier, represent the generic thought process to determine how a stock's assessment could be
2840 expanded/improved. This decision process needs to be tested and improved, but the guidance provided
2841 here and in Chapter 10 is designed as a starting point.

2842 **Table 8.1.** Level of ecosystem linkages and how they could inform the stock assessment process.
2843 1 = context within which stock assessment results can be better interpreted, 2 = forming
2844 hypotheses of how the stock assessment model could be altered, 3 = a leading indicator of
2845 potential change, 4 = changing stock assessment model parameters to account for ecosystem
2846 conditions, 5 = inclusion of ecosystem data as a covariate in a stock assessment model, 6 =
2847 inclusion of ecosystem data as a mechanistically linked, directly modeled process, 7 = to direct
2848 inclusion in development of harvest control rules.

		Pressures	Stock Assessment Factors	Linkage Levels
Ecosystem	Physical	Habitat (pelagic, benthic)	Distribution, abundance, selectivity, catchability, movement	1 through 6
		Climate (large-scale)	Distribution, maturity, growth, abundance, movement, consumption, reference points, projections, harvest control rules	1 through 7
		Winds (speed, upwelling)	Growth, abundance, catchability, recruitment, movement, projections	1 through 6
		Temperature/Salinity (surface, profile)	Distribution, maturity, growth, abundance, selectivity, catchability, recruitment, movement, consumption, reference points, projections	1 through 6
		Nutrients (nitrate, ammonium, iron)	Growth, recruitment, consumption	1 through 3
		Chemistry (acidification, hypoxia)	Maturity, abundance, harvest control rules	1 through 3
		Oceanography (current, height)	Distribution, growth, recruitment, projections	1 through 6
	Biological	Plankton (phyto, zoo, micro)	Recruitment	1 through 6
		Ichthyoplankton (eggs, larvae)	Recruitment	1 through 6
		Fish (juvenile, adult, spawning)	All Factors	1 through 7
		Diet (food web, competition)	Natural mortality, growth, abundance, recruitment, reference points	1 through 7
		Stress (predators, parasite, disease)	Natural mortality, reference points	1 through 6
		Socioeconomic	Behavior	Incentive (food, job, tradition)
Bycatch (avoidance, retention)	Distribution, catch, abundance, reference points, harvest control rules			1 through 7
Social Impacts (non-catch, tourism)	Catch, abundance			1 through 2, 7
Risk & Uncertainty (investment)	Harvest control rules			1 through 2, 7
Demographics (fleet size, gear type)	Catch, selectivity, catchability			1 through 7
Organization	Market Dynamics (price)		Catch, selectivity	1 through 2, 7
	Institutions (councils, certification)		Catch, selectivity	1 through 2, 7
	Infrastructure (docks, plants, ports)		Catch, abundance, catchability	1 through 2
	Navigation/Shipping		Selectivity, catchability	1 through 2

2849

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2851 In addition to expanding the scope of stock assessments by incorporating ecosystem or socioeconomic
2852 data, assessments can also be expanded through the coordinated evaluation of their results. For
2853 instance, the results from a collection of stock assessments within an ecosystem or fishing community
2854 may be combined to understand how stock dynamics are related and how communities are affected by
2855 variable harvests. This coordinated evaluation may facilitate the establishment of fishing levels across
2856 multiple stocks to conserve ecosystem functioning while optimizing fishing opportunity. Such an
2857 approach to fishery management is described in the revised NS1 Guidelines, which mention that harvest
2858 limits can be estimated for a group of stocks and these aggregate reference points can be used to
2859 optimize yield for the entire group. In fact, this approach is already in place in certain regions. For
2860 instance, a 2-million ton system-level cap is imposed on groundfish stocks in the North Pacific Ocean
2861 (Bering Sea-Aleutian Islands). This cap facilitates maximizing the catch of the most important stocks
2862 while reducing catches of other stocks to sustain biomass in the system. Overall, the coordinated
2863 evaluation of multiple stocks may enable the development of system or community-level harvest
2864 policies. In other words, harvest policies that account for interacting stocks, total fish production in a
2865 system, as well as cumulative or indirect effects of fishery or ecosystem dynamics. This system-level
2866 approach is an important component of NOAA Fisheries' EBFM Road Map²² and represents a critical
2867 connection between fish population dynamics and ecosystem science. As described in the EBFM Road
2868 Map, an appropriate place for these system-level approaches is within the regional Fishery Ecosystem
2869 Plans.

2870 Evaluating stocks and their assessments at the ecosystem or community level provides additional
2871 benefits beyond the establishment of coordinated harvest policies. By conducting multi-stock
2872 evaluations, certain features of an ecosystem or set of fishing practices may be highlighted as important
2873 drivers that affect multiple stocks simultaneously. For example, if a group of stocks exhibits a relatively
2874 drastic change in abundance at a certain time, there may be many potential causes worth evaluating,
2875 such as environmental shifts or changes in fishermen targeting behavior. It may then be efficient to
2876 address these issues in a way that is most beneficial to the whole system. Other benefits of coordinated
2877 evaluations relate to the assessment and management process. For instance, if issues arise, either with
2878 the data, analyses, or other step in the process, then it will be apparent if those same issues apply to
2879 multiple stocks. The issues may then be addressed so that they benefit the entire system/community.
2880 Along those lines, a multi-stock evaluation also facilitates a system-level gap analysis. If certain gaps
2881 apply to multiple stocks then there may be efficient ways to address those gaps and improve
2882 assessments for many stocks.

2883 8.6. Conclusions

²² <http://www.nmfs.noaa.gov/op/pds/index.html>

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2884 With changing ecosystems and complex socioeconomic factors driving stock and fishery dynamics, it is
2885 important that the scope of stock assessments expands to support more holistic approaches to fishery
2886 management. These expansions can occur by including ecosystem or socioeconomic factors in individual
2887 stock assessments, or through the coordinated evaluation of single species assessments at the
2888 ecosystem or community level. At a minimum, it is important that the potential drivers and decision
2889 points discussed in this chapter be considered during the stock assessment process, potentially
2890 facilitated through the development and implementation of FEPs. The ultimate goal of these
2891 considerations is to improve assessments and the advice being provided to fishery managers in an
2892 attempt to prevent overfishing while achieving optimum yield for fisheries. Given the strong connection
2893 between system-level thinking and EBFM, this chapter emphasizes the fundamental connection
2894 between single-species stock assessments and EBFM. Thus, improving assessments through expanding
2895 their scope not only improves single species fisheries management, but is also important in achieving
2896 EBFM.

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2927 **Chapter 9—Innovative Science for Improving Stock** 2928 **Assessments**

2929 **Chapter highlights:**

- 2930 • **Changing systems and mixed-stock fisheries warrant development, testing, and**
2931 **implementation of ecosystem-linked and multispecies assessment methods.**
- 2932 • **Strategic investments in data collection and statistical and analytical assessment methods are**
2933 **needed to meet the demand for increasing the quantity and quality of stock assessments.**
- 2934 • **Investments in advanced sampling technologies should be guided by stock and ecosystem**
2935 **assessment priorities, and should enhance NOAA's infrastructure with integrated survey and**
2936 **ocean observation systems.**
- 2937 • **Advancing the research and development of advanced sampling technologies requires**
2938 **partnerships among academic institutions, industry, and other agencies.**
- 2939 • **Calibration studies are necessary for enhancing ongoing data collection operations with new**
2940 **technologies, particularly when attempting to generate direct estimates of stock abundance.**
- 2941 • **General modeling frameworks that facilitate ease of use, robust testing, community-level**
2942 **development, modular applications, and best practices are needed.**
- 2943 • **Improved use of decision analysis tools and ensemble modeling techniques will better convey**
2944 **uncertainty for risk analysis in fishery management decisions.**

2945

2946 **9.1. Introduction**

2947 Stock assessments are conducted via a multi-step interdisciplinary partnership (Chapter 1) to provide
2948 reliable, complete, and transparent advice to fishery managers. Many of the fundamental scientific
2949 achievements and evolution that form the basis for fisheries science and management today were
2950 realized in the twentieth century (Quinn, 2003). Contemporary stock assessments build upon these early
2951 accomplishments as well as new developments (Methot, 2009), thereby representing a synthesis of
2952 scientific achievements within each step of the process: data collection and processing, stock
2953 assessment modeling, and developing and communicating recommendations. Advancements in stock
2954 assessment science have not only been achieved within the field of fisheries science, but
2955 accomplishments in other disciplines are also being leveraged (e.g., mathematics and statistics,
2956 computer technology and programming, ecology, advanced sampling technologies, sample design, and
2957 risk management). Therefore, the stock assessments of today can benefit from data collected by a
2958 variety of technologies and in accordance with sound statistical designs, access to advanced computing
2959 power that facilitates the rapid execution of big data analysis using complex mathematical and statistical
2960 algorithms, and sophisticated approaches to visualizing and interpreting risk and uncertainty associated
2961 with a range of management scenarios.

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2962 Despite the numerous advances in stock assessment science during the past century, meeting current
2963 demands for an increased quality and quantity of assessments will require a stronger reliance on
2964 innovative science and technology. Chapter 4 provided an overview of the current state of data
2965 collection for fishery stock assessments, and Chapter 5 described the status of assessment models in
2966 NOAA Fisheries. This chapter offers several potential improvements related to new, innovative science
2967 that may apply to the entire stock assessment process. Many of the ideas in this chapter are not new,
2968 but are already in varying stages of development, testing, and/or use. Although suggestions described in
2969 this chapter could potentially improve stock assessments, they should not be adopted for all
2970 assessments, but rather through a thoughtful and strategic decision process, because there may be
2971 limited resources and/or tradeoffs to consider. These tradeoffs emphasize the overlapping and
2972 integrated nature of the elements of the next generation stock assessment enterprise described
2973 throughout Section 3. The following subsections provide detailed recommendations related to
2974 innovative science to benefit the stock assessment process, and they should be considered along with
2975 improvements to efficiency and prioritization (Chapter 10) and to expand the scope of stock
2976 assessments (Chapter 8).

2977 9.2. Innovations in data collection and processing

2978 The reliability of stock assessment results is directly related to the quality of available data. In other
2979 words, if data are not available, or if the information contained in the data is not informative with
2980 regard to stock or fishery dynamics, then stock assessment results should be interpreted with caution.
2981 Certainly, quantitatively characterizing the uncertainty in assessments became increasingly important
2982 after the adoption of uncertainty-based buffers between the overfishing level and a recommended
2983 catch level. Many of the recommendations in this section pertain to innovative science and technology
2984 that may expand and improve the data collected for stock assessments. However, there is also a need
2985 for recommendations and innovation related to the general processes and practices of data collection.
2986 For instance, changes and investments in data collection operations must be made strategically;
2987 therefore, a national group may be necessary to coordinate and prioritize those changes and
2988 investments. Establishing such a group within NOAA Fisheries is recommended here to conduct strategic
2989 planning for stock assessment data and to work with the gaps and recommendations resulting from the
2990 stock assessment prioritization exercise (Chapter 10) as well as with other relevant national working
2991 groups (e.g., advanced sampling technologies, stock assessment methods, and survey vessel
2992 coordinators). Although regional experts have the best knowledge of data gaps for particular species,
2993 changes in funding often occur nationally. Thus, a national group that is coordinated across regions and
2994 connected with other national strategic efforts is ideal for conducting a comprehensive gap analysis of
2995 stock assessment surveys to evaluate the sufficiency of sampling coverage and intensity across stocks,
2996 and to determine where new technologies and other investments can be considered to address data
2997 gaps. This group can coordinate across stock assessment data inputs with a goal of obtaining the
2998 appropriate level of sampling for each stock, implemented with methodologies and technologies to
2999 provide data for stock assessments in a way that best meets management objectives.

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3001 As discussed in Chapter 4, fishery-independent data sources are important for understanding and
3002 monitoring fish stocks and provide fundamental inputs to assessments. Thus, maintaining and
3003 expanding (where necessary) NOAA's fish survey capabilities is crucial to improving stock assessments.
3004 The ongoing work to ensure a sufficient and functioning NOAA fleet, charter vessel arrangements, well-
3005 designed surveys, and integration of new technologies and ocean observing systems is necessary for
3006 maintaining these important data streams.

3007 Opportunities for improving the data already being collected for stock assessments also exist. A primary
3008 focus of fishery-independent surveys is to estimate a time series of stock abundance that serves as input
3009 to the stock assessment model (Chapter 1). In most cases, abundance trends from surveys are relative;
3010 that is, they capture proportional changes in stock size but not absolute measures of abundance each
3011 year. The assessment models can infer absolute abundance from the trend information if the time series
3012 trend is long enough to provide contrast (i.e., show declines when catch is high and increases when
3013 catch is low). However, such contrast is not assured, and information on absolute stock abundance that
3014 comes directly from the survey is beneficial and easily included in contemporary assessment models.
3015 Obtaining measures of absolute biomass from surveys does not necessarily require new types of
3016 surveys, but can be achieved through research on existing surveys. For instance, if the surveys are
3017 calibrated to measure the proportion of the available biomass sampled (catchability) and the likelihood
3018 of sampling fish of a given age (selectivity), then absolute abundance can be estimated. Therefore,
3019 resources should be directed at research on survey catchability and selectivity to work toward better
3020 survey calibration and facilitate estimates of absolute abundance for priority stocks whose assessments
3021 would benefit most from this information (advanced sampling technologies [Section 9.2.3] may be
3022 helpful in conducting this type of research). The potential for improving stock assessments with better
3023 calibrated surveys is high, particularly in cases where other stock assessment data (e.g., catch and
3024 biology) are limited or highly uncertain.

3025 Another issue affecting the quality of abundance data from stock assessment surveys is changing species
3026 distributions. Many stocks are responding to climate variability and climate change by shifting their
3027 distributions in a variety of ways (Nye et al., 2009; Pinsky et al., 2013). For surveys, particularly those
3028 with fixed sampling-designs, these shifts may compromise the ability to estimate abundance trends,
3029 particularly when stocks shift outside of the surveyed area. In other words, distribution shifts may cause
3030 survey catchability to vary over time, yet it is often assumed to be constant when estimating abundance.
3031 Thus, there is a relationship between species distributions and the recommendation calling for better
3032 understanding of survey catchability. Part of that work will be related to researching species
3033 distributions and habitat associations as related to survey designs. In some cases, it may be appropriate
3034 to alter and/or expand survey designs so they track and respond to shifting distributions. Ocean
3035 observation systems (autonomous and fixed platforms) are good options for supplementing the spatial
3036 coverage of surveys without increasing ship time. In other cases, it may be sufficient to calibrate surveys

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3037 with respect to climate so that annual catchability for a particular species can be characterized (Adams
3038 et al., 2015).

3039 **9.2.2 Fishery-dependent data**

3040 Data collected from fisheries provide fundamental information for stock assessments on numerous
3041 factors (e.g., total catch, fishing strategies, catch composition—species, ages, sizes, sexes, and bycatch
3042 and discarding practices). Fishery catch rates are also occasionally analyzed to characterize changes in
3043 stock abundance over time, commonly for stocks that do not have dedicated abundance surveys. As
3044 described in Chapter 4, fishery-dependent abundance trends are necessary in certain scenarios, but
3045 these catch rates are hard to validate as a good indicator of stock abundance and must be treated
3046 carefully. Because many harvested stocks do not have dedicated surveys, it could be very beneficial to
3047 partner with fisheries to obtain more reliable estimates of abundance. Where there is a gap in survey
3048 coverage, and when funds are not available for establishing a scientific survey, the fisheries presence on
3049 the water represents a great opportunity for collaboration. The recommendation here is to establish
3050 more partnerships with the fishing industry and explore low-cost scientific work as part of normal fishing
3051 operations where some subset of fishing activity is conducted according to a sampling design. Such
3052 partnerships offer many benefits, such as filling critical data gaps, building stakeholder engagement and
3053 trust, and improving assessments and management. Overall, this approach would be less involved than
3054 surveys conducted with chartered fishing vessels but more standardized than the approaches currently
3055 used to extract abundance trends from fishery catch rates. In cases where fisheries cannot conduct
3056 scientific sampling, another option may be to impose a sampling design for a given stock and subsample
3057 catch rates from fishermen's logbook data according to that design. In this way, the fishery is retrofitted
3058 (roughly) as a survey.

3059 Given that fisheries represent the primary sources of many key inputs to stock assessments, there is a
3060 general need to optimize the ways in which fisheries are monitored. For instance, fishery observers
3061 provide necessary information related to incidentally caught species ("bycatch"), catch composition, and
3062 fishing practices for commercial fisheries, yet many fisheries have little or no observer coverage. For
3063 recreational fisheries, phone, mail, and dockside surveys are typically used to generate estimates of
3064 catch, effort, fishing strategies, and discards. These surveys will never provide complete accounting of
3065 recreational catches, but in an effort to improve estimates for federally managed stocks, the Marine
3066 Recreational Information Program (MRIP) recently optimized its statistical sampling design. Commercial
3067 fishery observer programs, particularly in regions with limited observer coverage, may also consider
3068 revising and expanding their sampling strategies. The ultimate goal is to provide accurate information
3069 for stock assessment and management, but given limited resources in certain regions, the following
3070 questions are of importance:

- 3071 • What is the effect of different levels of observer coverage?
- 3072 • How should observers be distributed over time, space, and across vessels in a fishery?
- 3073 • Which stocks are highest priorities for higher/lower observer coverage?

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3074 Answers to these questions are important and may be best addressed in a management strategy
3075 evaluation (MSE) context (Section 9.3.3), but they are central for optimizing the collection of critical
3076 fishery-dependent data.

3077 Another recommendation to improve the collection and provision of fishery-dependent data for stock
3078 assessments is through an increased use of electronic monitoring and electronic reporting (EM/ER).²³
3079 These electronic technologies allow fishermen to record their catches and fishing activities and make
3080 that information available in near real-time. There are also platforms, such as video camera systems,
3081 that can be used to monitor catches as they are brought onboard. Such systems could potentially offer
3082 an option for a low-cost expansion of observer coverage, as well as for catch accounting in Alaska. These
3083 technologies do not represent a viable replacement for observer programs, but they can be used
3084 to enhance observer-collected data. NOAA Fisheries has already invested in research, development, and
3085 testing of EM/ER, and a small number of fisheries have implemented these innovative approaches to
3086 data collection and monitoring of commercial fisheries. In 2016, Congress appropriated \$7 million for
3087 implementation of EM and ER in U.S. fisheries; these funds are expected to continue. Overall, these
3088 technologies may offer improvements to fishery-dependent data collection; therefore, the use of EM/ER
3089 will continue to be explored.

3090 This section calls for increases in fishery-dependent data collection, but there are various costs to
3091 consider in doing so. A primary expense is the cost associated with expanded operations (i.e., new
3092 equipment and staff time for data collection and program management). However, there are added
3093 costs related to processing and analyzing more data. These costs cannot be overlooked, because in
3094 many cases, resource availability for data processing and preparation is a major factor that constrains
3095 the throughput of assessments. This issue is addressed in more detail in Section 9.2.5.

3096 **9.2.3 New data types**

3097 Chapter 8 described the need and approach for expanding the scope of stock assessments to consider
3098 the effects and inclusion of ecosystem and socioeconomic impacts. As consideration of these effects
3099 becomes more common in stock assessments, a broader collection of supporting ecosystem and
3100 socioeconomic data will become necessary. Not only will these data be important for the assessments
3101 that expand in scope, but as NOAA Fisheries progresses toward ecosystem-based fisheries management
3102 (EBFM), these data will be crucial for EBFM implementation as described in NOAA Fisheries' EBFM
3103 Roadmap.²⁴

3104 Fortunately, ecosystem and socioeconomic programs within NOAA Fisheries and its partners are actively
3105 collecting this information today. Additionally, ongoing work is being leveraged (e.g., stock assessment
3106 surveys that also collect ecosystem information) and many opportunities exist for further leveraging. For

²³ <https://www.st.nmfs.noaa.gov/advanced-technology/electronic-monitoring/index>

²⁴ <http://www.nmfs.noaa.gov/op/pds/documents/01/120/01-120-01.pdf>

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3107 instance, fishery-independent data collection aboard NOAA ships and chartered vessels could be
3108 expanded at a relatively low cost to collect more interdisciplinary data for ecosystem research. Also,
3109 coordinated and standardized ocean observations, as achieved through international collaborations
3110 such as the Global Ocean Observing System²⁵ and their coordination of Essential Ocean Variables,
3111 facilitates access to ecosystem data that may be useful in stock assessments. However, as mentioned
3112 previously, an important consideration in expanding data collection efforts is ensuring staff capacity for
3113 processing data and for conducting research to understand the ecosystem processes (Section 9.2.4). This
3114 consideration may explain the lack of ecosystem and socioeconomic data to support full evaluations of
3115 these drivers in all stock assessments.

3116 Numerous socioeconomic and ecosystem factors must be considered under a holistic approach to
3117 managing living marine resources (Figure 8.1). Within an ecosystem, the key living and non-living
3118 features include information on food webs; diseases and parasites; oceanography (e.g., temperature,
3119 salinity, oxygen concentration, pH, and current dynamics); climate conditions; structural habitat; and
3120 toxins. Given the variety of factors, diverse and innovative approaches are needed to collect and
3121 characterize this information. Advanced sampling technologies, particularly from the following
3122 disciplines, will continue to enhance data collections: biotechnology (e.g., characterization of food webs
3123 using biosensors for sampling lipid, fatty acid, stable isotopes, genetics, and macroscopic analyses; and
3124 detection of diseases and parasites using genetic, macroscopic, physiological, and standard medical
3125 diagnostic analyses); remote sensing platforms and ocean observation systems (e.g., monitoring physical
3126 water conditions using satellites, autonomous vehicles, and standard oceanographic instrumentation);
3127 high-resolution and seasonal to decade-long climate models for forecasting climate conditions at scales
3128 relevant to most fishery management decisions; underwater sensor technologies (e.g., quantification
3129 and characterization of biological communities and their habitats using optics and sonar); and
3130 chromatography and other detection techniques for toxins.

3131 There is a basic need to collect socioeconomic data to understand and manage fisheries in consideration
3132 of their community-level importance as well as their economic contributions. However, the
3133 recommendation for increasing the collection of this information is made here in the context of the
3134 stock assessment process. In addition to modeling stock dynamics, assessments also model fishery
3135 dynamics. Because fisheries support recreation, food, and livelihoods, their dynamics are driven largely
3136 by socioeconomic decisions. Although innovation and technology may enable the improved collection of
3137 socioeconomic data, the higher priority is to expand the collection of information related to fishermen's
3138 decision processes, sales, revenue, value-added impacts, and jobs. These data are collected mainly
3139 through on-the-ground outreach. However, some of this information may be well suited for collection
3140 using EM/ER (Section 9.2.2).

3141 9.2.4 Advanced sampling technologies

²⁵ <http://goosocean.org/>

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3142 The previous section provided recommendations for expanding the types of data being collected for
3143 stock assessment purposes. Although many of the recommendations are related to technological
3144 advancements, the technologies discussed in this section focus largely on methods for monitoring stock
3145 abundance. NOAA Fisheries has long recognized the importance of advanced sampling technologies for
3146 enhancing survey data collection, improving abundance estimates, and minimizing uncertainties in
3147 measurements and estimates. The research and development in advanced sampling technologies
3148 include testing and calibration of the sampling tools, improving the efficiency of data processing, and
3149 evaluating the feasibility of transitioning technologies into operations (Chapter 4). Technology
3150 investments should be guided by stock assessment priorities and address information gaps to improve
3151 stock and ecosystem assessments (e.g., Chapter 10). In addition, these investments should benefit
3152 NOAA's next generation infrastructure with more efficient survey operations and integrated ocean
3153 observation systems.

3154 For the research, development, and evaluation of advanced sampling technologies, NOAA will continue
3155 to rely on partnerships among academic institutions, industry, and other agencies. Promoting these
3156 partnerships with research and development of technology will be increasingly important, especially
3157 given that NOAA's limited pool of technology expertise will need to implement and sustain these
3158 technologies aboard its survey operations.

3159 Sensing technologies continue to be integrated into ship survey operations to achieve multidisciplinary
3160 objectives, and this area holds significant potential for improving stock assessments. In particular, these
3161 technologies provide opportunities for calibrating ongoing abundance surveys by directly observing the
3162 area sampled by traditional gear (e.g., trawls) and the number, size, and type of species available to that
3163 gear. A recent upgrade of the northeast scallop survey included an advanced optical imaging system,
3164 which was calibrated and has facilitated estimation of absolute, rather than relative, abundance indices.
3165 Thus, advanced technologies facilitate the estimation of absolute stock abundance and therefore may
3166 be used to address recommendations in Section 9.2.1. Another benefit of sensor technology is the
3167 ability to deploy sampling gear in areas that have been difficult to survey with traditional gear (e.g.,
3168 rocky and coral habitats). In most cases, data-limited stocks (e.g., fish groups associated with reef or
3169 rocky habitat) in federal fishery management plans lack data because of difficulties in sampling such
3170 habitats. Therefore, advanced sampling technologies offer exciting opportunities for improving the
3171 assessment and management of these important species.

3172 With the implementation of advanced technologies, larger volumes of data are typically collected. This is
3173 particularly true for acoustic and optical surveys. For example, the next generation of fisheries acoustic
3174 systems will collect four times more data. In addition, using stereo video systems to enhance visual
3175 surveys will also drastically increase data collection. Although these large data streams need to be
3176 stored, this concern is minor compared with the need for rapid access to processed data for analysis and
3177 visualization. One approach NOAA Fisheries has taken to address this issue is to collaborate with the
3178 computer vision technology industry to develop tools for automated image analysis. This technology

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3179 continues to evolve rapidly; therefore, continued investments in processing efficiencies are critical and
3180 expected to be beneficial.

3181 Another promising, low-cost technique to explore for filling important stock assessment data gaps is
3182 environmental DNA (eDNA). This technology has typically been used to document the presence of a
3183 species in a given system by detecting the DNA of that species. However, more recently, eDNA has
3184 demonstrated potential for measuring abundance of a species under the theory that the concentration
3185 of a species' DNA in the environment is in proportion to the density of that species (Takahara et al.,
3186 2012). Given the simplicity of collecting water samples for later DNA analysis, it may be relatively cost-
3187 effective to collect this information on either new platforms or by leveraging ongoing fishing or survey
3188 operations.

3189 Wise investments in advanced sampling technologies must be guided by stock assessment priorities to
3190 resolve key information gaps. Unmanned platforms (e.g., aerial systems, moorings, gliders, and
3191 autonomous and remotely operated underwater vehicles) will become relatively low-cost options for
3192 deploying acoustic and optical technologies, especially when compared to the cost of building, running,
3193 and staffing a traditional research vessel. However, ships remain the key infrastructure for conducting
3194 surveys and deploying technologies that augment and improve survey coverage. As technologies are
3195 implemented, calibrations are required at various levels, ranging from sensor, inter-vessel, and sampling
3196 gear performance, to changes in survey designs that are improved with technologies. Continued
3197 investment in these platforms and their calibration is necessary for expanding the coverage of stock
3198 abundance surveys and improving the assessment and management of data-limited species. Overall,
3199 these technologies provide an opportunity among NOAA programs, academic institutions, and industry
3200 to build an integrated survey and ocean observation infrastructure for NOAA's next generation stock
3201 assessment enterprise.

3202 **9.2.5 Improving data management, processing, and delivery**

3203 As emphasized throughout this document, data collection systems play a critical role for the success and
3204 improvement of stock assessments. In 2013, NOAA Fisheries conducted a series of independent reviews
3205 of its data collection and management systems for stock assessments.²⁶ It became clear from these
3206 reviews that comprehensive improvements are warranted. Additionally, the Open Data Initiative²⁷
3207 formally calls on federal agencies, such as NOAA Fisheries, to offer public access to government
3208 information resources in a "computer readable" form. Thus, NOAA Fisheries is transitioning its data and
3209 information systems to be more secure, easier to access, and more readily understood by the public.
3210 These improvements offer opportunities, not only to address the Open Data Initiative, but also to
3211 improve the stock assessment process.
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²⁶ <http://www.st.nmfs.noaa.gov/science-program-review/>

²⁷ <https://www.data.gov/>

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3213 Although the previous sections provide a vision for data types and collection techniques, this section
3214 specifically refers to data management in relation to stock assessment efficiency. As NOAA Fisheries
3215 creates data and information systems that comply with the Open Data Initiative, it is an opportune time
3216 to address data issues that lead to confusion and delay in the stock assessment process. For some
3217 assessments, analysts face challenges in obtaining all necessary data. These challenges arise because
3218 many sources of data are managed by individual programs and partners, data require varying degrees of
3219 processing before analysis, and the access and ability to process the data is limited. It is most efficient if
3220 stock assessment scientists can simply obtain all necessary data in the formats required as early as
3221 possible in the stock assessment process. There is a need to improve data management in NOAA
3222 Fisheries and with partner organizations that provide data to the stock assessment process (particularly
3223 within the networks used to compile fishery-dependent data). Stock assessments will become more
3224 streamlined, and in some cases, more accurate, by creating systems that are open and easily accessible,
3225 organized according to standard formats and data dictionaries, and that contain effective and
3226 automated error-checking and processing procedures to facilitate access to timely and accurate data.
3227 These technological and process-oriented improvements address objectives described in Chapter 10
3228 related to improving the timeliness, efficiency, and effectiveness of the stock assessment process.

3229 The development of streamlined systems for compiling and processing data (e.g. catch, abundance,
3230 composition) for assessment applications represents a first step toward improving assessment data
3231 delivery. For example, a web-based interface, such as the Alaska Fisheries Information Network²⁸
3232 (AKFIN) simplifies data processing steps and ensures greater transparency in how the data were
3233 compiled. More regional systems such as AKFIN are nonetheless needed. Features should provide the
3234 user with ways to easily search and compile the information (e.g., through construction of maps, tables,
3235 and diagnostic figures) while also allowing easy documentation of the steps that were taken in the
3236 preparation of assessment input data. In the interest of transparency, routine retracing of these steps
3237 should be made feasible, and to facilitate thorough evaluation, interfaces should be designed that
3238 encourage users to examine data closely for characteristics such as incorrect data points and differences
3239 due to alternative processing techniques. For example, the ability to easily examine fishery data by
3240 sector, season, and spatial distribution can help users evaluate the number of fisheries that should be
3241 explicitly modeled in an assessment (and allow for the easy creation of alternative configurations for
3242 testing the sensitivity of an assessment). For situations where data from fishery-independent surveys
3243 are available, analytical tools for processing such data collections can benefit from applications that use
3244 innovative statistical techniques, such as better accounting for spatial dynamics (see the discussion in
3245 Section 9.3 on software developments).

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²⁸ <http://www.psmfc.org/program/alaska-fisheries-information-network-akfin>

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***Box 9.1. Summary of Data Collection and Processing
Recommendations***

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- Establish a national working group in NOAA Fisheries focused on data collection for stock assessments.
- Conduct a gap analysis for stock assessment survey coverage and intensity in each region to facilitate survey prioritization.
- Conduct research to estimate survey catchability and selectivity to facilitate estimation of absolute abundance for key stocks.
- Adjust surveys to track shifting species distributions and conduct studies to calibrate surveys where distributions have changed.
- Partner with the fishing industry to conduct low-cost monitoring as part of normal fishing operations to fill data gaps and/or subsample fishery catch rates according to a sampling design.
- Increase use of cost-effective electronic monitoring and reporting to improve fishery-dependent data collection.
- Enhance broad spectrum sampling of ecosystem and socioeconomic data using new and existing platforms and technologies.
- Expand use of advanced sampling technologies (acoustics, optics, eDNA, and unmanned platforms) for tracking stock abundance by calibrating surveys and sampling in “untrawlable” habitat.
- Provide centralized open access to updated and processed stock assessment data.
- Utilize standardized and understandable data dictionaries and formats.
- Where possible, establish automated quality control and data

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9.3. Innovations in stock assessment modeling

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Analytical tools available for conducting stock assessments are more powerful and more efficient than ever. This innovation has facilitated the integration of large amounts of data from diverse sources, comprehensive characterizations of statistical uncertainty, and the evaluation of multiple hypotheses about stock and fishery dynamics within an assessment. The tools themselves cannot “fix” issues in the

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3272 data, but as tools develop, they contain enhanced functionality that allow for appropriate treatment of
3273 data and presentation of results and uncertainties. The recommendations in this section pertain mostly
3274 to technical advancements related to the functionality of analytical tools for stock assessments. These
3275 recommendations address many of the challenges raised in Chapter 5, offering a direction for improving
3276 stock assessment models. Some examples include new approaches for conducting data-limited
3277 assessments, promising statistical tools, and alternative strategies for evaluating risk in fishery
3278 management settings. The section concludes with a presentation of options for integrating ecosystem
3279 information into stock assessment models.

3280 9.3.1 Improved software and advanced models

3281 Advances in software have greatly facilitated application developments for fisheries stock assessments.
3282 The ability to develop open source software packages that focus on reproducibility of results and
3283 provide assistance with documenting those results has provided more time for assessment model
3284 developers and analysts to concentrate their efforts on prototyping and designing alternative models
3285 that account for a range of reasonable assumptions. This flexibility is important for providing an
3286 improved characterization of the true uncertainty surrounding assessment results (see Section 9.3.3).

3287 The software package that continues to form the foundation of the majority of NOAA Fisheries' stock
3288 assessments is Auto Differentiation Model Builder²⁹ (ADMB; Fournier et al., 2012). The main advantage
3289 of ADMB is its ability to efficiently run complex nonlinear models with many estimated parameters,
3290 which is how most modern stock assessment models are configured. NOAA Fisheries continues to be the
3291 primary funding source for ADMB, providing global leadership in assessment model support and
3292 development. Unless assessments migrate to another platform, it is important for the entire stock
3293 assessment enterprise that this support continues at a level sufficient for ADMB to be able to adapt to
3294 ongoing advancements in assessment science. For example, in 2016 the ADMB project embraced a
3295 European-developed project, Template Model Builder³⁰ (TMB), which offers a substantial increase in
3296 speed for certain classes of model structures. NOAA Fisheries' scientists are significantly engaged in both
3297 ADMB and TMB.

3298 Modern open source statistical programming languages such as R³¹ represent another significant
3299 advancement for stock assessments. These programming languages improve the efficiency and rigor by
3300 which assessment data are evaluated, alternative assessment scenarios are conducted, and results are
3301 assimilated and presented. These languages are relatively accessible to analysts without formal training
3302 in computer programming, but they provide users with access to powerful programming tools (including
3303 C++ and FORTRAN libraries) within a common interface. Also, given the open source nature and global
3304 popularity, users also have access to tested and reviewed software packages that allow the

²⁹ <http://admb-project.org/>

³⁰ <https://github.com/kaskr/adcomp/wiki>

³¹ <https://www.r-project.org/>

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3305 implementation of common methods without the need to develop the methods from scratch. This
3306 access is particularly important for assessment analysts who are asked to evaluate numerous
3307 assumptions and configurations over shortened time periods, and NOAA Fisheries' scientists have
3308 contributed these software packages to the public domain (e.g., r4ss³²).

3309 A valuable opportunity available to assessment developers is the ability to coordinate with colleagues on
3310 projects via virtual and cloud-based platforms. This coordination has been enabled by modern online
3311 version control systems (e.g., git³³), which provide easy access to develop code, write documentation,
3312 and facilitate model testing and exchange of ideas and methods. Many assessment platforms have been
3313 developed by single authors or small teams in independent settings. However, the community-level
3314 development option makes it easy to access a broad range of expertise, resulting in enhanced
3315 functionality and more thorough testing. Overall, the software packages, diversity of knowledge, and
3316 collaborative opportunities available to assessment model developers have matured to a point where
3317 NOAA Fisheries can now take a more professional approach to the development of general assessment
3318 tools. The assessment model, Stock Synthesis (Methot and Wetzel, 2013) has already migrated into
3319 NOAA's Virtual Lab³⁴ where git capabilities allow access to NOAA and invited external developers. The
3320 recommended approach to tool development will be to start with professional software architecture
3321 and to create modular applications to facilitate the rapid incorporation of new features as needed. This
3322 approach is an important component of the next generation stock assessment framework, because it
3323 allows for standard models that improve efficiency and transparency, as well as easy expansion of
3324 models (including more holistic options) driven by needs identified through prioritization.

3325 The cutting edge of assessment model development lies in the ability to treat certain model
3326 components (e.g., natural mortality) not as fixed constants, but rather as factors that vary randomly
3327 over time, age, and/or space in a way that is informed by available data and constrained by an
3328 estimated statistical distribution. This technique has many names, including state-space models, random
3329 effects models, mixed-effects models, and hierarchical models, among others. The use of this statistical
3330 technique helps to address several challenges in the assessment process. In particular, the
3331 characterization of uncertainty may be improved by accounting for variation in the model structure (i.e.,
3332 process error). This approach relates to improved risk assessment (Section 9.3.3) as well as an ability to
3333 indirectly account for ecosystem and socioeconomic effects (Chapter 8 and Section 9.3.4). Even when
3334 there is not a clear understanding of the mechanisms that cause stock and fishery dynamics to drift over
3335 time, and when data are unavailable to model those mechanisms, allowing for a random but informed
3336 variation of a model component may sufficiently account for these external drivers in some cases.
3337 Although these techniques are not yet common in U.S. stock assessments, many European stocks are

³² <https://cran.r-project.org/web/packages/r4ss/index.html>

³³ <https://git-scm.com/>

³⁴ <https://vlab.ncep.noaa.gov/group/stock-synthesis/home>

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3338 assessed using the State-space Assessment Model (SAM³⁵), which does allow for random effects. Recent
3339 development of TMB, which allows for efficient estimation of complex statistical models with numerous
3340 random effects, now opens the door to implementing this technique more broadly in stock assessments.
3341 It is recommended here that many stock assessments capitalize on this opportunity to better
3342 characterize changes in processes and better account for spatial dynamics.

3343 A specific technical challenge for modern assessment methods relates to “data weighting.” This term
3344 refers to the appropriate specification (or estimation) of variances associated with different data
3345 components. This term also includes how to elicit and apply prior information, particularly for data-
3346 limited situations, and how to specify process error variances where estimation is presently difficult or
3347 impractical. In general, data weighting requires some degree of subjectivity. However, recent
3348 developments to estimate variances of composition data hold some promise for objective approaches
3349 (e.g., Francis, 2014; Thorson, 2014). Tests for these approaches and how they may apply to data-limited
3350 situations require simulation testing (e.g., Deroba et al., 2014). Furthermore, approaches that augment
3351 information on a particular stock based on data from similar species and regions are a clear, cost-
3352 effective way forward (for example applications see Punt et al., 2011; Punt and Dorn, 2013;). As noted
3353 in Bentley (2014), models for management face the challenge to balance opposing risks of inappropriate
3354 management “action” due to assessment inaccuracy, and inappropriate management “inaction” due to
3355 assessment uncertainty.

3356 **9.3.2 Using multiple models to generate advice**

3357 Methods that combine results from multiple alternative models are generally referred to as “ensemble
3358 modeling.” This approach involves generating multiple projections of future system states using a range
3359 of assumptions about how to configure the assessment. Therefore, ensemble modeling has the
3360 potential to capture structural uncertainty in addition to the observation uncertainty that is typically
3361 quantified. This approach is widely used in climate modeling where uncertainty is reflected in the
3362 accuracy of the approximations to the well-known and accepted physical principles of climate and the
3363 inherent variability of the climate system. For the purposes of weather forecasts (e.g., predicting a
3364 hurricane track), model ensembles are created from a suite of models whose performance is updated
3365 (with precise data) at regular intervals and monitored to provide probability statements on near- and
3366 medium-term predictions. The past predictions of each model can be evaluated relative to known storm
3367 tracks and used to weight its contribution to the ensemble for future predictions.

3368 Fish stocks and fishery management operate at a slower pace than weather predictions. The challenges
3369 with fisheries, however, are that the observations are rarely precise; many drivers affecting fish stocks
3370 (other than fishing) typically go unobserved (e.g., the impact of tides, food availability, predation, and so
3371 on); and there is less opportunity for validating past predictions (e.g., hurricane forecasts can be
3372 compared with the actual hurricane track, but the true abundance of a fish stock is seldom known). In

³⁵ <https://www.stockassessment.org/>

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3373 these settings, more formal methods of combining model alternatives, such as Bayesian Model
3374 Averaging, (e.g., Buckland et al., 1997; Durban et al., 2005; Hoeting et al., 1999; Kass and Raftery, 1995;
3375 Raftery et al., 2005; Chimielechi and Raftery, 2011) or bootstrapping approaches (Stewart and Martell,
3376 2015) can be applied. Critical simulation testing has shown that model averaging approaches
3377 outperformed methods that generated advice based on a “best” model (Wilberg and Bence, 2008). It is
3378 recommended that stock assessments capitalize on these advances in ensemble modeling to generate
3379 management advice with more complete characterizations of uncertainty. However, it is important to
3380 stress that each model included in the final ensemble should be considered plausible according to the
3381 assessment analysts and reviewers (at least). Further, all models should be well documented and
3382 contributed early enough in the assessment to be included in the assessment review process. Thus,
3383 every model in an ensemble should have consistent levels of review and transparency.

3384 9.3.3 Risk assessment for fisheries management decisions

3385 The evaluation of risk and accounting for uncertainty are clear requirements for setting annual catch
3386 limits (ACLs) as specified in the MSA (e.g., to provide a sufficiently low chance of overfishing while
3387 maximizing catch; Methot et al., 2014). These actions involve estimating scientific uncertainty (Chapter
3388 5) and evaluating management uncertainty (Patrick et al., 2013). Approaches are outlined later to
3389 evaluate uncertainty in the implementation of management actions with a goal of satisfying this and
3390 other objectives for fishery managers and stakeholders. Such methods should be shown to be robust to
3391 management objectives (i.e., low probability of leading to an overfished state while optimizing yield).
3392 For management purposes, a key for new analytical tools will be to balance research models and
3393 operational management tools that are used as a basis for setting catch limits and determining status.

3394 The field of decision theory provides useful analytical methods for finding optimal solutions in the
3395 assessment of risk. However, these approaches suffer from a lack of transparency, and simpler methods
3396 are often preferred by fishery managers. An example where a risk-averse, decision-theoretic approach
3397 was replaced by a more straightforward method has been adopted for certain (“Tier 1”) stocks managed
3398 under the Bering Sea/Aleutian Islands Groundfish Fishery Management Plan (Amendment 56). In this
3399 example, the risk-averse approach to developing a catch recommendation (i.e., Acceptable Biological
3400 Catch, ABC) was found to be equal to an approach that simply used a certain type of averaging (i.e., the
3401 harmonic mean) of the estimate of the overfishing limit (F_{MSY}). An appealing characteristic of this
3402 approach is that the harmonic mean is some percent reduction from F_{MSY} , and when uncertainty in the
3403 assessment (particularly around F_{MSY}) is high, the recommended catch is decreased as one might expect
3404 in a precautionary harvest control rule. This approach has proven useful for accounting for scientific
3405 uncertainty, but fishery managers must also consider other factors, such as management uncertainty
3406 and socioeconomic factors, when optimizing yield.

3407 Another management measure that attempts to account for assessment uncertainty related to risk of
3408 exceeding an overfishing limit is known as the P* approach (Shertzer et al., 2008). This method relates
3409 the probability that a projected future catch would exceed the overfishing (F_{MSY}) level and allows the

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3410 policy makers to establish the level of risk related to a catch limit selection. For example, if P^* was set to
3411 0.4, then this would represent a 40% chance that the corresponding catch limit would exceed the true
3412 overfishing limit. Although effective at addressing specific sources of uncertainty, the P^* and decision-
3413 theoretic approaches do not account for considerations related to interactions among fisheries and
3414 multiple species within an ecosystem.

3415 An important advancement for evaluating risk in fishery management is the growing application of
3416 simulation-tested management strategy evaluations (MSEs; Butterworth et al., 1996; Butterworth, 2007;
3417 Punt et al., 2014). A distinct advantage of this decision analysis tool is that models used for developing
3418 catch recommendations (i.e., the actual management strategies or control rules) are designed to be
3419 transparent and relatively simple. Also, the approach can incorporate any number of considerations,
3420 including biological, ecosystem, and socioeconomic factors. This aligns well with the NS1 Guidelines,
3421 which suggest that a council can consider the socioeconomic and ecological tradeoffs between being
3422 more or less risk averse. Further, by conducting simulation testing, there is a certain amount of
3423 confidence in the results. In a well-designed MSE, stakeholders are engaged throughout the process to
3424 ensure that the performance metrics that directly relate to management objectives are easy to
3425 understand (Punt et al., 2014). The challenges for this approach include developing defensible operating
3426 model configurations, particularly for testing control rules in data-limited situations. Borrowing from
3427 related species and stocks from other areas could help establish plausible estimates for biological
3428 parameters (e.g., Smith et al., 2015).

3429 The MSE approach benefits from using disparate sources of information and models (including
3430 multispecies and ecosystem considerations) to devise plausible realities for testing management
3431 options. Looking forward, recent developments in statistical programming languages such as R (Section
3432 9.3.1) have made it easier for stakeholders to participate in MSEs. For instance, by having access to tools
3433 that are designed to work within a specific assessment framework, such as the `ss3sim`³⁶ package for
3434 Stock Synthesis (Methot and Wetzel, 2013), more time can be spent on developing objectives and
3435 performance metrics with stakeholders than on coding simulation analyses. Other R packages specialize
3436 in user-friendly interfaces to evaluate policy choices given uncertain states of nature, such as `mseR`
3437 (Kronlund et al., 2012) and the MSE tool developed for the International Pacific Halibut Commission.³⁷ It
3438 is recommended here that NOAA Fisheries continues to invest in the development of MSE tools and the
3439 resources necessary for development and expansion of MSEs to inform management decisions in the
3440 face of uncertainty.

3441 **9.3.4 Holistic stock assessment models**

3442 Ecosystem information is beginning to form a more integral part of modern stock assessments. Effective
3443 marine conservation and management requires an understanding of how ecosystem drivers (e.g.,

³⁶ <https://github.com/ss3sim/ss3sim>

³⁷ <http://shiny.iphc.int/sample-apps/mseapp/>

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3444 temperature changes) can affect assessment results (in particular, biological reference points). As these
3445 broader applications become a more integral part of the stock assessment process, any number of
3446 management decisions can account for this information, including catch levels. Stock-specific ecosystem
3447 considerations within an assessment can help prioritize factors most likely to affect processes related to
3448 the stock. In addition, these considerations can provide further specifics on future productivity and
3449 potential management actions that may be needed (e.g., Shotwell et al., 2014).

3450 Chapter 8 provided a full discussion of holistic approaches to stock assessments that consider ecosystem
3451 and socioeconomic factors. Most current stock assessment models can incorporate many of these
3452 factors today, but there remains a need for research and development. With mixed-stock fisheries and
3453 climate change forcing systems into unobserved states with consequences for fisheries (e.g., Ianelli et
3454 al., 2011; Meuter et al., 2011; Holsman et al., 2016), it is imperative that next generation stock
3455 assessment models have straightforward options for accounting for ecosystem and/or socioeconomic
3456 factors, and that the effects of these additional factors be easily understood and tested. Example model
3457 features that would facilitate more holistic assessments include capabilities for spatial structure and
3458 connectivity, options to incorporate multispecies dynamics, state-space implementations that allow
3459 efficient models with random change and variability, the ability to apply multiple model
3460 configurations/types, and standard diagnostic and reporting features for rapid dissemination of results.
3461 The recommendation here to develop assessment tools with these capabilities could result in more
3462 efficient, but also more comprehensive (holistic), stock assessment models.

3463 9.3.5 Expanding and improving process studies

3464 Many of the recommendations provided in this chapter are challenging to implement without a more
3465 complete understanding of key processes. For instance, in order to expand the scope of a stock
3466 assessment to include ecosystem and socioeconomic factors, it is not only important to collect the
3467 necessary data (Section 9.2.3) and to have assessment tools capable of incorporating those data
3468 (Section 9.3.4), it is also necessary to understand the main processes that drive stock and fishery
3469 dynamics. These process studies will provide guidance on how to configure expanded models. This
3470 research is also useful in helping to select plausible models for ensembles (Section 9.3.2) and to design
3471 and implement MSEs (Section 9.3.3). Thus, process research has an important role in improving the
3472 basis on which models of fish population dynamics and ecosystem dynamics are built. It is
3473 recommended here that NOAA continue to invest in these efforts and, in particular, that these
3474 investments be guided by stock assessment priorities (Chapter 10). Key areas for process studies that
3475 would address stock assessment priorities include the following research areas:

- 3476 • Habitat and environmental factors affecting the distribution of fish, fisheries, and the design of
3477 sampling programs
- 3478 • Factors constraining the physiology of fish in a changing environment
- 3479 • Flow of energy through marine food webs

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- 3480
- Connection between changes in the marine environment and fluctuations in birth and growth
- 3481 rates of young fish

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3483 **9.4. Conclusions**

3484 Although stock assessment science has benefited from numerous advancements during the past
3485 century, continued research and development is still required. A series of research initiatives within
3486 NOAA Fisheries allow federal researchers to develop projects that specifically tackle these objectives.
3487 These nationally run programs fund priority projects across the regions that improve stock assessments.

3488 Another path for improving assessments is through coordinated workshops and symposia that
3489 specifically address theories, estimators, and assumptions within particular aspects of stock assessment.
3490 These workshops provide the opportunity to synthesize current research and develop guidelines and
3491 best practices; examples include NOAA Fisheries' National Stock Assessment Workshops and the
3492 workshops being organized by the Center for the Advancement of Population Assessment
3493 Methodology.³⁸ The next generation stock assessment framework described in this document is
3494 attainable given the current state of the science, ongoing prioritized investments in research, and
3495 opportunities to collaborate broadly throughout the stock assessment community.

3496

Box 9.2. Assessment Modeling Recommendations

3497

- Utilize advancements in statistical techniques, such as state-space, geo-statistics, sample weighting, auto-correlated processes, and so on.
- Provide a more complete characterization of uncertainty and utilize ensemble modeling and decision analysis tools to convey structural uncertainty and inform fishery management decisions.
- Improve professionalism of model development (professional architecture, thorough testing and publication of test results, thorough documentation and user guides, community development, and cloud-based computing).
- Expand the scope of assessment models where appropriate to include spatial dynamics, multispecies and ecosystem processes, and/or socioeconomics.
- Rely on stock assessment priorities to guide investments in innovative science and technology and the resources necessary to implement these advancements.

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³⁸ <http://www.capamresearch.org/>

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3602

3603 **Chapter 10—An Efficient and Effective Stock Assessment** 3604 **Enterprise**

3605 **Chapter highlights:**

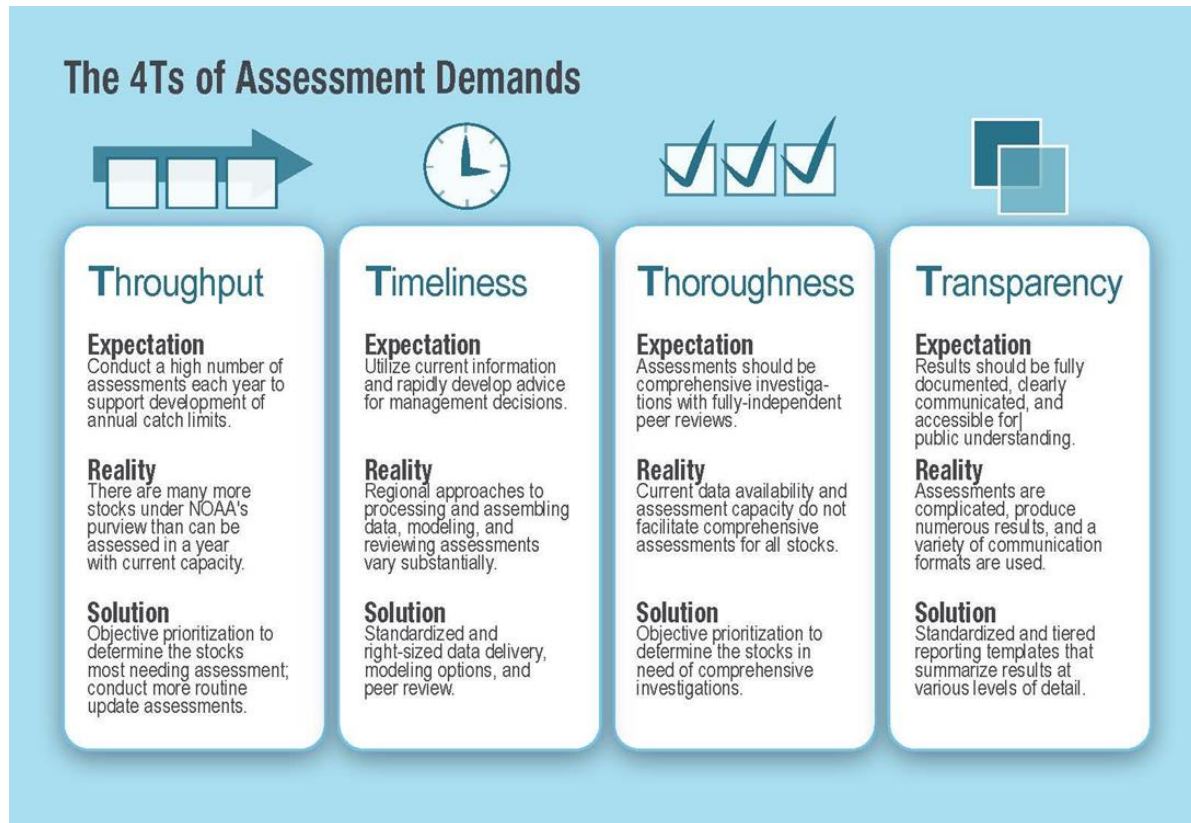
- 3606 • **The demand for increasing the quantity and quality of stock assessments has overloaded**
3607 **NOAA's stock assessment enterprise.**
- 3608 • **The completion rate of stock assessments is affected by varying requirements regarding the**
3609 **complexity of data sources, and how timely, thorough, and transparent assessments need to**
3610 **be to support effective management.**
- 3611 • **A national method for categorizing and prioritizing stock assessments is proposed to balance**
3612 **stock-specific needs, better use assessment resources, and identify gaps in NOAA's stock**
3613 **assessment enterprise.**
- 3614 • **Stock assessments should use more standardized processes regarding data preparation and**
3615 **delivery, assessment modeling, peer review, and communication.**
- 3616 • **Research is necessary to continue improving stock assessments, and the standardized**
3617 **operational process must be adaptable to incorporate advancements.**

3618 **10.1. Introduction**

3619 NOAA Fisheries' national stock assessment enterprise consists of several regional assessment programs
3620 that provide scientific advice to regional fishery management organizations (Chapter 3). Overall, this
3621 federal fishery management system operates in accordance with the MSA; however, the regional
3622 assessment programs and management organizations have developed independently over time. Thus,
3623 the processes by which MSA mandates are addressed can vary by region. Although the science–
3624 management interface has successfully achieved its goals for federal fisheries (Chapter 2), the demands
3625 and challenges surrounding the provision of best scientific information are substantial, conflicting, and
3626 broadly applicable. These issues can be classified according to the “4Ts” (Figure 10.1).
3627

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3628
3629 **Figure 10.1.** The major demands and challenges facing NOAA Fisheries' stock assessment enterprise
3630 summarized by 4Ts (throughput, timeliness, thoroughness, and transparency).
3631

3632 There are unrealistic expectations surrounding the 4Ts and it is not possible to simultaneously achieve
3633 high grades for each T. Figure 10.1 summarizes expectations and realities for the current stock
3634 assessment enterprise while also offering solutions to better meet expectations. These solutions do not
3635 intend to meet all expectations, but rather offer a balanced approach that manages expectations and
3636 suggests improvements where feasible. Thus, in this chapter, the range of improvements provided will
3637 achieve a more efficient and effective stock assessment process.
3638

3639 Nationally, there are many more federally managed fish stocks than can be assessed in a single year with
3640 NOAA Fisheries' current stock assessment capacity. The annual stock assessment demand in a given
3641 region typically exceeds the number of assessments that NOAA scientists can complete. However,
3642 annual assessments may be unnecessary for stocks that are not highly valued commercially,
3643 recreationally, or for other reasons. Also, stocks that do not exhibit substantial fluctuations in
3644 abundance from year to year may not require annual assessments. Because it is unnecessary to revise
3645 catch recommendations for certain stocks every year, and because NOAA Fisheries has limited stock
3646 assessment capacity, it is essential to determine which stocks are most in need of assessment. For high-
3647 priority stocks, it is also important to set the frequency at which assessments should be conducted in
3648 following years, and determine how comprehensive each assessment should be (i.e., the key data

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3649 sources that should be used to calibrate the assessment as well as the nature of peer review that should
3650 occur). This chapter describes an objective national approach for establishing an assessment portfolio
3651 and offers suggestions for developing more efficient regional assessment processes.

3652
3653 This portfolio approach is fundamental to maximizing available stock assessment resources, guiding
3654 future investments, and achieving sustainable fisheries and resilient communities to the maximum
3655 extent possible. The main components of the portfolio approach include the following:

- 3656
- 3657 1. Classifying the stock assessments conducted by NOAA Fisheries
 - 3658 2. Establishing stock-specific targets for assessment frequency and the level (types of data used) of
3659 each assessment
 - 3660 3. Developing annual prioritized lists of stocks to assess in each region
 - 3661 4. Conducting gap analyses that compare classified assessments against their target levels
 - 3662 5. Using the resource assessment to right-size the stock assessment enterprise and seek funding as
3663 needed

3664
3665 A similar approach to strategic planning was introduced in the 2001 Stock Assessment Improvement
3666 Plan (Mace et al., 2001), which included an assessment classification system and strategic guidance
3667 outlined by the Three Tiers of Assessment Excellence (Chapter 2). Overall, this system provided guidance
3668 and justification for expanding and improving the stock assessment program. However, with the
3669 increasing demand for stock assessments, and the evolution of legal mandates, scientific knowledge and
3670 capability, and assessment processes, it is clear that a new portfolio approach is needed. In the following
3671 sections, we describe each of the three components of this new approach with reference to the existing
3672 system.

3673

3674 **10.2. Classifying stock assessments**

3675 Not all stock assessments are created equal. In Chapter 1, stock assessments were defined as being a
3676 process that results in a product. However, both the process and the product vary across the United
3677 States. See Chapter 6 for a description of the various regional assessment review processes (Table 6.1),
3678 and Chapter 5 for the range of stock assessment modeling approaches and their data requirements
3679 (Table 5.1). Thus, the type of product produced and degree of effort required for each assessment varies
3680 substantially. Further, the fishery management process may rely on analyses to support decisions, such
3681 as establishing annual catch limits, which use assessment science but do not assess the status of the
3682 stock and therefore are technically not stock assessments. For example, one approach to adapting catch
3683 regulations without conducting a full stock assessment is to rely on estimates from a previous
3684 assessment to forecast stock abundance and catch recommendations using updated catch data. These
3685 approaches are very useful analyses that support management between more complete stock
3686 assessments; however, they should not be considered stock assessments. Additionally, stock assessment
3687 research is conducted outside the operational assessment process to improve stock assessment

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3688 methods. This work can be just as involved (if not more) than an operational assessment, but is not
3689 immediately used to provide management advice.

3690 To offer a consistent language on the various types of assessment-related analyses conducted by NOAA
3691 Fisheries, the following general categories are recommended:

- 3692 • **Research stock assessment**—development or revision of a stock assessment data type or
3693 method, typically subjected to the regional assessment review process. If the activity both
3694 produces a substantial revision to the assessment method and applies that method to produce
3695 management advice, then the activity is labelled as both a research assessment and an
3696 operational assessment (next category).
- 3697 • **Operational stock assessment (or “stock assessment”)**—analyses conducted to provide
3698 scientific advice to fishery managers with particular focus on determining stock status and
3699 recommending catch limits. These are the predominant assessment activities and include
3700 assessments using any of the methods described in Table 5.1, updated with the most recent
3701 data. Within the range of operational assessments will be first time applications of previously
3702 researched methods (“new” or “benchmark” assessments); applications with updated data
3703 streams and minor revisions to methods within the scope of previously researched themes; and
3704 applications that simply update the model with the most recent data. However, if only catch
3705 data are updated then the activity falls into the next category.
- 3706 • **Stock monitoring update**—methods used to provide stock-level advice to fishery managers
3707 between stocks assessments. These analyses include the methods described in Table 5.1, but
3708 only when they are updated using the most recent catch information to develop new catch
3709 advice. These are sometimes called partial updates. Because there are no changes in the
3710 methods or data series in stock monitoring updates, just updated catch data, the conduct and
3711 review of these analyses should be very routine and intense scrutiny is not warranted.

3712 Because a major focus of this plan is to set priorities for conducting assessments at frequencies and
3713 levels that are most appropriate for each stock, there is a need to establish a consistent approach to
3714 tracking and classifying assessments (i.e., everything captured in the “operational stock assessment”
3715 category). A stock assessment classification system was described in the 2001 SAIP (Mace et al., 2001).
3716 This system is currently used by NOAA Fisheries to classify individual assessments according to five
3717 categories, three of which capture the input data used in each assessment, and two for describing the
3718 assessment approach. The input data are categorized according to catch, abundance, and life history
3719 data, and the assessment approach is described in terms of the modeling technique used and frequency
3720 at which the stock is assessed. Overall, this system has proven useful for tracking stock assessments,
3721 evaluating assessment capacity, and addressing program gaps. For instance, as the preference to
3722 incorporate ecosystem dynamics into the assessment process has continued to increase, the
3723 classification system has been used to summarize which stocks already include such information (Box
3724 5.1).

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3725 However, the current assessment classification system has limitations. The level of detail captured in the
3726 categories is not sufficient to fully summarize assessments. Model configurations are largely driven by
3727 the available input data, so an expansion of the original data categories is warranted. Also, the original
3728 assessment model category blends modelling approaches and data inputs. For example, the highest
3729 level in this category refers to a model that incorporates ecosystem, environmental, spatial, and/or
3730 seasonal information. However, these types of data can be included using many assessment techniques
3731 from simple to comprehensive.

3732
3733 A new Stock Assessment Classification System is proposed and summarized in Table 10.1. This system
3734 includes the high-level model categorization described in Chapter 5 (Table 5.1), tracks the age of the
3735 assessments, and expands the categorization of available input data. Appendix A provides a detailed
3736 description of the levels of each category in Table 10.1.

3737
3738 **Table 10.1. NOAA Fisheries' Stock Assessment Classification System.** Seven attributes will be used to
3739 classify individual stock assessments. Quantitative levels are defined for input data attributes to support
3740 gap analyses.

3741

	Attribute	Level
Assessment Application	Model Category	<ul style="list-style-type: none"> • Data-Limited • Index-Based • Aggregate Biomass Dynamics • Virtual Population Analysis • Statistical Catch-at-Length • Statistical Catch-at-Age
	Age	<ul style="list-style-type: none"> • Years since assessment conducted
Input Data	Catch	<ol style="list-style-type: none"> 0. None 1. Major gaps preclude use 2. Major gaps in some sector(s) 3. Minor gaps across sectors 4. Minor gaps in some sector(s) 5. Near complete knowledge
	Size/Age Composition	<ol style="list-style-type: none"> 0. None 1. Major gaps preclude use 2. Support data-limited only 3. Gaps, but supports age-structured assessment 4. Support fishery composition 5. Very complete
	Abundance	<ol style="list-style-type: none"> 0. None

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	<ol style="list-style-type: none"> 1. Uncertain or expert opinion 2. Standardized fishery-dependent 3. Limited fishery-independent 4. Comprehensive fishery-independent 5. Absolute abundance
Life History	<ol style="list-style-type: none"> 0. None 1. Proxy-based 2. Empirical and proxy-based 3. Mostly empirical estimates 4. Track changes over time 5. Comprehensive over time and space
Ecosystem Linkage	<ol style="list-style-type: none"> 0. None 1. Informative or used to process input data 2. Random variation, not mechanistic 3. Direct linkage(s) 4. Linkage(s) informed by process studies 5. Fully coupled

3742

3743

3744 Overall, the Stock Assessment Classification System will improve national tracking of NOAA Fisheries'
3745 stock assessments and will provide a clear picture of the data available for each assessment. Further, the
3746 new categories specific to ecosystem linkages and size and age data will provide a more comprehensive
3747 understanding of how these key aspects of fish stock dynamics are being incorporated into stock
3748 assessments.

3749

3750 **10.3. Prioritizing stock assessments**

3751 Historically, fish stock assessment prioritization has been conducted following independent regional
3752 processes. Each of the eight Regional Fishery Management Councils, in conjunction with their
3753 corresponding NOAA Fisheries science centers and regional offices, establish stock assessment
3754 schedules for the stocks under their management purview. These organizations utilize independent
3755 processes to identify and prioritize stocks in need of assessment. For instance, essentially all stocks
3756 managed by the North Pacific Fishery Management Council are assessed annually or biennially. By
3757 contrast, due to limited data availability, assessments are infrequent or yet to be conducted on stocks
3758 managed by the Caribbean Fishery Management Council. Within these extremes, most regional
3759 processes are informed by a multitude of factors when selecting the stocks to be assessed in a given
3760 year. Additionally, NOAA Fisheries supports and conducts assessments of stocks managed by state,

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3761 interstate, or international organizations. In many cases, the assessment schedules for these stocks are
3762 established by the partner agencies.

3763
3764 Given that the socioeconomics, fishery dynamics, and species harvested are unique for each region,
3765 regional processes must determine assessment schedules. However, using a range of independent
3766 approaches among the regions is challenging for stakeholders that need to understand why certain
3767 assessments are conducted in a given year. If each region follows a unique protocol, it is difficult to track
3768 how assessment schedules are determined. This limits NOAA Fisheries' ability to evaluate stock
3769 assessment capacity from a national perspective, because the overall demand for stock assessments can
3770 be unpredictable when various approaches to scheduling are used. For federally managed stocks, annual
3771 catch limits are a required component of fishery management plans. Yet, NOAA Fisheries' current stock
3772 assessment capacity is not sufficient to support assessments of all federally managed stocks each year.
3773 For stocks that are relatively stable over time, it may be unnecessary to conduct annual stock
3774 assessments; however, to achieve optimum yield for fisheries, many stocks may need annual
3775 assessments. Using an objective process to establish the list of stocks in need of assessment and the
3776 frequency at which those assessments should be conducted would provide important guidance for
3777 NOAA Fisheries to determine how best to allocate federal resources to address regional needs. Thus,
3778 maintaining a transparent and predictable prioritization process is crucial for maximizing the usefulness
3779 of overall assessment capacity to meet national mandates.

3780

3781 10.3.1 A national protocol for prioritizing stock assessments

3782 The national prioritization process for stock assessments is based on the concept that it is not necessary
3783 to conduct the most data-rich, ecosystem-linked assessment for every stock every year. That level of
3784 effort is not needed to achieve good management of fisheries. Stable stocks and their fisheries get little
3785 benefit from frequent reassessment. Minor stocks may be of less overall importance relative to the cost
3786 of an assessment, but they can be managed well enough if they occur in a complex with other, well-
3787 assessed and well-managed stocks.

3788 NOAA Fisheries has developed a standard protocol for prioritizing fish stock assessments (Methot,
3789 2015). The purpose of this protocol is to provide an objective framework that will help guide regional
3790 decisions about which stocks require assessment and the level at which those assessments should be
3791 conducted. This framework can be adapted to best suit regional needs and is expected to continue to
3792 evolve. For each region, this national protocol represents one of many potential factors to consider
3793 when determining assessment schedules. However, by using this standardized approach, there will be
3794 an objective basis against which difficult or controversial decisions can be evaluated.

3795 This section, along with Tables 10.2 and 10.3, provide a brief summary of the prioritization protocol.
3796 Section 10.3.2 then expands upon the protocol by describing a process for setting target assessment
3797 levels for each stock. Thus, this document should be used along with Methot (2015) to fully understand
3798 and implement the national prioritization process.

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3799 A summary of the five main elements of the prioritization protocol are provided in Table 10.2. NOAA
3800 Fisheries is pursuing full implementation of the prioritization protocol, and this process is a crucial piece
3801 of the NGSa enterprise described in this document. The original process described by Methot (2015)
3802 uses 14 factors (Table 10.3) and combines them using formulas that identify target assessment
3803 frequencies for each stock, as well as scores and ranks that establish relative priorities for stocks
3804 needing assessments. Additionally, the factor concerning the presence of new information can guide
3805 decisions about whether an assessment should be conducted as a routine update, a more involved
3806 benchmark assessment, or addressed separately in a research assessment track (10.5.2).

3807 Overall, regional planners should aim to achieve a feasible workload that addresses the highest
3808 priorities. For example, a mix that includes a few new and/or benchmark assessments and many more
3809 routine updates is likely manageable under current assessment capacity. Conducting assessments at a
3810 higher frequency than is proposed or on stocks that can be managed with minimal baseline monitoring
3811 is unnecessary and represents an inefficient use of assessment and management resources.

3812

3813 **Table 10.2.** Overview of the national protocol for prioritizing fish stock assessments.

3814

<h2>1. Who</h2>	<ul style="list-style-type: none">• NOAA Fisheries in collaboration with regional experts and managers conduct prioritization in each region
<h2>2. What</h2>	<ul style="list-style-type: none">• Determine and include the stocks that require assessments versus those that can be sufficiently managed through baseline monitoring
<h2>3. When</h2>	<ul style="list-style-type: none">• Intended to inform the scheduling of annual assessments• Total annual effort required for the prioritization process will decrease after initial implementation
<h2>4. How</h2>	<ul style="list-style-type: none">• Regional experts develop scores for 14 factors• 9 factors establish target assessment frequencies• Managers develop weights for 12 factors, including assessment frequency, to reflect regional priorities• Calculate and rank weighted scores for 12 factors• Use results as objective guidance for scheduling assessments

3815

3816

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3817 **Table 10.3.** The 14 factors used in NOAA Fisheries' national stock assessment prioritization protocol, 9 of
3818 which are used for determining target assessment frequency and 12 are used to establish priority for
3819 assessments.

Factor	Scoring Range	Scoring Based On	Target Assessment Frequency	Determine Annual Priorities
Commercial Fishery Importance	0 to 5	National catch and value databases; calculated as $\log_{10}(1 + \text{landed catch value})$	X	X
Recreational Fishery Importance	0 to 5	Regional recreational fisheries expert opinion	X	X
Importance to Subsistence	0 to 5	Regional fisheries expert opinion	X	X
Rebuilding Status	0 or 1	National stock status database	X	X
Constituent Demand	0 to 5	Regional fisheries expert opinion	X	X
Non-Catch Value	0 to 5	Regional fisheries expert opinion	X	X
Relative Stock Abundance	1 to 5	Most recent spawning biomass and target/threshold levels, as available from SIS database		X
Relative Fishing Mortality	1 to 5	Most recent fishing mortality estimates and limit levels, as available from SIS database		X
Key Role in Ecosystem	1 to 5	Maximum of bottom-up and top-down components; assigned by regional fisheries expert opinion	X	X
Unexpected Changes in Stock Indicators	0 to 5	Regional fisheries expert opinion, where indicators are available		X
New Type of Information	0 to 5	Regional fisheries expert opinion		X
Years Assessment Overdue	0 to 10	Calculated as: year for setting priorities - year of last assessment - target assessment frequency + 1 year		X
Mean Age in Catch	value	Recent average of mean age; direct measurement or assessment estimates	X	
Stock Variability	-1 to +1	Coefficient of variation (CV) for recruitment from assessment estimates	X	

3820
3821 *SIS = Species Information System

3822 **10.3.2. Stock assessment targets—an expansion of the national prioritization protocol**

3823 As described in *Prioritizing Fish Stock Assessments* (Methot 2015), elements of the national prioritization
3824 process require further development. In general, there is a need to stress that the prioritization process
3825 is one of several decision-making tools being used in federal fisheries management, including already
3826 established regional prioritization processes (the national process can provide additional information).
3827 To maintain consistency and capitalize on multiple efforts, it is important that the results of other
3828 national exercises, such as the climate vulnerability analyses recommended in the National Climate
3829 Science Strategy (Link et al., 2015) be officially included in the stock assessment prioritization process.
3830 These results can be used to help guide expert opinion in developing scores for several existing factors
3831 (e.g., “Unexpected changes in stock indicators” and “New type of information”) and in the new steps
3832 described below.

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3833 A primary focus in the prioritization document (Methot 2015) was to describe a process for setting
3834 target assessment frequencies. This process can be summarized as follows:

- 3835 1. Begin with mean age in catch (or proxy)
- 3836 2. Multiply by a regional scaling factor (default = 0.5)
- 3837 3. Adjust for recruitment variability
 - 3838 a. -1 year: Recruitment CV > 0.9
 - 3839 b. +1 year: Recruitment CV < 0.3
- 3840 4. Adjust for fishery importance
 - 3841 a. -1 year: Stock in top 33% of regional fishery importance
 - 3842 b. +1 year: Stock in bottom 33% of regional fishery importance
- 3843 5. Adjust for ecosystem importance
 - 3844 a. -1 year: Stock in top 33% of ecosystem importance
 - 3845 b. +1 year: Stock in bottom 33% of ecosystem importance
- 3846 6. Results will be between 1 and a maximum of 10 years

3847

3848 There is no need to refine the process for setting target assessment frequencies here, but what follows
3849 are several new steps in the prioritization process that serve as guidance for setting target assessment
3850 levels. These new steps were developed because the prioritization document indicated that this aspect
3851 of prioritization would be developed in this revised SAIP. By expanding the process here, stock
3852 assessment prioritization will be aligned with the design of a next generation stock assessment (NGSA)
3853 enterprise.

3854 The assessment level essentially reflects the types of data included in an assessment, so in effect a
3855 target assessment level establishes priorities for data collection and analytical techniques. The Stock
3856 Assessment Classification System (Table 10.1) describes how comprehensive each assessment was
3857 conducted according to five data input categories. Thus, to align the national prioritization protocol with
3858 the NGSA enterprise, the process for setting target assessment levels described next directly
3859 corresponds to the five categories of the classification system. This approach will facilitate a
3860 comprehensive gap analysis that compares current assessment levels to target levels.

3861 The following guidance is proposed to describe how the national prioritization protocol can be used to
3862 establish targets for each of the five stock assessment categories. This guidance serves as an addendum
3863 to Methot (2015) and should be implemented as part of that process. The process described here is for
3864 setting baseline target assessment levels that should be evaluated and considered in the context of
3865 other existing information. For example, the results of other strategic efforts, such as NOAA Fisheries'
3866 Climate Vulnerability Analyses (Link et al., 2015), may be used to adjust baseline targets. Also, decision
3867 analysis tools, such as management strategy evaluations, represent comprehensive approaches that can
3868 be used to evaluate data tradeoffs and determine target assessment levels. When available, the results
3869 of more thorough research and decision analyses should serve a primary role in establishing target
3870 assessment levels. Adjustments to this approach to target setting will become apparent as testing and
3871 implementation develop in each region. However, after a consistent approach is fully implemented, it is

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3872 anticipated that targets will remain relatively stable over time. Significant shifts in targets will most likely
3873 be a result of notable changes, such as emerging fisheries, substantial changes in market dynamics,
3874 major ecosystem shifts, or the development of groundbreaking technologies and/or research.

3875 **Target catch level:** Because most stock assessment models assume a high degree of certainty, if not
3876 complete certainty in the amount of fish removed by the fishery, it is important to strive for complete
3877 knowledge of catch when stocks are being assessed with traditional statistical methods. However, when
3878 a stock is subject to little or no fishing, limited catch monitoring may be appropriate. Given these fairly
3879 stark needs regarding catch monitoring, the following describes a simple framework for establishing
3880 target catch levels. The target levels for catch and all following attributes correspond to the levels
3881 described in Table 10.1. Various levels for the factors in Table 10.1 were not considered to be
3882 appropriate targets; thus, there may not be a scenario in the following tables that corresponds to each
3883 level in Table 10.1 (i.e., certain levels are skipped).
3884

Target Catch Level	Stock Scenario
0	<ul style="list-style-type: none"> Stocks not caught as target or bycatch in any fishery
2	<ul style="list-style-type: none"> Stocks subject to very minimal catch so that fishing-induced mortality most likely does not have measurable effects on stock dynamics
5	<ul style="list-style-type: none"> All other stocks

3885
3886 **Target size and/or age composition level:** Stock assessments that include size or age composition data
3887 produce more complete descriptions of the effects of fishing on fish stocks than assessments that do not
3888 include this information. Also, if natural mortality is estimated within a stock assessment model,
3889 including composition data may improve the ability to estimate this mortality (Magnusson and Hilborn,
3890 2007). However, collecting and processing composition data requires significant allocation of resources,
3891 so it may be unnecessary to include this information in assessments of lower profile stocks. Three of the
3892 four factors that determine target assessment frequency from the prioritization protocol (recruitment
3893 variability, fishery importance, and ecosystem importance) represent metrics that, together, are useful
3894 for determining the importance of age/size composition data. The remaining assessment frequency
3895 factor (mean age in the catch) is not as useful. Thus, to establish target levels for size and/or age
3896 composition data, the following formula is recommended to calculate an importance metric, which
3897 adjusts the target assessment frequency equation from Methot (2015) by excluding the scaled mean age
3898 in the catch:
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Calculating Size/Age Importance

1. **Set Size/Age Importance = 0**
2. **Adjust for recruitment variability (using the coefficient of variation – CV)**
 - a. -1 when recruitment CV > 0.9
 - b. +1 when recruitment CV < 0.3
3. **Adjust for Fishery Importance**
 - a. -1 when stock is in top 33% of regional fishery importance
 - b. +1 when stock is in bottom 33% of regional fishery importance
4. **Adjust for Ecosystem Importance**
 - a. -1 when stock is in top 33% of regional ecosystem importance
 - b. +1 when stock is in bottom 33% of regional ecosystem importance

Possible values range from -3 to 3

Target Size/Age Composition Level	Stock Scenario
0	• Stocks that are not a priority for assessments
2	• Stocks with Size/Age Importance > 1
4	• Stocks with Size/Age Importance from -1 to 1
5	• Stocks with Size/Age Importance < -1

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Target abundance level: When stock assessments incorporate indices of abundance or biomass, the indices are used as observed changes over time (i.e., input data about abundance or biomass patterns). Thus, assessment results can be biased when observed trends do not reflect actual dynamics, and it has been shown that fishery catch rates can be misleading about abundance (Cooke and Beddington, 1984). In some cases, estimates of absolute abundance should be included in an assessment rather than indices of relative abundance. Further, in the absence of stock assessments, abundance trends serve as useful indicators of stock dynamics for baseline monitoring. The usefulness of abundance data and the limitations associated with fishery catch rates suggest that fishery-independent monitoring of

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3925 abundance should be in place for most managed stocks. Thus, in the following scenario we recommend
3926 high targets for abundance levels, except for stocks not subject to fishing mortality.
3927

Target Abundance Level	Stock Scenario
0	<ul style="list-style-type: none"> Stocks not caught as target or bycatch in any fishery and in the bottom 33% of regional ecosystem importance
3	<ul style="list-style-type: none"> Stocks subject to very minimal catch so that fishing-induced mortality most likely does not have measurable effects on stock dynamics
4	<ul style="list-style-type: none"> Stocks subject to fishing-induced mortality and not in the top 33% of regional fishery or ecosystem importance
5	<ul style="list-style-type: none"> Stocks in the top 33% of regional fishery or ecosystem importance Stocks subject to measureable fishing-induced mortality, but with uncertain catch data (Catch Level < 3) Stocks for which absolute abundance estimates are feasible

3928
3929 **Target life-history level:** High-quality information about a stock's life history facilitates the ability to
3930 isolate and evaluate fishing impacts, and improves overall assessment accuracy and precision. The
3931 highest levels of life-history data should be reserved for stocks that require more complete evaluations
3932 of the effects of fishing, while stocks with relatively lower importance can be successfully managed with
3933 less detailed life-history information. The approach to determining size/age composition levels is useful
3934 here, and in fact, there are strong connections between the role of life history and size/age composition
3935 data in an assessment model. Therefore, the approach to setting target life-history levels mimics that for
3936 size/age composition.
3937

Target Life History Level	Stock Scenario
0	<ul style="list-style-type: none"> Stocks that are not a priority for assessments
2	<ul style="list-style-type: none"> Stocks with Size/Age Importance > 1

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- Stocks with Size/Age Importance from -1 to 1

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- Stocks with Size/Age Importance < -1

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3939 **Target ecosystem linkage level:** Determining when and how to directly account for ecosystem dynamics
3940 within a stock assessment is not a straightforward process. In some cases, unexplained drifts in
3941 assessment results (e.g., retrospective biases) indicate that additional factors should be included, but
3942 often there is not sufficient information to identify the specific drivers that were overlooked. In other
3943 cases, research studies have described connections between specific ecosystem dynamics and stock
3944 productivity, but the ability to model and/or forecast the relationship may be limited. Further, it has
3945 been shown in certain scenarios that including ecosystem factors may not always improve the ability to
3946 achieve management objectives (Punt et al., 2013). In many cases, empirically based approaches that
3947 use ecosystem information to guide management decisions may be more appropriate than to directly
3948 include that information in the analytical framework. As mentioned in Chapter 8, decisions on creating
3949 ecosystem linkages in stock assessments are made in the context of the following range of decisions:

3950

- 3951 1. Based on the stock's value, status, and biology, is there an incentive to expand its assessment to
3952 include ecosystem or socioeconomic factors?
- 3953 2. Is there evidence to suggest that stock or fishery dynamics are tightly coupled with some
3954 variable ecosystem or socioeconomic feature?
- 3955 3. Are data available to model this relationship within the assessment framework?
- 3956 4. Can ecosystem or socioeconomic dynamics be incorporated in a way that maintains a
3957 manageable assessment model?
- 3958 5. Can the relationship between stock, fishery, and ecosystem or socioeconomic dynamics be
3959 forecasted with at least a moderate degree of certainty?

3960

3961 In general, the standard for including ecosystem information is lowest for Decision 2 above, but raises
3962 through Decision 5, which itself presents a substantial challenge to linking assessments to dynamic
3963 ecosystem features. However, if the answer to Decision 2 is "yes," but there is not sufficient data or
3964 capabilities to meet Decisions 3, 4, or 5, then gaps have been identified, which then may be addressed
3965 to improve the assessment.

3966

3967 Given the complexity of marine systems, the challenges associated with creating and forecasting reliable
3968 mechanistic ecosystem linkages in stock assessments, and variable benefits to incorporating these
3969 linkages into assessments, decision analysis tools (such as MSEs) should be used for evaluating when
3970 and how to expand single-species stock assessment models to include ecosystem features. When
3971 available, the results of these analyses should serve as default advice for guiding target levels for the
3972 ecosystem linkage category. In general, stocks that are good candidates for linking assessments to

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3973 ecosystem dynamics include those that serve as key forage, that rely heavily on a specific habitat during
3974 one or more life stages, and that are particularly sensitive to fluctuations or shifts in environmental
3975 conditions (e.g., temperature). Further, higher profile stocks warrant strong consideration of ecosystem
3976 linkages to maximize economic opportunity while being responsive to potential changes or shifts in
3977 dynamics, thereby ensuring long-term resiliency. The role of ecosystem variability and change should be
3978 at least considered in the development or improvement of every stock assessment. However, in the
3979 absence of results from more complete decision analyses, we offer the following approach that uses an
3980 Ecosystem Linkage Index (ELI) that builds mainly off the information already being assembled for stock
3981 assessment prioritization.

Calculating Ecosystem Linkage Index (ELI)

1. **Set ELI = 0**
2. **Adjust for recruitment variability (using the coefficient of variation – CV)**
 - a. -1 when recruitment CV > 0.9
 - b. +1 when recruitment CV < 0.3
3. **Adjust for Fishery Importance**
 - a. -1 when stock is in top 33% of regional fishery importance
 - b. +1 when stock is in bottom 33% of regional fishery importance
4. **Adjust for Ecosystem Importance**
 - a. -1 when stock is in top 33% of regional ecosystem importance
 - b. +1 when stock is in bottom 33% of regional ecosystem importance
5. **Adjust for Habitat Association**
 - a. -1 if it is clear that a stock relies on a particular habitat niche that is sensitive to ecosystem change during one or more life stages (e.g., anadromous species)
 - b. +1 if stock is thought to easily adapt to changes in physical properties of the ecosystem
6. **Adjust for Model Issues**
 - a. -1 if current assessment model exhibits issues that may be appropriately addressed by including ecosystem dynamics (e.g., retrospective or residual patterns)

Possible values range from -5 to 4

**Target
Ecosystem**

Stock Scenario

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Linkage Level	
0	• Stocks that are not a priority for assessments
1	• Stocks with ELI > 2
2	• Stocks with ELI from -3 to 1
4	• Stocks with ELI = -4
5	• Stocks with ELI = -5

4010 ***NOTE: This approach should be used only when more complete research or decision analyses, such**
4011 **as MSEs, are not available to guide decisions about creating ecosystem linkages.**

4012
4013 If the ELI suggests a certain stock is a high priority for building ecosystem linkages into the assessment,
4014 but there is not the capability to do so, then this may indicate a need for additional research, data
4015 collection, and management strategy evaluations to determine how to address the potential gap.

4016
4017 **10.4.0 Establishing a right-sized stock assessment enterprise**

4018 The new Stock Assessment Classification System (Table 10.1, Appendix A) and expanded assessment
4019 prioritization protocol provide a national framework that will inform strategic decisions regarding the
4020 national stock assessment enterprise. The classification system will be used to identify how stock
4021 assessments are currently being conducted, and the expanded prioritization protocol will be used to set
4022 target levels for each assessment. This national framework is meant to enhance, not replace, ongoing
4023 regional approaches to determining assessment priorities, which involve important collaborations
4024 among NOAA Fisheries, management organizations, and stakeholders. Discussions among these regional
4025 expert groups will necessarily remain the primary source of input for setting assessment objectives, but
4026 the framework described here offers a consistent planning tool that supports discussions about target
4027 levels. By comparing existing levels to targets, regional stock assessment gaps can be identified and
4028 prioritized. The majority of these gaps will concern data for assessments, but some will be related to
4029 research and modeling improvements. Because there are ongoing regional processes and multiple
4030 strategic efforts underway at NOAA Fisheries (Figure 1.1), the stock assessment gaps identified through
4031 this process will be evaluated alongside the results of these other efforts.

4032
4033 The initial work needed to collect the information for each stock is substantial, but after it is collected
4034 and a data management infrastructure is established, updating and maintaining stock-specific details
4035 should be fairly straightforward. The intention is that information will be reviewed and updated
4036 annually, if necessary, to inform near-term assessment scheduling and investments. The process will

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4037 likely evolve in the initial years as it is tested and implemented until it produces objective results that
4038 are most useful to regional planners.

4039

4040 10.5. Standardized approaches

4041 The process of conducting stock assessments in NOAA Fisheries has developed somewhat independently
4042 by region and management jurisdiction. Also, many assessment processes have expanded in scope over
4043 time to include more data as enhanced data collection programs and research studies have become
4044 available, involved more participants, and included more thorough, independent, scientific reviews of
4045 the assessments. As regional processes developed and expanded, they became associated with varying
4046 degrees of efficiency. In most cases, differences in efficiency across regions can be attributed to regional
4047 attributes, such as the number of states and partners involved in monitoring catches, number and types
4048 of fisheries, and diversity of species and habitats. This variability across regions limits the degree to
4049 which assessments can be standardized. Nevertheless, establishing and using more standardized
4050 approaches may improve efficiency overall and contribute to a more transparent and understood
4051 process.

4052 A high throughput of assessments cannot be accomplished if lead assessment scientists must be
4053 engaged in building input data sets from raw fishery and survey data, and if the assessment methods
4054 themselves are in constant flux. A mature assessment enterprise needs to separate research efforts
4055 where innovations can be freely explored from operational efforts where assessment results are
4056 delivered to fishery managers. Standardized data systems can keep a wide range of indicators updated
4057 and can deliver processed data in a form ready to be used in assessment models. Standardized models
4058 make it easier for less experienced analysts to complete assessments, easier for fuller development of
4059 the model itself, easier for reviewers of model results, and easier to communicate to constituents and
4060 managers. Yet, standardization cannot stand in the way of innovation. There needs to be a parallel track
4061 for conducting research on population dynamics, statistics, and other fields; and a deliberate process by
4062 which good research is transitioned into the operational models. Also, standardized processes should
4063 not be completely rigid so they can accommodate the high diversity of stocks, fisheries, jurisdictions,
4064 and so on.

4065

4066 10.5.1 Stock assessment analytical tools

4067 Over the past several decades, the analytical tools and approaches used in fishery stock assessments
4068 have evolved rapidly. These advances have been a benefit to sustainable fisheries management, and
4069 growth in this field will only continue. Development of stock assessment software and tools, including
4070 those for data processing, running assessment models, and developing forecasts, are typically
4071 performed by stock assessment and fishery scientists (as opposed to software developers). It is crucial
4072 that assessment scientists be involved in these developments, because not only do they need complete
4073 conceptual and practical understanding of the tools, they also have the knowledge necessary to design

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4074 tools that are applicable in specific assessment scenarios. However, because fishery assessment and
4075 management systems have developed according to a regional design, many regions have produced tools
4076 with very similar features. NOAA Fisheries has numerous scientists with a wide variety of expertise and
4077 capabilities for developing assessment tools, and development often may draw from a vast professional
4078 network that extends outside NOAA. With a capacity at this scale, tremendous efficiency could be
4079 gained by a unified, community approach to sharing expertise and developing assessment tools. This
4080 approach would also facilitate increased use of fewer standard tools, which would improve efficiency in
4081 both conducting analyses and in understanding and reviewing the assessments. Additionally, partnering
4082 with professional software developers could facilitate enhanced functionality, maintenance, stability,
4083 and also free up time for NOAA scientists to engage in important assessment and fishery-related
4084 research projects. The recommendations presented in Box 10.1 relate to the development, provision,
4085 and use of stock assessment analytical tools.

4086
4087 ***Box 10.1. Recommendations for Development of Analytical
Tools***

- 4088
- 4089 **1. Provide national coordination of stock assessment tools and use professional software development practices.**
 - 4090 **2. Develop tools in community and cloud-based environments to capitalize on diverse expertise from a variety of collaborators.**
 - 4091 **3. Use standardized, tested, verified, and fully documented tools in operational assessments to facilitate efficient and well-understood analyses.**
 - 4092 **4. Increase opportunities for NOAA scientists to conduct research related to assessment analyses.**
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4097 **10.5.2 The stock assessment process**

4098 Fishery stock assessments represent an applied operational science that provides fundamental
4099 information to fishery managers for setting harvest regulations. Industries, small businesses, and
4100 individuals plan around these management decisions; thus, it is imperative that the scientific advice be
4101 timely, transparent, and reliable. Further, to facilitate planning, many stakeholders value long-term
4102 stability in regulations. Given the role of stock assessments in fishery management, it is important that
4103 consistent, well understood, and thoroughly reviewed methods be used to conduct operational
4104 assessments. The process by which assessments are conducted currently varies by region, which is
4105 suitable given that fisheries management is an inherently regional process. However, some assessment
4106 processes can further be improved in regard to one or more of the preferred qualities (timeliness,
4107 transparency, and/or stability).

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4108
4109 The framework for conducting and reviewing stock assessments described in Table 10.4 is
4110 recommended as a general structure for regions to use and adapt according to their needs. The driving
4111 concept behind this framework is to provide a streamlined approach to updating scientific advice for
4112 managers using *operational assessments*. Major changes to model configurations, data sources, etc.
4113 would then be evaluated in *research assessments* that do not produce the scientific advice that is being
4114 used for management. The operational assessments then use methods that have already been
4115 independently reviewed. These assessments can be applied to develop scientific advice for fishery
4116 managers without the additional scrutiny of the methods and would be reviewed with a focus on the
4117 application of those methods. The research assessments are evaluated for their usefulness to consider
4118 in future operational assessments.

4119
4120 **Table 10.4.** Recommended process for conducting operational and research stock assessments.

	Operational Assessment	Research Assessment
Preparation	<ul style="list-style-type: none"> Stocks selected for assessment based on results of national assessment prioritization protocol. Streamlined, integrated data systems provide efficient access to data in formats needed for assessments and are publicly accessible and transparent to facilitate additional investigations. General tools provide timely public access to data summaries and figures. The suite of analytical tools used in the assessment is accessible, documented, tested, and independently reviewed prior to use. 	<ul style="list-style-type: none"> Occur as needed to improve operational assessments. Scoped to evaluate, test, document, and review potential changes to operational assessments (not to provide advice to managers). Connected to research recommendations from previous operational assessment; evaluated soon after completion to prioritize importance and feasibility of addressing recommendations in a research assessment. Broad interdisciplinary engagement upfront is encouraged so a range of expertise can be used to inform assessment improvements. Stakeholder involvement is also encouraged so outside data, analyses, and ideas can be evaluated, and trust in potential changes is built from the beginning.
Conduct	<ul style="list-style-type: none"> Designated analysts use a suite of previously reviewed procedures and data sets. Assessment model or suite of models configured according to previously accepted specifications. Minor changes to previous 	<ul style="list-style-type: none"> New procedures, data sets, and configurations are made available to address issues with operational assessments and/or make general improvements. The scope of improvements may include ecosystem and socioeconomic drivers and considerations, and

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	<p>approaches are acceptable, especially to account for issues that may arise as a result of additional years of data.</p> <ul style="list-style-type: none"> • A full exploration of model sensitivity is not necessary as that should have been conducted during the research assessment (the accepted suite of models is used to characterize observational and structural uncertainties). • Primary objectives are to update stock abundance forecast and provide probability distributions of future catch based on the harvest control rule and characterize recent and projected overfishing and overfished statuses. 	<p>management strategy evaluations represent one framework recommended for use in these investigations.</p> <ul style="list-style-type: none"> • Improvements may include harvest policy investigations and/or use of simpler methods to achieve management objectives and/or use as interim approaches between more involved assessments. • Research assessments should be applied to particular stocks and evaluated against the recent operational assessment (using the actual assessment data at some point) to determine the influence of the proposed improvements (both long-term and short-term effects should be evaluated). • For research assessments to be accepted into the next operational assessment there must be a long-term commitment to collect and provide the accepted data and methods.
<p>Documentation and Review</p>	<ul style="list-style-type: none"> • Documentation of results should be concise with information relevant for fishery management summarized clearly upfront. • Analytical techniques should be summarized very briefly with reference to original descriptions. • Data sources can also be referenced and do not need full descriptions, just depiction of major trends. • Uncertainty should be characterized for all results, and decision tables should be used to summarize uncertainty and risk associated with a range of management decisions. • Anomalies, concerns, and research recommendations documented for future consideration. • Review is streamlined for quality assurance by a standing 	<ul style="list-style-type: none"> • New procedures, data, and findings with application to particular stocks should be fully documented to support use and serve as reference in future operational assessments. • Documentation may be prepared as an assessment report, technical memorandum, and/or peer-reviewed publication equal to the scope and novelty of changes. • Unresolved issues and additional research recommendations should be documented to inform future research assessments. • Independent, comprehensive review is conducted to provide objective evaluation of proposed changes. • Review panels may include some regional expertise, but should be independent of analysts and should include fully external reviewers (such as through the CIE) equal to the degree of controversy and novelty of the proposed changes. • Review panels should focus on the

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	<p>committee of regional experts.</p> <ul style="list-style-type: none">• Review is not intended to make harvest-level recommendations, determine stock status, or declare whether the best scientific information available was used, but rather to evaluate whether the previously approved approach was applied correctly.• If the new application of an operational assessment is not deemed appropriate for management, a default approach to generating catch advice should be established and agreed to upfront.	<p>scientific merits and feasibility of implementing proposed changes relative to current operational assessments with less of a focus on interpretations, applications, and consequences of assessment results.</p> <ul style="list-style-type: none">• Review panels should not expect all issues to be resolved and therefore should not be asked to accept/reject the entire assessment, but rather should evaluate each component to facilitate future use of one or more proposed changes.• Major changes identified by review panels should not be expected to be addressed immediately but should be considered as additional research recommendations.
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Completion of a technically accurate assessment is not the final step of an effective assessment. The results must be communicated to a diverse range of constituents to achieve success.

Because the operational assessment process is intended to be as efficient as possible, there is a need for standardized approaches to documentation. Yet, to trust the results, affected constituents must get enough information about the assessment and the data and methods supporting it. Fishery managers also must receive assessment products that clearly describe the risks and benefits of possible controversial decisions. Fellow scientists must have access to detailed results in order to conduct meta-analyses and other comparative studies. Deliberate development of the right communication product for each audience is needed. A succinct and standard reporting template can reduce the time required for compiling results and facilitate access of results to fishery managers and other interested parties, not just regionally, but nationally as well. Further, by using a standardized template, the primary assessment results can be compared and evaluated across stocks. This step may be particularly important for making management decisions within a fishery management plan that contains multiple stocks. Managers and stakeholders may also benefit from easy access to other information and analyses, not just the primary stock assessment results (e.g., the prioritization results and stock-specific targets described previously, summaries of important stock indicators, and climate vulnerability analyses). Appendix B provides a recommended template (completed with a case study) that attempts to summarize the results of an operational stock assessment as well as additional information. This template attempts to provide brief organized access to the primary information for which most assessments are accessed, and its use would provide consistent national representation of NOAA Fisheries' stock assessment results.

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4145 Finally, regardless of whether operational or research assessments are conducted, scientific products
4146 used to support fishery management should have a level of review that corresponds with the degree of
4147 novelty of the work, and the controversy and importance of the resulting management action. Extensive
4148 review processes have been developed in all regions (Chapter 6), and some have become so intensive
4149 that the throughput of assessments is constrained. Effective certification that the best scientific
4150 products are being used can be attained with a modified review approach built around the separation of
4151 research from operations and the use of standardized data and methods. The most extensive and
4152 intensive review involving highly independent external reviewers should be focused on the research
4153 products that are designing and developing new methods. Here the alternative experiences and
4154 backgrounds of the external reviewers can make the greatest contribution to improved methods. Then,
4155 application of these accepted standardized methods to the most recent standardized data can receive
4156 sufficient quality assurance when reviewed by knowledgeable regional experts, including council's
4157 Scientific and Statistical Committees, who have good knowledge of regional data sources and
4158 assessments for other stocks in that region.

4159
4160 Whether comprehensive and fully independent, or streamlined through standing committees, reviews
4161 are most beneficial when guided by clear terms of reference (ToR). These terms should ensure that
4162 reviews focus on the science conducted to support fisheries management given the information
4163 available at the time. Although reviewers can provide important research recommendations, those
4164 recommendations should be reserved for future research assessments, and current reviews should not
4165 be contingent on incorporation of those recommendations. Further, it is not appropriate for review
4166 panels to perform management actions, such as determining stock status, harvest recommendations, or
4167 formal declarations about the assessment representing the best scientific information available. The
4168 focus of the review is to determine which, if any, major issues may limit the usefulness of the
4169 assessment for fishery managers relative to what is already available. Along those lines, reviews should
4170 be conducted in a way that facilitates use of components of the stock assessment, rather than a simple
4171 accept/reject of the entire package. To promote an effective and efficient review of operational stock
4172 assessments, Box 10.2 includes a suite of generic statements that are recommended for inclusion in
4173 review terms of reference. These statements intend to help focus reviews so that they are most helpful
4174 to the assessment–management process. For research assessments, there is less of a need to constrain
4175 the peer review ToR because the scope of potential changes to an assessment are broad and can be
4176 evaluated in a variety of ways. However, it should be very clear in ToR for research assessments that the
4177 review is focused on the proposed changes and whether they would result in an improved operational
4178 stock assessment.

4179

4180 10.6. Conclusions

4181 In this chapter, a number of process-oriented changes are recommended that may affect NOAA
4182 Fisheries' stock assessment programs as well as our fishery management partners and stakeholders.
4183 These recommendations have been carefully vetted with the overall goal of creating a timelier, more

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4184 efficient, and more effective stock assessment enterprise. Although adoption of these recommendations
4185 may require an investment of time and resources from NOAA Fisheries and our partners, the long-term
4186 gains will offset the short-term costs.

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Box 10.2. Recommended statements to include in operational stock assessment review terms of reference (ToR)

- Determine, according to the best of your knowledge, if all data considered for use in the stock assessment were made available with sufficient time to review and evaluate their utility to the assessment. If not, please explain.
- Of the data considered for inclusion in the assessment, determine if final decisions on inclusion/exclusion of particular data were appropriate and justified. If not, please explain.
- Determine whether the final data that were included in the stock assessment were prepared and processed appropriately, and potential sources of bias were addressed and/or documented appropriately. If not, please explain.
- Given the data selected for use in the assessment, determine if the methods used to analyze those data and characterize uncertainty were appropriate and sufficient for accomplishing the following:
(For each category, if you feel the methods were not appropriate or if previous analyses are more appropriate, please explain.)
 - Estimating biological reference points related to stock size
 - Estimating biological reference points related to fishing intensity
 - Estimating stock size in the final assessment year
 - Estimating fishing intensity in the final assessment year
 - Estimating an historical time series of stock size
 - Estimating an historical time series of fishing intensity
- If applicable, please review the methods used for forecasting, including the characterization of uncertainty, to determine whether they were appropriate and sufficient for the following:
(For each category, if you feel the methods were not appropriate or if previous analyses are more appropriate, please explain.)
 - Developing harvest recommendations for the next 1–4 years
 - Developing harvest recommendations beyond 4 years
 - Projecting biomass relative to corresponding biological reference point(s)
 - Projecting fishing intensity relative to corresponding biological reference point(s)

*Note: The structure of ToR in review of research stock assessments should be less constrained than ToR for operational assessments, and should be designed to focus the review on any changes to the assessment that are being proposed and whether these changes would likely improve the next operational assessment.

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4212 **References**

4213 Link, J. S., R. Griffis, and S. Busch (eds). 2015. NOAA Fisheries Climate Science Strategy. NOAA Tech.

4214 Memo. NMFS-F/SPO-155, 70p.

4215 Magnusson, A., and R. Hilborn. 2007. What makes fisheries data informative? *Fish Fish.* 8:337–358.

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4218 Methot, Richard D. Jr. (ed.). 2015. Prioritizing fish stock assessments. NOAA Tech. Memo. NMFS-F/SPO-

4219 152, 31 p.

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4222 **SECTION IV. SUMMARY,**
4223 **RECOMMENDATIONS, AND**
4224 **IMPLEMENTATION**

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4227 PLACEHOLDER, TO BE COMPLETED

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Acronyms

4230	ABC – Acceptable Biological Catch	4268	LMRCSC – Living Marine Resources Cooperative
4231	ACLs – Annual Catch Limits	4269	Science Center
4232	ADMB – Auto Differentiated Model Builder	4270	MAFMC – Mid-Atlantic Fishery Management
4233	AFSC – Alaska Fisheries Science Center	4271	Council
4234	AKFIN – Alaska Fisheries Information Network	4272	MARMAP – Marine Resource Monitoring and
4235	AKRO – Alaska Regional Office	4273	Assessment Program
4236	ASMFC – Atlantic States Marine Fisheries	4274	MMPA – Marine Mammal Protection Act
4237	Commission	4275	MREP – Marine Resource Education Program
4238	BSIA – Best Scientific Information Available	4276	MRFSS – Marine Recreational Fisheries
4239	CESUs – Cooperative Ecosystem Studies Units	4277	Statistics Survey
4240	CFMC – Caribbean Fisheries Management	4278	MRIP – Marine Recreation Information Program
4241	Council	4279	MSA – Magnuson-Stevens Act
4242	CIE – Center for Independent Experts	4280	MSE – Management Strategy Evaluation
4243	CIs – Cooperative Institutes	4281	MSY – Maximum Sustainable Yield
4244	CPUE – Catch Per Unit Effort	4282	NCSS – NOAA Fisheries Climate Science Strategy
4245	CWA – Clean Water Act	4283	NEAMAP – Northeast Area Monitoring and
4246	CZMA – Coastal Zone Management Act	4284	Assessment Program (Note: This is used twice,
4247	EBFM – Ecosystem-based Fisheries	4285	page 21 and 23, and both times the full thing
4248	Management	4286	was spelled out as well)
4249	ELI – Ecosystem Linkage Index	4287	NEFMC – Northeast Fisheries Management
4250	EM/ER – Electronic Monitoring and Electronic	4288	Council
4251	Reporting	4289	NEFSC – Northeast Fisheries Science Center
4252	ESA – Endangered Species Act	4290	NEPA – National Environmental Policy Act
4253	FIS – Fisheries Information System	4291	NGSA – Next Generation Stock Assessment
4254	FMC – Fisheries Management Council	4292	NPFMC – North Pacific Fisheries Management
4255	FMO – Fisheries Management Organization	4293	Council
4256	FO – Fisheries Organization	4294	NRC – National Research Council
4257	FSC – Fisheries Science Center	4295	NRCC – Northeast Regional Coordinating
4258	FSSI – Fish Stock Sustainability Index	4296	Council
4259	GARFO – Greater Atlantic Regional Fisheries	4297	NS1 – National Standard 1
4260	Office	4298	NWFSC – Northwest Fisheries Science Center
4261	GMFMC – Gulf of Mexico Fisheries	4299	OFL – Overfishing Level
4262	Management Council *****	4300	PFMC – Pacific Fishery Management Council
4263	HAIP – Habitat Assessment Improvement Plan	4301	PIFSC – Pacific Islands Fisheries Science Center
4264	HMS – Highly Migratory Species	4302	PIRO – Pacific Islands Regional Office
4265	IEAs – Integrated ecosystem assessments	4303	PRSAIP – Protected Resources Stock
4266	IUU – Illegal, Unregulated, and Unreported	4304	Assessment Improvement Plan
4267	fishing		

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- 4305 **QUEST** – Quantitative Ecology and
- 4306 Socioeconomics Training Program
- 4307 **RFMOs**- Regional Fishery Management
- 4308 Organizations
- 4309 **RO** – Regional Office
- 4310 **RTR** – Research Training and Recruitment
- 4311 **SAFE** – Stock Assessment and Fishery Evaluation
- 4312 **SAFMC** – Southeast Atlantic Fishery
- 4313 Management Council
- 4314 **SAIP** – Stock Assessment Improvement Plan
- 4315 **SAM** – State-space Assessment Model
- 4316 **SAW/SARC** – Stock Assessment
- 4317 Workshop/Stock Assessment Review
- 4318 Committee
- 4319 **SCAA** – Statistical Catch-At-Age
- 4320 **SCAL** – Statistical Catch-At-Length
- 4321 **SEDAR** – Southeast Data, Assessment, and
- 4322 Review
- 4323 **SEFIS** – Southeast Fishery Independent Survey
- 4324 **SEFSC** – Southeast Fisheries Science Center
- 4325 **SERO** – Southeast Regional Office
- 4326 **SSC** – Scientific and Statistical Committee
- 4327 **STAR** – Stock Assessment Review
- 4328 **SWFSC** – Southwest Fisheries Science Center
- 4329 **TMB** – Template Model Builder
- 4330 **ToR** – Terms of Reference
- 4331 **UNOLS** – University National Oceanographic
- 4332 Laboratory System
- 4333 **VPA** – Virtual Population Analysis
- 4334 **WCR** – West Coast Region
- 4335 **WPFMC** – Western Pacific Fishery Management
- 4336 Council
- 4337 **WPSAR** – Western Pacific Stock Assessment
- 4338 Review

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4339 **Appendix A. NOAA Fisheries' Stock Assessment Classification System**

Attribute	Level					
	0	1	2	3	4	5
Catch	No quantitative catch data	Some catch data, but major gaps for some fishery sectors or for historical periods such that their use in assessments is not supported	Enough catch data establish magnitude of catch and trends in catch for a major fishery sector in order to apply a data-limited assessment method. This includes fisheries that are closed and it is known that negligible catch is occurring	Catch data is generally available for all fishery sectors to support quantitative stock assessment, but some gaps exist such as low observer coverage, high levels of self-reported catch, weak information on discard mortality	No data gaps substantially impede assessment, but catch is not without uncertainty (e.g., recreational catches estimated from surveys)	Very complete knowledge of total catch
Size and/or age composition	No composition data collected	Some size or age composition data has been collected, but major gaps in coverage, not used in assessment, or historically preclude use in assessments	Enough size or age composition data has been collected to enable data-limited assessment approaches	Enough size or age composition data is collected over a sufficient time series to be informative in age/size structured assessment models	Enough age composition data has been collected over a sufficient time series to enable assessments methods that need age composition data from the fishery	Very complete age and size composition data, including, as needed on stock-specific basis, knowledge of ageing precision, spatial patterns or other issues

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Abundance	No indicator of stock abundance or trend in stock abundance over time	Fishery-dependent catch rates (CPUE) are available, but high uncertainty about their standardization over time; or expert opinion on degree of stock depletion over time	Fishery-dependent catch rates (CPUE) are sufficiently standardized to enable their use in full assessments	Limited fishery-independent survey(s) provide estimates of relative abundance; however, the temporal or spatial coverage of the stock is limited or the sampling variability is high	Complete fishery-independent survey(s) provide estimates of relative abundance, and the survey(s) cover a large proportion of the spatial extent of the stock with several years of tracking at a level of precision that supports assessments	Calibrated fishery-independent survey(s) or tag-recapture provide estimates of absolute abundance
Life history	No life history data	Estimates of most life history factors not based on empirical data; instead derived using proxies, meta-analyses, borrowed from other species, or without scientific basis	Estimates of some life history factors based on stock-specific empirical data, but at least one derived using life history proxies, meta-analyses, borrowed from other species, or without scientific basis. Generally supports data-poor assessments that use life history information	Estimates of most life history factors based on stock-specific empirical data	Data are sufficient to track changes over time in at least growth	No major gaps in life history knowledge, including detailed stock structure, spatial and temporal patterns in natural mortality, growth, and reproductive biology

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<p>Ecosystem linkage</p>	<p>No linkage to ecosystem dynamic or consideration of ecosystem properties (environment, climate, habitat, predator-prey, etc.) in configuring the assessment (i.e., equilibrium conditions assumed for ecosystem)</p>	<p>Ecosystem-based hypotheses inform the assessment model structure (e.g., defining the stock boundaries and/or spatial or temporal features) and/or are used for processing assessment inputs (e.g., abundance index), but no explicit linkage to any ecosystem drivers (environment, climate, habitat, predator-prey, etc.)</p>	<p>The assessment includes some form of variability or effect to explicitly account for unidentified ecosystem dynamic(s) (e.g., time/space "regimes", random variation, or other approaches to changing features without direct inclusion of ecosystem data)</p>	<p>One or more assessment features is linked to a dynamic (i.e., data) from at least one of the following categories: environment, climate, habitat, predator-prey data (e.g., covariate)</p>	<p>The assessment model is linked to at least one ecosystem dynamic, and one or more process studies directly support the manner in which environmental, climate, habitat, and/or predator-prey dynamics are incorporated (e.g., consumption rates measured and covariate informed by results)</p>	<p>The assessment approach is configured to be coupled or linked with an ecosystem process (e.g., multispecies, coupled biophysical, climate-linked models)</p>
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Appendix B – Executive Summary

A variety of national methods and initiatives have recently been proposed to help meet the objectives of NOAA Fisheries' next generation stock assessment (NGSA) enterprise. As detailed in Section III, the three main goals are to move stock assessments toward expanded scope through ecosystem linkages, improved assessment through innovative science, and engaged in a more timely, efficient, and effective process. Implementation of these national initiatives has already begun in several regions around the country and the data collection and supporting analyses have been enormous. It is imperative that the output of these initiatives be assimilated within the stock assessment process to highlight progress toward NGSA and increase communication to stakeholders and fishery managers.

Over the past several years, a new framework has been proposed to start the process of integrating ecosystem and socioeconomic information into the stock assessments of the North Pacific region (Shotwell et al. 2016). These stock profiles and ecosystem considerations (SPECs) generate an ecosystem baseline for a given stock or stock complex that start with four primary elements. First, an overall ecosystem status rating summarizes the results from the national initiatives to provide immediate and succinct context for the priorities of the stock or stock complex. The rating should include subjects relevant to the particular fishery management plan of the stock (e.g., data classification, prioritization, and vulnerability assessment). The rating is based on four categories of low (L), moderate (M), high (H), and very high (VH). These ratings indicate whether this particular factor is of low to high importance for the stock (e.g., a low habitat prioritization implies that more habitat research would have low impact for improvement of this stock assessment). The second element starts as an informal life history conceptual model that provides the relevant information on the stock life history stages and potential survival bottlenecks between stages. The third element, is a qualitative stock profile that follows the format of the overall rating but further identifies strengths and weaknesses over a suite of response categories (e.g., stock status, economics, biology). Finally, the first three elements are used in concert to develop a list of potential ecosystem or socioeconomic indicators that are then compiled for monitoring as time series in a graphical report card.

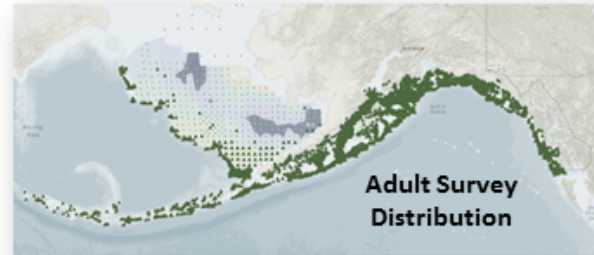
Another step toward the NGSA framework is the development of a succinct and standard reporting template of stock assessment results. This template can be used to communicate results quickly and efficiently to the broader community of stakeholders, fishery managers, and other interested parties. It also reduces time to compile results, while allowing comparisons across a large variety of stocks. The following is an example of such a template that summarizes relevant stock assessment results and SPEC elements for Alaska sablefish. These executive summaries can be somewhat fluid in their complexity and may be enhanced with information from process studies or benchmark reviews through highlights within the summary. Also, intensive reviews may lead to recommendations that could be included in terms of reference sections to guide priorities for future research. Ultimately, this executive summary and the synthesis of the national initiatives through the SPEC framework provide the necessary building blocks to move toward an ecosystem approach to fisheries management.

Citation: Shotwell, S.K., D.H. Hanselman, S. Zador, and K. Aydin. 2016. Stock-specific Profiles and Ecosystem Considerations (SPEC) for Alaska groundfish fishery management plans. Report to Joint Groundfish Plan Team, September 2016. 15 pp.



Sablefish (*Anoplopoma fimbria*)

- FMP: Bering Sea Aleutian Islands and Gulf of Alaska
- Custom statistical catch-at-age model (ADMB), last data year 2016

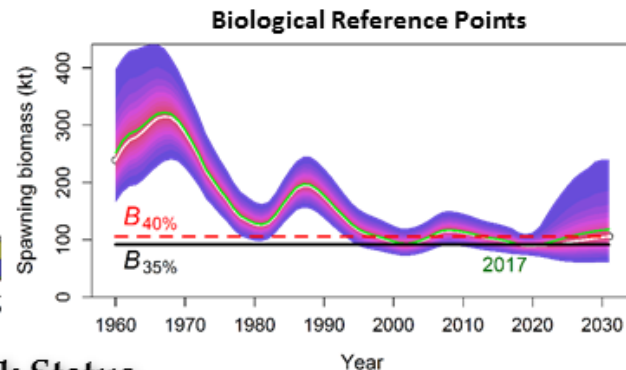
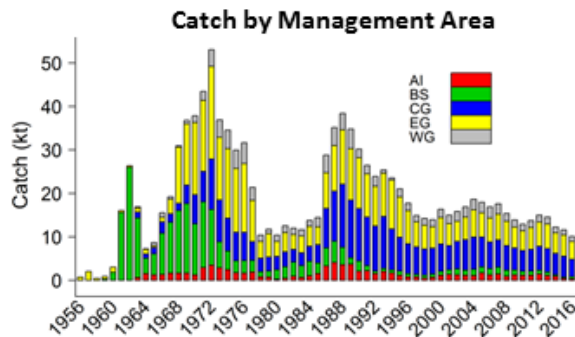


NOAA Fisheries Data Classification System

Category	Catch	Size/Age	Abundance	Life History	Ecosystem
Current/Target	5/5	5/5	4/5	4/5	1/4

Stock Assessment

Benchmark assessment in 2016 included CIE recommendations to: 1) account for whale depredation on the survey and fishery, and 2) propagate more of the structural uncertainty of management quantities.



Stock Status

This stock is not subjected to overfishing, currently overfished, nor approaching an overfished condition.

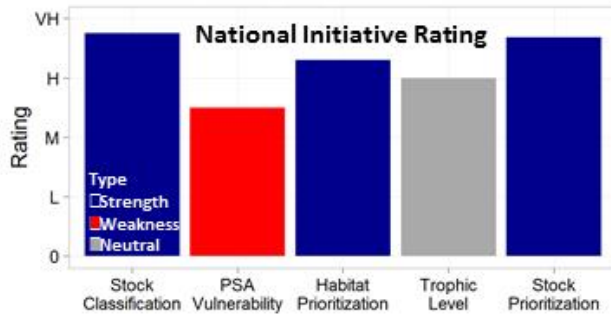
Year	ABC	OFL	Total Biomass	B/ B_MSY	F/ F_MSY	Recruits (mill #s)	Total Catch	Ex-Value (mill \$)
2012	17,240	20,400	257,952	1.126	0.675	10.55	15,046	127.4
2013	16,230	19,180	242,524	1.095	0.655	1.24	14,468	90.8
2014	13,722	16,225	231,726	1.072	0.576	9.24	12,156	95.5
2015	13,657	16,128	231,493	1.055	0.574	17.25	11,463	93.7
2016	11,795	13,397	231,796	1.029	0.533	12.88	9,993	
2017	13,083	15,931	239,244	1.002	0.061			

Assessment: <http://www.afsc.noaa.gov/REFM/Docs/2016/GOAsablefish.pdf>

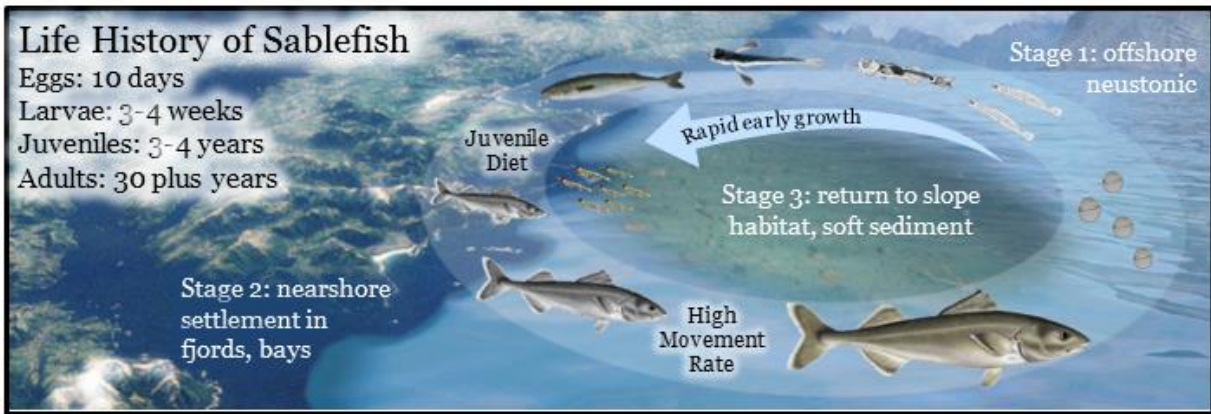


Sablefish (*Anoplopoma fimbria*)

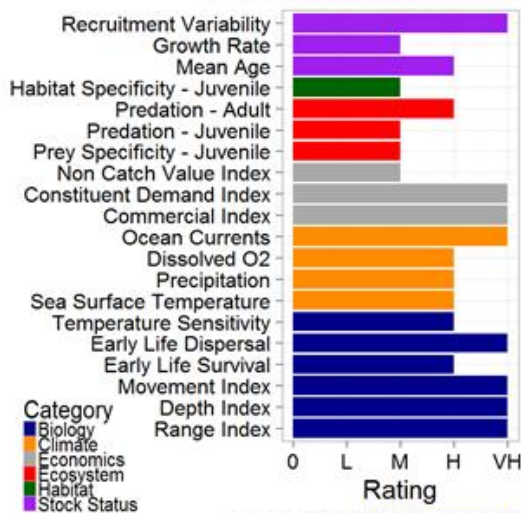
Terms of Reference



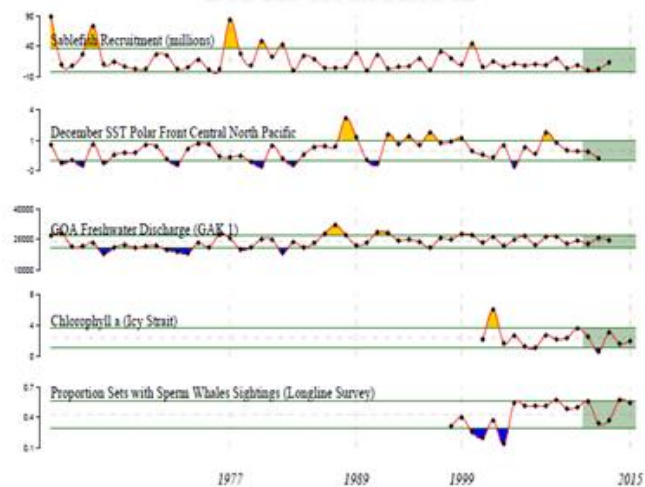
- 1) Explore spatial model for defining regional recruitment contribution
- 2) Research energetic condition as life-stage specific recruitment indicators
- 3) Improve understanding of spawning dynamics (e.g. timing, location)
- 4) Continue ecosystem research to improve tactical advice (forecasts)



Stock Profile



Stock Indicators



Assessment: <http://www.afsc.noaa.gov/REFM/Docs/2016/GOAsablefish.pdf>