SEDAR
Procedural Guidance Document 2
Addressing Time-Varying Catchability

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Executive Summary

The issue of time-varying catchability has arisen in many recent stock assessments in the southeastern U.S. Discussions have included whether time-varying catchability exists, and if so, how it should be incorporated. To date there has been little agreement in principle or application. Because of this, the Southeast Data Assessment and Review (SEDAR) Steering Committee set up a procedural workshop to address the issue.

The workshop included presentations on the theory of time-varying catchability, evidence for its existence, a review of previous studies on the subject, and a review of methodologies for estimating and incorporating it into stock assessments (Section 2.1). A presentation was given on the implications of not incorporating it (Section 2.2). Three case studies were presented illustrating the practical application of alternate methodologies on real world fisheries and data sets (Section 2.3). An analysis of captain and technology effects on CPUE was presented (Section 2.4). Another presentation illustrated how time-varying catchability can be incorporated into the Stock Synthesis stock assessment software program (Section 2.5).

Critical discussions were held with the fishers attending the workshop about the likely timeline and mechanisms of catchability changes in various fisheries in the Southeast (Section 3). This was one of the first discussions of its kind to take place and proved to be an extremely valuable component of the workshop. The participation and cooperation of the fishers was a key contributing factor to the success of the workshop overall.

Following a series of lengthy and detailed discussions (Section 4), participants developed a set of recommendations regarding the incorporation of time-varying catchability into southeastern stock assessments (Section 5). Most importantly, the workshop recommended that time-varying catchability should be considered in future stock assessments in the southeastern U.S. based on strong theoretical and empirical support for its existence. Time-varying catchability should be evaluated as part of each assessment. A list of alternative methods for incorporating time-varying catchability was developed for use in future stock assessment processes. The list includes the data needs, pros, and cons of each method. It was stressed that methods should be flexible because no one method will be best for all cases, and because there have not been enough studies testing the performance of alternative catchability models. The effects of both density-dependent and density-independent mechanisms on catchability should be considered. Recommendations were also made regarding stock assessments of species with limited data.

Information regarding fishery-specific changes in catchability developed in this workshop should be combined with information compiled at future data workshops as part of the process of incorporating time-varying catchability. Specifically, it is important to consider potential mechanisms, such as changes in technology, behavior, and management, and when they occurred.

The workshop also offered recommendations regarding the direction of future research and methods (Section 6). These included supporting the many recommendations of earlier SEDAR reports relating to understanding how catchability has changed in various fisheries. The group also recommended that future SEDAR assessments include terms of reference that focus specifically on time-varying catchability.

It was stressed that the state of the art for modeling catchability has not reached an endpoint and that further theoretical and empirical study is warranted. A list of needed research priorities was developed.

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1 Introduction

1.1 Workshop time and place

The SEDAR Procedural Workshop II – Catchability was held February 9 – 12, 2009 in Atlanta, Georgia.

1.2 Objectives of the workshop

- Develop recommendations for incorporating catchability changes in SEDAR assessments,
- Recommend criteria for consideration when modeling catchability for individual species or fisheries, and
- Prepare a SEDAR procedures document addressing these recommendations that will be used to guide future SEDAR assessments.

1.3 List of participants

Workshop Facilitator
Jim Berkson .... NMFS SEFSC/ Virginia Tech

Workshop Panel
Steven Atran..GMFMC Staff
Luiz Barbieri .... FWRI
Tom Becker..
Russell Brown..NMFS NEFSC
John Carmichael..SAFMC Staff
Paul Conn..NMFS SEFSC Beaufort
Don DeMaria .... SAFMC Snapper Grouper AP
Bob Dixon..NMFS SEFSC Beaufort (retired)
Ben Hartig.. SAFMC Mackerel AP
Xi He..NMFS SWFSC Santa Cruz
George Geiger..SAFMC member
Brian Linton..NMFS SEFSC Miami
Kevin McCarthy..NMFS SEFSC Miami
Richard Methot .... NMFS/S&T
Clay Porch..NMFS SEFSC Miami
Marcel Reichert..SC DNR
Bob Rowe ....
Jim Thorson ....Virginia Tech
Steve Turner..NMFS SEFSC Miami
Steve Saul .... University of Miami
Kyle Shertzer ....NMFS SEFSC Beaufort
Bob Spaeth..Southern Offshore Fishing Assoc.

Mike Wilberg .... CBL/University of Maryland
Bob Zales II .... PCBA

Observers
Dennis O'Hern .... Fishing Rights Alliance

Staff
Patrick Gilles .... NMFS SEFSC Miami
Julie Neer .... SEDAR
Tina O'Hern .... GMFMC

1.4 List of workshop working papers

Document Number	Title	Author
SP2-01	Incorporating Time-varying Catchability into Population Dynamic Stock Assessment Models	Michael J. Wilberg, James Thorson, Brian Linton, and Jim Berkson

1.5 Problem statement

Over the course of developing stock assessments through the SEDAR process it was recognized that certain topics arose repeatedly in discussions. Such topics typically involve well known areas of uncertainty in assessment methods and input data sources, and discussions related to these topics often occupy considerable time in data and assessment workshops as participants strive to come up with reasonable solutions. Because each workshop is composed of a slightly different mix of individuals, differing solutions are at times proposed for these common uncertainties. While it is within the charge to each individual workshop to make the best decisions possible based on the information before them, the lack of a consistent approach for addressing common problems across stocks and assessments can contribute to unnecessary criticisms of the assessments and the assessment process itself.

One area in particular where this became apparent was the treatment of catchability in fishery dependent CPUE analyses. Although fishermen and scientists have long recognized that the ability to catch fish changes over time as technology and methods advance, most assessment models applied a simplifying assumption of constant catchability, so that all differences between observed and estimated CPUE are attributed to observation variability in the CPUE observation and so that long-term trends in CPUE have a strong influence on estimates of population trends. Within the SEDAR process, this assumption was challenged and overturned during assessments of Gulf and South Atlantic gag (SEDAR 10) when the assessment workshop panel put forth two competing baseline assessments; one that assumed constant catchability and one that incorporated a 2% annual increase in catchability for fishery-dependent CPUE indices. The SEDAR 10 Review Workshop Panel (RW) agreed that constant catchability was unlikely, but chose to base advice on the model incorporating the typical constant catchability treatment of CPUE because they believed the 2% annual change was inadequately justified and not representative of the many complex factors which affect catchability in fisheries. The catchability issue arose again in SEDAR 12 when the Assessment Workshop put forth the same two catchability scenarios for red grouper. In this case the RW preferred to base their advice on the increasing catchability option.

Differing recommendations by two review panels facing the same uncertainty of catchability raised concerns that rippled through the SEDAR program, culminating in the SEDAR Steering Committee convening a supplemental review of grouper assessments in 2007. Recommendations regarding catchability made through the supplemental review included treating catchability consistently across assessments, not assuming that catchability is a constant by default, and convening a workshop to develop an acceptable approach to model catchability in SEDAR stock assessments. This workshop fulfills recommendations of several SEDAR assessment panels and the supplemental grouper assessment review to consider catchability in detail.

1.5.1 Pertinent catchability comments from previous SEDAR workshops

1.5.1.1 SEDAR 10 Review Workshop (RW)

"**Catchability:** The RW discussed the relationship of technology to catchability and the effects of catchability changes on fishery-dependent abundance indices. The RW recognized that technology improvements over time, particularly better electronics, have made fishermen more effective and efficient at catching fish, but disagreed with the assumption of a simple linear (2% annually) constant increase. This issue is important for the present stock assessment because the assessments rely heavily on fishery-dependent catch rate abundance (CPUE) indices."

"Research Recommendation: Time-varying catchability: The RW is of the opinion that catchability has changed over time, however, it does not believe that a constant 2% increase per year adequately describes the changes in catchability that are likely to have occurred. Step changes with the introduction of new equipment or management measures are more likely than monotonic changes. Learning and technological changes in navigation, fish detection and catching equipment have no doubt increased the efficiency of nominal fishing effort. However, management measures (increases in minimum size, time and area closures, bag limits) and changes in fishing behavior (moving on when "enough" fish have been caught) would be expected to result in decreased catchability. The Panel believes that, overall, catchability is likely to have increased. The Panel recommends that a special workshop be convened to estimate and quantify changes in catchability over the last 25 to 30 years."

1.5.1.2 SEDAR 12 Review Workshop

"**Fishery catchability** – Commercial and recreational fishery CPUE have been included in the red grouper model as plausible indexes of the trend in stock abundance. However, the RP recognizes that it is not possible to standardize the units of fishery effort over time to the same degree that the units of effort in a fishery-independent survey (such as the bottom longline survey and the video survey) are held highly constant. The panel agreed that it would be unrealistic to assume constant fishery catchability over 20 years and requested that an annual 2% increase in catchability be incorporated in the base run to reflect increased fishing power (efficiency) principally due to technology innovations (GPS, GIS, cell phone communication, etc.) that cannot be quantitatively included in the standardization. This means that over a 15-year period, a 35% increase in observed fishery CPUE would be expected from a stock that was level in its abundance. The representatives of the fishing industry attending the meeting agreed that 2% per year was within a likely range. The RP finds that the direct information to calculate the historical drift in catchability does not exist and makes some research recommendations in TOR-9. For sensitivity analyses, the RP recommends model runs based on 0% and 4% per year trend in catchability."

1.5.1.3 Supplemental Grouper Assessment Review

"**Evaluation Panel:** The Evaluation Panel (EP) spent considerable time discussing the history of the decisions outlined above along with the various reasons why catchability has likely increased for fishery dependent indices. The Evaluation Panel agrees with both SEDAR 10 and SEDAR 12 Assessment Panels and Review Panels in that catchability has likely increased. The discrepancy between the SEDAR 10 and SEDAR 12 decisions as to whether a constant 2% increase in catchability should be included in the preferred model arose as a result of different groups of people arriving at different conclusions when presented with imperfect information. In particular, neither panel was aware of any information quantifying the dynamics of the change in efficiency of the snapper-grouper fishery. The SEDAR 10 Review Panel was simply not comfortable with making a simplistic assumption of a constant 2% increase whereas the SEDAR 12 Review Panel decided that a simplistic assumption of a constant 2% increase was more realistic than assuming a constant catchability. Such discrepancies should not be considered unusual or cause for concern.

The Evaluation Panel does, however, feel that future assessments of gag and red grouper should be consistent in their assumption of increasing catchability, but the Panel is not in a position to comment on whether one specific value or method for modeling this increase is more appropriate than another. The assumption of constant catchability for fishery dependent abundance indices in the snapper-grouper complex, however, should no longer be the default assumption for future assessments. Future assessments should examine the sensitivity of their output to the assumed level of increasing catchability. The Evaluation panel agrees with the recommendation from the SEDAR 10 Assessment Panel and Review Panel that a special workshop be convened to estimate and quantify changes in catchability over the last 25 to 30 years."

"Review Panel Recommendation: EP ToR 1b: The treatment of the catchability coefficient for fishery-dependent indices of abundance in each assessment. The EP concluded that the treatment of catchability among these stocks should be consistent, and that constant catchability should not be the default. The RP did not have enough information to endorse or refute this position and would have liked to see more sensitivity runs to better understand the implications of this issue. However, the RP concluded that the base cases need not be redefined at this time. The EP's recommendation for a workshop on the modeling of catchability (including other species) and new directed research is warranted."

2 Workshop Presentations

2.1 Presentations on time-varying catchability background by Jim Thorson, Brian Linton, and Mike Wilberg

Catchability is an important parameter in many stock assessment models because it relates an index of abundance to stock size. Catchability does not represent a single process, but rather a complex set of interactions between fish and fisherman or scientists. Numerous studies provide strong evidence that time-varying catchability is common across fisheries and in many fishery-independent surveys and can be caused by anthropogenic, environmental, biological, and regulation changes. Many causes of time-varying catchability have been identified, and time-varying catchability has been documented in a wide range of fisheries, spanning commercial and recreational fisheries, freshwater and marine systems, and fisheries for finfish and shellfish. In some cases, catchability may change with abundance or the area inhabited by a stock, environmental effects, due to changes in fisherman behavior or gear, or because of changes in management regulations. Changes in catchability can affect both fishery-dependent and fishery-independent data sources, although it is generally thought to be more prevalent in fishery-dependent data. For fishery-independent data, catchability change is especially likely when a survey does not cover the full area of the stock, although a variety of other causes, such as gear saturation and density-dependent gear avoidance behavior, may also contribute.

While time-varying catchability violates the assumptions of many assessment methods, trends in catchability over time are more critical because they can cause biased estimates of stock size, fishing mortality rates, and acceptable catch levels in stock assessment models that do not compensate for them. Several general methods have been developed to "correct" or CPUE data series for time-varying catchability or to allow catchability to vary over time within an assessment model: 1) standardization of indices of abundance, 2) ignoring or down-weighting an index if its catchability is suspected to have changed, 3) modeling catchability as a function of time, 4) modeling catchability as a function of density or an environmental variable, or 5) allowing catchability to change over time using state space models. State space techniques and modeling catchability as a function of time do not ascribe causation for changes in catchability (i.e., are descriptive methods), while use of functions of density or external variables assumes that the variables used to describe changes are the dominant ones (i.e., mechanistic methods). Indices of abundance should be standardized for known factors that affect catchability. Mechanistic models of time-varying catchability can be useful if the major causes of change over time can be determined. Methods that allow catchability to vary over time without specifying a cause (i.e., function of time and state space methods) can be useful to model combined effects of multiple factors on catchability, particularly when variables thought to influence catchability are unrecorded or imprecise.

Results can differ substantially among models that make different assumptions about time-varying catchability, but there has been little formal evaluation of alternative methods for incorporating time-varying catchability in assessment models. Although many of the methods have not had formal comparisons of their performance under a wide range of circumstances, several general conclusions can be described: 1) models that assume constant catchability perform poorly if catchability changes systematically over time, 2) mechanistic models will likely perform well if they capture the major factors affecting catchability, but are likely to not perform well if the correct mechanisms are not specified, and 3) patterns in time-varying catchability can be well-described using random walks if data are adequate to estimate parameters. Methods to decide among various catchability models have been studied less than performance of individual models.

2.1.1 Discussion of Jim Thorson's presentation

The group discussed whether improved fishery-independent monitoring would reduce the need to rely upon fishery-dependent data and therefore alleviate many of the complex problems being discussed here. Although that is a widely held perception, in reality it is likely that a compromise position will be taken in which both fishery-dependent and fishery-independent data sources are used in future assessments.

One reason for this is the sheer cost of conducting a fishery-independent monitoring program that provides adequate coverage over both time and space. It is comparatively much more economical to make modest changes that improve the resolution of existing fishery-dependent data collection programs. Another reason is that any new fishery-independent surveys will provide information for the future, but there will always be a need to rely on fishery-dependent data for insight into past population conditions.

In addition to changing current data collection programs, we note a general need for methods that do a better job of extracting information from existing data sources. For example, tracking catch rates of individual fishermen chosen from different areas may provide important perspectives that are lost when total fishery CPUE is examined.

2.1.2 Discussion on Brian Linton's presentation

No discussion took place at the completion of this presentation.

2.1.3 Discussion on Mike Wilberg's presentation

In the approach outlined in the presentation, index values were assumed to follow a lognormal distribution. If a limited number of factors affect catchability, the year-to-year deviations in catchability may not be log normally distributed. An inquiry was made about how the modeling approach would perform under a normal error structure. Wilberg noted that a lognormal approach was convenient as it assumes multiplicative errors on the real scale, and additive errors on the log scale. In addition to questions about error distributions, the group also noted that the model allows for change over time rather than statistical evaluation of a hypothesis.

The group discussed the potential of a negative impact resulting from including multiple data sources, noting that there may be a tradeoff between down-weighting indices where changes in catchability are suspected vs. excluding these data from the model. It was noted that trends in less reliable data would have similar impacts as trends in the most reliable data sources, albeit with less influence.

The group noted that if there is a priori information about changes in catchability, this can guide the choice of approaches. For example, abrupt changes in regulations or fishing gear may suggest that a step function approach is appropriate. When there are more gradual changes, the choice of approaches becomes more difficult.

Random walk approaches can be a useful way of detecting changes in CPUE over time when the causes of change are poorly understood. Under this approach, it is often possible to detect changes in catchability if fishing mortality rates are high or a reliable survey is available. Random walk methods did not perform well in situations with low levels of exploitation. Simulations presented at the workshop were limited in the sense that natural mortality and fishery selectivity were held constant over time. If they are in fact varying, the estimation of changes in catchability likely becomes more difficult.

It was noted that it would be difficult to estimate variance components for indices, age compositions and all parameters in conjunction with a random walk model. If the random walk model works, it can address bias issues but there are tradeoffs in terms of estimating variance components.

Resource stakeholders noted that it is important to ground truth stock assessment approaches with actual quantitative observations of the resource. As an example, they noted the disappearance of larger amberjack from inshore areas and that offshore artificial structure may be concentrating larger individuals. There are models that consider refugia that allow catchability to go to zero even while abundance is still positive. The group discussed approaches to increasing data sources, noting recent advances in web-linked underwater video. It was noted that the region has two statistically-designed video surveys for reef fish, but that the spatial and temporal coverage of these surveys needs to be expanded. Additional fishery independent surveys also may be warranted. There may be a need to expand these types of programs to monitor situations like localized depletion issues.

2.2 Implications of mis-specified q in estimating stock depletion rates: Some preliminary simulation results by Xi He, Steve Ralston, and Alec MacCall

Specifying correct catchability (*q*) functions in stock assessment models is very important because mis-specified *q* functions may lead to over- or under estimates of important assessment outputs, such as depletion, virgin biomass and stock-recruit relationships. In this presentation, we present some preliminary results from a simulation study that compared stock assessment results with simulated data with different *q* functions (*q* as a function of biomass or independent of biomass) as well as time varying catchability. The simulation data were generated with age-based population models in which one fishery with constant selectivity occurred over an extended time period. The data were then inputted into assessment models with added sampling errors. In theses assessment models, different *q* functions and time-varying catchability options were specified, and assessment results were compared to the population parameters used to generate data. Preliminary results indicated that estimates of stock depletion were more affected by mis-specified time varying catchability (i.e. increasing catchability in a later fishing period) than they were by mis-specified *q* functions..

2.2.1 Discussion

There was no discussion following this presentation.

2.3 Catchability modeling case studies

2.3.1 Time-varying catchability in lake whitefish assessments by Brian Linton and Jim Bence

Commercial fishery statistics were integrated with biological data from the fishery to develop statistical catch-at-age models of lake whitefish (*Coregonus clupeaformis*) in the 1836 treaty-ceded waters of the upper Great Lakes. Sea lamprey (*Petromyzon marinus*) mortality was estimated separately from the modeling process and input as an age- and year-specific matrix for stocks showing measurable levels of predation. Natural mortality was calculated as a function of L_∞, the Brody growth coefficient, and water temperature. Models were composed of a population-dynamics submodel and an observation submodel that predicted observed data given the estimated population for each year. Agreement between the model predictions and observed data was measured through negative log likelihood. A white-noise process was used to estimate time-varying catchability of gillnets and trapnets. A double-logistic function of age was used to estimate time-varying selectivity of gillnets and trapnets, where a quadratic function of time was used to estimate changes in the age of 50% selectivity. Harvest limits were predicted using abundance and mortality rates from the models in conjunction with the target mortality and spawning potential reduction.

The sensitivity of model results to changes in parameters describing time-varying catchability of gillnets and trapnets was evaluated. Model results were not sensitive to changes in parameter starting values and bounds for log-scale annual catchability of gillnets and trapnets. Model results were sensitive to changes in standard deviations of log-scale catchability for gillnets and trapnets.

2.3.1.1 Discussion

Minor changes in the standard deviation for *q* had a large effect on management quantities. But, there was no data available to groundtruth the estimate of 0.1. This value was chosen by expert opinion.

The trapnet q value was very high in the last year. To account for this you could switch from a white noise model to a random walk model. You could also constrain the last year and set it equal to the previous year. A retrospective analysis was done.

In terms of estimating the standard deviation for catchability, assuming a positive value might be better than assuming it is zero. Treating it as a control variable for sensitivity analysis is a reasonable approach and something that should be done. Assessment analysts are advised against assuming a constant value for the standard deviation and just leaving it at that.

In terms of comparing the results across management regions, the results ended up being the same as for the region shown. They do borrow information from other management units when necessary. Meta-analysis across regions would be beneficial. (This may have already been done to some extent).

There had been regulatory changes over time including rezoning of management units, gear restrictions, state-funded trapnet conversions, minimum size limits, and TACs.

As q increased, effort declined because a small number of operations were involved. This could be related to just a few fishermen shifting fishing locations.

Trends in q tend to bias results. Could the white noise model be used more as a diagnostic? And if no trend emerges, could you just assume a constant q? Why use a white noise model if there is no trend? Deviations were constrained around the mean. This could accommodate a trend, but a random walk would be a better approach if there is a trend.

No tests had yet been completed to evaluate model sensitivity with regard to setting the standard deviation equal to 0.

Summary: In this study, time-varying catchability was expected to occur for many reasons and was thus incorporated into the assessment. It was modeled as white noise (in log space) with assumed standard deviation ($\sigma = 0.1$). Because results were sensitive to the assumed value, much discussion focused on this parameter. In this fishery, as in most, no direct data are available to estimate σ, and thus its value was chosen by expert opinion. The panel noted that constant catchability is a special case that occurs when $\sigma = 0.0$, and discussed considering σ as a control variable over which to examine uncertainty in management advice. The panel also noted that, in the terminal year, catchability of trapnet gear was unusually high. If terminal year estimates are questionable, as may be indicated by retrospective analysis, it could be useful to constrain those estimates in some meaningful way (e.g., set it equal to last year's estimate or to the overall mean).

2.3.2 Evaluating and estimating single- and multi-species catchability models in the Gulf of Mexico by Jim Thorson and Jim Berkson

2.3.2.1 Data analysis

Recent stock assessments in the southeastern U.S. have debated the existence of a 2% annual increase in catchability caused by gear improvements such as GPS. Recent tagging studies also demonstrate density-dependent habitat selection in Gulf of Mexico gag grouper, which is theorized to underlie density-dependent catchability, where catchability increases as population sizes decrease (Lindberg et al. 2006). Here we estimated catchability trends and density dependence for seven stocks and four gears in the Gulf by comparing abundance indices derived from catch-per-unit-effort (CPUE) data with abundance estimates obtained using virtual population analysis (VPA) calibrated with fishery-independent indices. Bayesian and mixed-effect methods were used to estimate trend and density dependence for all stocks jointly, while Monte Carlo simulation, generalized least squares, and bootstrap were applied as sensitivity analyses. This study found statistically significant evidence for density dependence and a 2% compounding annual increase in catchability. The estimated levels of density dependence imply that some stocks in the Gulf of Mexico may be rebuilding faster than previously estimated, while others (e.g., red snapper in the western Guulf) may be declining more rapidly. Multi-species estimation is an effective method for estimating time-varying catchability given the quantity and quality of data currently available in many other fisheries management regions. Results suggest that increasing catchability trends and density dependence should be routinely investigated in stock assessments that use CPUE data.

2.3.2.2 Simulation modeling

Time-varying catchability is prevalent in many management regions, and is often modeled using density dependence and time-trend parameters. A catchability model may be estimated using single- or multi-species data, and parameter estimates may be of interest as an input for stock assessment models or in their own right (e.g. catchability trends as an index of fishing efficiency). An operating model was developed to replicate the catch and CPUE data that exist in the Gulf of Mexico, and ordinary least squares was used to estimate catchability trends, density dependence, and annual catchability using six different estimation procedures and single-species or multi-species data. Estimated trend, density dependence, and annual catchability parameters were compared with operating model values to determine the precision and accuracy of different estimation procedures in a factorial model design. Multi-species estimation increased precision and accuracy of model parameters when errors were compared with those arising from standard catchability assumptions or single-species methods. Multi-species estimation did not dramatically increase errors when compared with the standard assumptions, even when density dependence and trend were absent. Procedures that imputed catchability parameters from similar species performed well given the data available in the Gulf of Mexico. Multi-species methods are immediately feasible to compensate for time-varying catchability in single-species assessments in the southeastern U.S. and other fisheries management regions.

2.3.2.3 Discussion

Most of the discussion centered on the differences and applications of the single- and multi-species models. Some workshop participants expressed concern over the fact that catches for seven stocks, with different life histories, different habitat utilization patterns, and even different fisheries sectors (i.e., commercial and recreational) were pooled for the multi-species analysis. Jim recognized this issue needs to be looked into (the hierarchical structure of the model is highly adjustable and can address these issues through data weighing), but pointed out that previous studies indicate that even species with different life histories seem to show similar density-dependent patterns. One of the strengths in this "proof of concept" analysis is that we can attempt to develop a set of generalized estimates from data rich species that can be used for data poor species—i.e., make the most out of available data.

2.3.3 Time-varying catchability in stock assessments for yellow perch in Lake Michigan by Mike Wilberg, Jim Bence, Brad Eggold, Dan Makauskas, and Dave Clapp

We examined the role of time-varying catchability in an assessment model for yellow perch (*Perca flavescens*) in southeastern Lake Michigan. The abundance of yellow perch declined greatly in southern Lake Michigan during the mid to late 1990s. Consequently, commercial fisheries in Illinois and Wisconsin were closed during 1996-1997 (and have remained closed) and stricter regulations were placed on the recreational fishery. Reproductive failure has been implicated as the primary cause of the population collapse, but previously the role of fishing in the collapse has not been rigorously investigated. We conducted an age-, size-, and sex-structured stock assessment of yellow perch to estimate population size and examine historical trends in fishing mortality in Illinois and Wisconsin waters of Lake Michigan. The model included time-varying catchability according to random walks separately in the recreational and commercial fisheries, constant catchability for fishery-independent surveys, and random walks for parameters of the growth model. Estimated catchability in the commercial fishery declined over time in Wisconsin, but increased slightly in Illinois. Estimated catchability in the recreational fishery declined over time in both states. Model estimates indicated that yellow perch abundance in 2002 was less than 10% of 1986 abundance in Wisconsin and about 20% in Illinois. Annual mortality rates for females age 4 and older averaged 69% during 1986-1996 in Wisconsin and 60% in Illinois during 1986-1997, which are quite high for a species like yellow perch that can live longer than 10 years. Our estimated fishing mortality rates on adult females during 1986-1996 exceeded widely used reference points, suggesting that overfishing may have occurred. The relative contribution of types of fishing to overall fishing mortality differed between Illinois and Wisconsin with commercial fishing mortality being more important in Wisconsin and recreational fishing mortality being more important in Illinois. Fishing mortality rates decreased substantially in the late 1990s after stricter regulations were imposed on recreational fisheries and commercial fisheries were closed. We believe unsustainably high fishing mortality rates likely caused the rapid decline of mature females in the mid-1990s. Spawning stock biomass (SSB) in 2002 was at its highest level since the early 1990s indicating that despite relatively poor recruitment during the last decade, management actions have been successful in reducing fishing mortality and building SSB. Changes in catchability were consistent with density-dependent changes, anecdotal effects of environmental changes, and desired effects of management changes.

2.3.3.1 Discussion

Discussion focused on technical, philosophical, and biological issues associated with the reported yellow perch analysis. On the technical side, it was asked how iterative reweighting was integrated with the MCMC analysis. Mike replied that highest posterior density estimation was used first, and then these estimated variances were fixed within MCMC to get at final uncertainty measures. One individual asked about diagnostics, and worried that there could be multiple modes in the posterior surface. Mike indicated that chains seemed to be mixing well and converging to one solution, but cautioned that age- and length-compositions had large sample sizes so this might not be a universal result.

On the philosophical end, there was a question about whether it was worth the effort to try to estimate time-varying catchability for fishery dependent indices when there was a decent fishery independent index available. An NRC report was referenced which concluded that fishery-dependent indices should be disregarded in such cases. Mike replied that this approach works well when the fishery independent index has a reasonably small CV – say 25%. As the CV of the fishery independent index increases, including fishery dependent indices (and attendant changes in catchability) becomes more important. One individual commented that often fishery dependent datasets have longer time series and are more cost effective so that they will often make sense to use (especially for the Gulf and south Atlantic).

Mike was asked about several features of the model fit, and their biological interpretation. For instance, there seemed to be some lack of fit in the fishery independent CPUE data. Mike indicated that survey catchability may have decreased over time despite being assumed constant in the model. Ostensibly, this might have to do with changes in water quality following zebra mussel introduction into the great lakes. On a related note, why was recruitment so low in recent years? Mike said that there was no conclusive answer, but that looking at larval abundance suggests it may be due to increased mortality during the larval pelagic stage, perhaps attributable to changes in the zooplankton community following zebra mussel introduction.

Mike commented that there was no attempt to run the model without fishery independent data, as this would necessitate substantial changes in model configuration. Thus, it is unclear how many model parameters can be time-specific (e.g., time-varying selectivity *and* time-varying catchability?) in absence of a reasonably precise fishery independent index. This issue deserves more investigation.

2.4 Captain and technology effects on vessel-specific CPUE in the Gulf of Mexico red grouper fishery by Kevin McCarthy

The objective of this work was to examine vessel-specific differences in CPUE among captains, as well as, between the periods before and after installation of GPS and GPS plotters. Commercial shallow water grouper longline fishers were interviewed to develop vessel-specific histories of technology and captain changes. Interviews were limited to commercial participants in the Gulf of Mexico shallow water grouper fishery. Eleven longline vessel histories have been compiled to date. Coastal logbook landings and effort data were used to calculate nominal red grouper CPUE for each vessel. Red grouper CPUE was calculated because Gulf of Mexico red grouper spawning stock biomass estimates were available from the 2006 red grouper assessment and provided some context in which to evaluate vessel-specific CPUE trends. Red grouper trips were defined as those trips during the red grouper open season with less than 50% sharks, deepwater grouper, amberjack, or tilefish in the reported landings. The median length of available vessel history was 15 years, median number of captains per vessel was 3, with a median of 2.5 years between captains. Half the vessels had GPS installed prior to 1998 and half had GPS plotters prior to 2001. A significant difference in CPUE was found among captains for six of the eleven vessels. Four vessels had no significant captain effect and one vessel had a single captain over its known history. Only those five vessels with no significant captain effect were examined for GPS and GPS plotter effects on CPUE, however two of the vessels had no change in GPS gear over their known history and could not be tested for GPS effects on CPUE. All three vessels tested had a significant difference in CPUE before and after the installation of GPS, although in some cases the sample size (number of trips) was small in some years after GPS use began. For three of the four vessels tested, significant differences in CPUE were found before and after GPS plotter use began. The period of GPS use, however, was confounded with the period of GPS plotter use. These were initial analyses. Additional interview data and more complete analyses are needed before any conclusions may be made regarding the effects of captains or technology on CPUE in the red grouper longline fleet.

2.4.1 Discussion

Most of the discussion focused on how the interview data can be further analyzed and used. Kevin reiterated that the analysis was preliminary and data has been available only recently. Further exploratory and more detailed analysis is needed as well as investigating possible analytical tools. The effects of regulations, environmental factors (hurricanes, red tides, etc.), and fishing behavior were discussed. It was suggested that General Linear Models be used as an analytical tool. Several suggestions were made for additional data sources (handline data (not enough data), vessel logbooks and other documents stored by Bob Spaeth) and analyses (analysis by month, e.g. months with highest catches, and variability of catches within a trip, if data is available) which were welcomed by Kevin.

2.5 Modeling catchability in Stock Synthesis by Rick Methot

There are a variety of methods for developing abundance indices from fishery independent data collected from research vessels (or contracted fishery vessels) and fishery dependent information adjusted to account for the concentration of fishing effort in time and space. It was emphasized that abundance indices should be proportional to the density of the stock throughout its range (not just where fishing occurs) and that, ideally, the degree of proportionality (catchability) should be constant through time. In point of fact, catchability is generally not constant, and it was recommended that assessment models be flexible enough to allow the user to incorporate changes in catchability and to constrain the uncertainty associated with those changes. It was noted that the stock synthesis model permitted users to investigate both time trends and density dependence in catchability.

Examples of fisheries assessments with different amounts of basic information were examined to demonstrate the effects of various constraints on catchability estimates. Bias and uncertainty in estimated population statistics (biomass, recruitment, fishing mortality) were influenced by the flexibility given to the stock synthesis model. With simulated data created with density-dependent catchability and temporal changes in population abundance, model estimates of catchability using a random walk approach failed to match the true value when catchability was assumed constant or a tight constraint was placed on deviations from the initial value. When catchability was less constrained the predicted catchability more closely matched the true values, but the coefficient of variation about the estimates of catchability in the terminal year were substantially higher. When age composition data were included, model predictions improved substantially, both in terms of accuracy and precision, and estimated time-varying catchability matched the true values closely. It was noted that in the stock synthesis model the user can control the level of constraint on the catchability parameter for an entire time series as well as for each year; annual constraints might be useful when anomalous events occur which affect the behavior of the fish and/or the fishers.

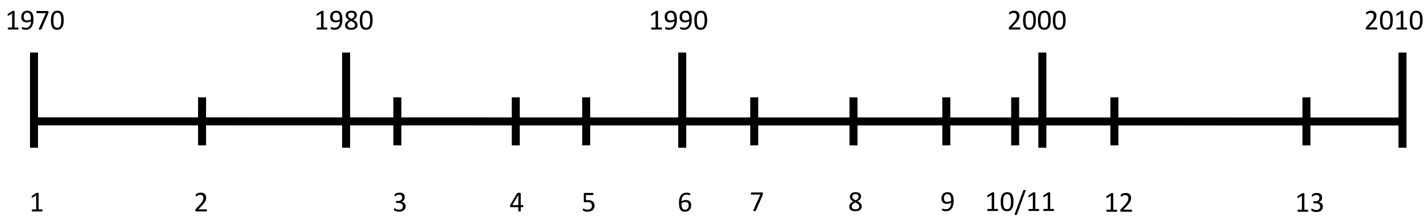
2.5.1 Discussion

It was noted that assessment models will often assign higher amounts of uncertainty to some estimated parameters than to others. For instance models often assign higher amounts of uncertainty to the parameters of the stock-recruitment relationship rather than to the estimated recruitment. The choice to estimate time-varying catchability or density dependence in catchability will reduce the model's ability to estimate some other parameters. It was noted that it might be difficult to estimate both natural mortality rate and catchability though it was thought that with sufficient data and high total mortality rates it might be possible. It would be expected that without constraining assumptions like fixed levels of natural mortality or low deviation in catchability, the estimates for the population parameters of interest to management would have higher variance.

It was noted that the ability of assessment models to accurately estimate changes in catchabilty would be impacted by the timing of the change within the time series. Changes that occur early or late in the time series would be more difficult to accurately estimate. The ability of the model to reflect changes in the middle of the time series would be impacted by the degree to which the potential for change in catchability was constrained.

3 Perspectives and advice from Constituents/Fishermen

3.1 Recreational Fishery



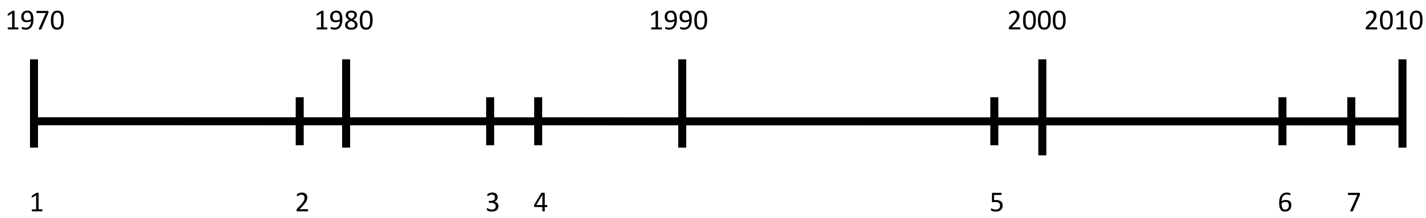
Factors that could potentially affect catchability:

1. 1970's: More offshore trips occurred. There were fewer vessels.
2. Mid 1970's: North Carolina's recreational boats obtained paper bottom machines.
3. Early 1980's: Fishing locations were published, allowing recreational fishing to expand geographically. Paper bottom machines became increasingly affordable for recreational boats.
4. Mid 1980's: Bottom fishing started. North Carolina boats switched from trolling to bottom fishing or a combination of the two.
5. 1987: Loran C became affordable for recreational fishers (~ $500) creating a substantial improvement in efficiency.
6. Mid 1980's or early 1990's: There were more offshore trips because of tow insurance, new offshore hull designs, (e.g. Contender boats) and four stroke engines. Early 1990's: Braided line (spider wire) allowed trips for bottomfish offshore of the central east coast of Florida.
7. 1992: Bottom color machines were obtained by the recreational fleet, but these resulted in only marginal improvement in fishing power.
8. Mid-1990's: The range of Florida boats had gradually expanded north and south over time so that by the mid 1990's all areas between inlets were now exploited.
9. Late 1990's: Electronics were common on boat packages with combined units (GPS with plotters) available. This had a substantial impact on the efficiency of less skillful anglers.
10. 1999: Bottom color machines were obtained by the recreational fleet, but provided little change in fishing power.
11. 1999: GPS became affordable for recreational fishers causing a large improvement in efficiency, allowing novice recreational fishers to quickly find areas once known (through publications or other fishers) but more difficult to find. This provided for recreational range expansion.
12. 2003: Radar improvement was used to follow birds, for a small fraction of high-end fishers. This was also true for the North Carolina charter fleet.
13. 2007-2008: As a result of the increase in fuel price and the resulting economic impact, there were more anglers per boat, the same areas were fished as in the past, and fewer trips were taken.

General Notes:

- The overall geographic distribution of the fishery has not changed over time.
- The south Atlantic geographic range expanded farther offshore – often 50 miles offshore.
- The northern Gulf experienced little change in geographic range.
- Publications (FL Sportsman) played an important role in teaching fishing technology and publishing fishing locations.
- Although the timeline provides specific dates, effects on catchability may be spread across years. For example, GPS became affordable in 1999, but implementation of the technology and related fishing knowledge (i.e., fishing locations) continues to be phased in.

3.2 *Headboat Fishery*



Factors that could potentially affect catchability:

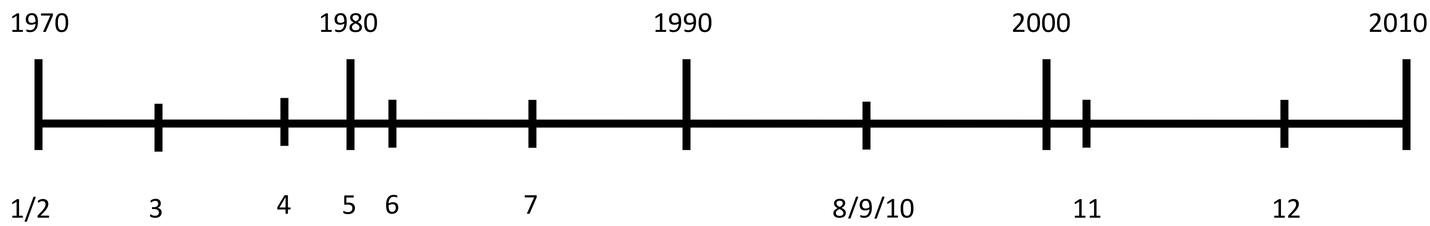
1. Late 1960's to early 1970's: The introduction of Loran A caused a very large improvement in efficiency.
2. Late 1970's to Mid 1980's: The change from Loran A to Loran C caused a large change in efficiency and equivalent to about a 20-25% time savings (notes for other fisheries suggest the improvement in efficiency of 1/12 to 1/6).
3. Mid 1980's: Longer trips were taken in the northern Gulf and Texas with farther distances traveled, creating geographic range expansion. Catamarans started operating on middle grounds bringing faster vessels and more fishing time. New hulls were introduced in central west Florida and new areas were fished.
4. Starting 1986: Artificial reefs in AL, MS, TX, LA changed specific fishing locations. There was a gradual increase in the number of artificial reefs in the Gulf and in some east coast areas (such as Palm Beach).
5. Late 1990's: Six- and twelve-pack boats started operating on the east coast of Florida from Ft. Pierce to the Keys. Six- and twelve-pack boats have more experienced anglers, conduct bottom fishing, and use live bait. This vessel effect needs to be accounted for when standardizing headboat CPUE.
6. 2006-2008 (past 2-3 years): Northern Gulf and Florida panhandle: Targeting changed away from red snapper due to increased red snapper abundance (fishers know they are guaranteed to catch them on each trip) and changes in regulations.
7. 2007-2008: Increased fuel prices and their resulting economic impacts have caused changes including boats running slower out to fishing grounds, translating into less time fishing. Also, boats started fishing closer to port, representing geographic range contraction. Since clients seemed pleased, this behavior may continue even with fuel prices reduced, as a way of recovering some lost costs.

General Notes:

- Starting in the 1960's and ongoing, there was a wood to aluminum and fiberglass hull construction change.
- More inshore fishing took place in the Carolinas over time (since 1970's).
- In south Florida (Miami-Ft. Pierce), the fuel price didn't affect the geographic distribution of the fleet because the shelf is very narrow and it is much easier to get to deeper water.

- Northern Gulf has had more half- day trips over time.
- Overall, there has been little change in the areas fished.
- In recent years, small scale targeting for triggerfish in the Carolinas has been affected by closed seasons.
- Moving from Loran C to GPS has caused little to no change in efficiency (flat line).

3.3 Charter/For Hire Fishery



Factors that could potentially affect catchability:

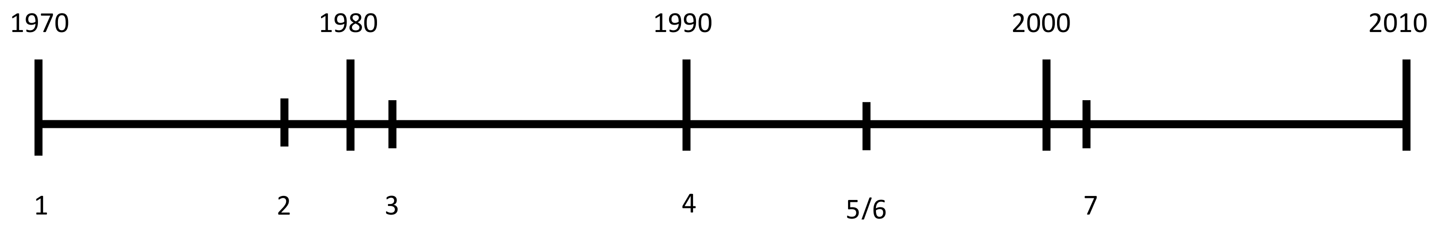
1. Late 1960's-early 1970's: The introduction of Loran A caused an important change in efficiency.
2. 1960's-1980's: In the charter off-season, some charter boats fished commercially, taking 1-3 day trips.
3. Mid-1970's: North Carolina recreational and for hire boats began using paper bottom machines.
4. Late 1970's to mid 1980's: There was a change from Loran A to C resulting in savings of 1/12 to 1/6 of time.
5. 1980: Some of the boats in the North Carolina charter deep water grouper fishery began using all electric reels.
6. Early 1980's: Areas outside of NC began using paper bottom machines (see mid-1970's for NC).
7. Last 20 years: On the East coast of Florida, there was a move to larger charter vessels (privately owned, used for overseas trips seasonally). In the last ten years, they began targeting reef fish.
8. 1995: The charter fleet began using GPS plotters, allowing for repeatability in fishing sites.
9. Mid-1990's: The charter/for hire fishery for bottom fish in the Gulf, that had taken place from the 1960's, ended due to the change in regulations.
10. Mid-1990s: GPS was introduced.
11. Early 2000s: The North Carolina charter fleet began using radar for tracking birds.
12. 2007-2008: High fuel costs caused slower travel, less time fishing, and fishing nearer to port.

General Notes:

- Electric reels had been used since the 1960's for charter for-hire reef fish fishing on headboats and charterboats in the panhandle.
- North Carolina had more offshore trips due to regulations that allowed for more catch of offshore species.
- In the Gulf, there was a moratorium placed on new charter boat permits in 2004.
- Other than for the North Carolina fleet, radar has not had an important effect on catchability up to now.
- Live bait in the charter/for hire sectors did not have much effect.

- Introducing circle hooks to the recreational/charter/for hire sectors may improve catchability for novice fishers once they learn not to set the hook.

3.4 Commercial Fishery



Factors that could potentially affect catchability:

1. Late 1960's to early 1970's: The introduction of Loran A was an important change, improving fishing efficiency by one-half.
2. Late 1970's to mid 1980's: The change from Loran A to Loran C was important, causing a time savings between 1/12 and 1/6.
3. Early 1980's: Paper machines were introduced to the commercial fleet.
4. 1990: Longline gear use was restricted by depth, east of Cape San Blas to 20+ fathoms, and west of Cape San Blas to 50+ fathoms.
5. Mid-1990's: GPS was introduced.
6. Mid-1990's: The introduction of the GPS plotter for longline and vertical line created a time savings of 5%.
7. Roughly 2000 to present: A mosquito fleet made up of smaller faster boats using boutique vertical line was created on the west coast of Florida. This fleet makes 1-2 day trips fishing for grouper for restaurants.

General Notes:

- There has been no change in fishing areas over the last 30 years except for regulatory restrictions.
- The same boats have been used over the past 30 years.
- There have been no significant gear or vessel changes over the last 30 years.

4 General Discussion

4.1 Tuesday afternoon's discussion

Workshop objectives were reviewed during this discussion session and included the development of recommendations for which methods we could use (if any) to parameterize catchability, recommendation of criteria to use when modeling catchability, and the preparation of a SEDAR procedures document to address these recommendations. Workshop participants discussed the following:

- Whether time-varying catchability should routinely be considered in future assessments,
- If it is no longer appropriate to set the slope of the catchability trend to an arbitrary, fixed value (e.g., 2% increase per year), and
- The need for further study of the performance of various methods to model time-varying catchability.

Suggestions included:

- Synthesizing a time line (or portions of a time line) for catchability developed by the commercial and recreational anglers independently for the various fishery sectors and gears.
- Implementing the random walk approach.
- Implementing a multi-species approach which incorporates density dependence and a trend in catchability (done external to the stock assessment).
- A combination of some of these methods – but no good comparison of these methods exists, so we can't say that one works better/worse in any given condition.

We may need to consider density-dependent changes together with gear changes, spatial changes, regulatory actions, technological changes, or changes in fisher behavior and be open to the fact that catchability may actually decrease with time given, for example, a density-dependent effect. One can implement both the random walk and density-dependent analysis, where, for example, you add variance constants for years where you have additional information.

However, it likely is overly ambitious to try to develop a "cookbook" of techniques or advice for dealing with time-varying catchability. Instead, useful guidance should be developed for steering assessments away from drawing arbitrary conclusions about catchability and more consistent approaches should be explored for how to incorporate time-varying catchability into stock assessment. It is also cautioned to avoid ranking the various approaches toward dealing with time-varying catchability. Given the quality of data in the southeast, there is a wide range of results one may obtain when applying these methods. Clearly, more simulation testing is greatly needed to confirm the sensitivity of these approaches to various scenarios. For fisheries that are sufficiently data rich, it is useful to estimate a density-dependent effect and a technological effect, not necessarily from random walk. In addition, for multispecies fisheries, such as the South Atlantic vertical line fishery and probably several Caribbean fisheries, it may be possible to apply catchability information and inferences from past assessments and apply this to other species (such as to serve as a prior in a Bayesian framework). Ultimately, it is important to explicitly determine which factors are important if we want to model changes in catchability.

Time-varying catchability may be an explanation as to why different data sources are not telling the same story. It may also cause a time retrospective pattern. A model can put all these different data sources together to tell one story about the overall stock. An explanation of why different data sources tell different stories and inclusion of this information in stock assessment models will improve model performance. Incorporating time-varying catchability may help unify the patterns from disparate data sets. More precise estimates of catchability will lead to more precise estimates of abundance. After testing some of these methods about time-varying catchability, one may determine that there is no real change in catchability over time. The issue however is that if you don't test this and catchability does change over time, and this is not included in modeling, you hurt your ability to predict how abundance changes over time. While looking at the data to identify times when catchability changes, it is cautioned that if one looks at it long enough, one is likely to find a cause for catchability change that may or may not be an actual cause, and ultimately becomes rationalized as a factor contributing to catchability change.

Those present at the workshop acknowledged the likely existence of time-varying catchability and supported the development of good recommendations on how to take this into account during stock assessment since there won't always be people with expertise on this subject at each assessment meeting.

The group felt that the density-dependent and random walk approaches have some support in the literature and should be considered as candidates, however they each have various estimation performance issues, particularly toward the end of time series. Another issue is the software used to conduct each model because different implementations of the same basic approaches each have their own nuances. Models and modeling software can and should evolve with these changing assessment procedure expectations. The SEDAR process presents the opportunity to have several different regions that share a common framework compare alternate time-varying catchability methodologies across stocks, years, and factors.

It is important to determine how to appropriately identify years of significant change in catchability. Individual vessel analysis may be one tool that can be used to start identifying years or groups of years when changes in catchability were taking place. In some situations, it may be too specific to say that in a given year, catchability has changed by a specific quantity, however one could give the model some sort of expectation that catchability may change without forcing the model to assign an absolute amount. When comparing these various approaches, it is difficult to parse the time (random walk) effect from density effect. If you strongly think you have a density effect, then you should include this is in the model, whereas if you think you have a time effect, then this should be included. If you think you have both density and time effects, then you could include both but this likely means that you will have high CV as a consequence, so it is a trade off. The simulation showed that the precision on parameter estimates will be high if you have low standard error on time variant catchability, but can be substantially higher if catchability changes over time. It is necessary to go through this sort of testing approach so that you can see the consequences of each method used to handle catchability.

If you have large changes in abundance (such as a stock recovery) and are consistently monitoring across time and space, then we can be in a better position to estimate how catchability is changing over time or with density dependence. For example, the recreational fishery for red snapper has been intentionally slowed down by the recreational anglers because they realize the potential weakness of the stock as it is rebuilding. While this fishery is rebuilding, it continues to have a closure, which changes how the anglers target fish. To deal with this situation, it may be necessary during standardization to subset trips with a likelihood of catching red snapper. Such micro-selection issues might benefit from or be controlled for by including time-varying catchability in the stock assessment.

If you have density-dependent catchability, then catchability will change based on how fast the population changes. Therefore if you have a short quick change in a population (such as occurred with anchovy), the random walk approach will not work well because this approach requires a trend over a longer time frame. If there is a gradual change in abundance, even if it is caused by density dependence, catchability may be approximated by a random walk. How quickly a population changes per year will be a factor in determining which method is most appropriate. How the behavior of the average fisher responds to the fish population is not something inherent to the population itself, so when the population changes, the question becomes how fast does effort readjust itself relative to abundance changes. We see density dependence due to spatial overlap of where fishing occurs and where fish are (not due as much to competition for hooks). The exact scale on which spatial overlap needs to be examined is hard to determine. In addition, how fast things occur (such as a fisher catching a lot of fish on a particular spot causing temporary local depletion, then the departure of the fisher from the spot, followed by a return of the fisher once the fish return) can create the appearance of density dependence.

Additional discussion questions to consider include the following: How much does the inclusion of catchability into an assessment affect the uncertainty of the assessment? Once a stock recovers, should we go back and still consider catchability in the historical data at all? For example, as abundance goes up, does it do any good to tease out the catchability function in kingfish? Will going back and including catchability in past assessments tell us any more than we already know?

4.2 Wednesday morning's discussion

The group discussed if it is no longer acceptable to assume constant catchability and if it is no longer acceptable to assume an arbitrarily increasing level of catchability (e.g., catchability increases by 2% annually). It was noted that there is a relatively strong case for assuming density dependence in catchability for many species.

Several potential approaches for handling time-varying catchability were discussed including identifying a timeline of key events and then estimating catchability for 2-3 time periods, using random walk and white noise methods, and a multi-species density-dependent approach to estimate catchability external to the single species assessments. It was also noted that there may be some situations where we might still want to assume constant catchability. Decisions should be made about approaches based on the quantity and reliability of available data.

It was suggested that the workshop might generate a menu of methods to address time-varying catchability that stock assessment biologists could consider and make evaluations based on the quantity and quality of available data. There was concern expressed that methodology selection may be dependent on the relative expertise of the stock assessment biologist. It was suggested that as quantitative approaches are developed they should be coded in standardized software packages such as the Stock Assessment Toolbox so that they are vetted outside of the Southeast Region. It may be possible for a methods-oriented group to develop a simpler form of Stock Synthesis that focuses on dynamics and processes common across stock assessments in the Southeast.

The group noted that change is happening continually in the fisheries and that we do not know what will happen in the future. The group determined that it would be useful to develop a base timeline of major events that are likely to have affected catchability on a regional basis including technological introductions, changes in market conditions, significant changes in fishery participation and regulatory impacts. It was noted that many of these effects would need to be evaluated separately for various fishing fleets. This would allow for consideration of these effects in conjunction with density-dependent effect, noting that they may affect catchability in different ways.

5 Workshop Recommendations

5.1 Review of Methods

Many methods have been developed to incorporate time-varying catchability in stock assessment models, but there is little consensus about best practices in this area. We provide a summary of the most common methods, but the reader is referred to the review of time-varying catchability by Wilberg et al. (2009) for more detailed accounts of these methods.

5.1.1 Index standardization

All CPUE indices should be standardized to account for as many changes in catchability as possible before inclusion in stock assessments. The reader is referred to the report on the SEDAR Indices Workshop for recommendations on standardizing CPUE indices. In addition, we identified important factors leading to changes in catchability over time (Section 3), which should be considered when standardizing CPUE indices. Factors that cannot be incorporated in the standardization process, should be accounted for using other methods for estimating time-varying catchability in stock assessments.

5.1.2 Index weighting

When fitting assessment models, relative weights are specified for CPUE indices to determine how closely each index is fit by the assessment model. The reader is referred to the report on the SEDAR Indices Workshop for recommendations on weighting CPUE indices.

5.1.3 Step functions

Step functions require that time blocks are specified, and separate catchability parameters are estimated for each block (Prager, 1994; McAllister and Ianelli, 1997; Simpendorfer et al., 2000). Mohn (1999) recommended that time blocks be no less than five years in length.

5.1.3.1 Data needs

- Information on when changes in catchability occurred. Section 3 of this report could be used as a starting point for discussions during future SEDAR data workshops.

5.1.3.2 Pros

- Simple approach to addressing time-varying catchability
- Incorporates mechanisms for time-varying catchability when available
- Simple statistical tests can be used to determine if additional parameters are necessary

5.1.3.3 Cons

- Lose continuity of CPUE time series
- Can miss changes in catchability when mechanisms are not identified

5.1.4 State space methods

State space methods include white noise (Fournier and Archibald, 1982; Butterworth et al., 2003) and random walk (Fournier et al., 1998; Wilberg and Bence, 2006) processes.

5.1.4.1 Data needs

- Good age or length composition data
- A good fishery independent survey is helpful but not necessary

5.1.4.2 Pros

- Can be easily combined with other methods for estimating time-varying catchability
- Data driven methods, which do not require knowledge of underlying mechanisms
- Integrates changes in catchability over a wide range of mechanisms
- Allows for transparent setting and evaluation of control variables (i.e., catchability process error variance)

5.1.4.3 Cons

- In surplus production model, cannot separate process error in observation submodel from process error in population submodel
- Increased numbers of parameters leads to a decrease in precision of model estimates
- Have to specify process error variance for time-varying catchability
- Estimation of time-varying catchability constrained to range of age or length composition data

5.1.5 Density dependence

Density-dependent catchability has been demonstrated in many fisheries and fishery independent surveys (Wilberg et al., 2009). Catchability can be modeled as a power function of stock density (Paloheimo and Dickie 1964).

5.1.5.1 Data needs

- Meta-analysis required to estimate prior probability for density-dependent parameter.
- Good age/length composition data or fishery independent survey required if informative prior not specified.

5.1.5.2 Pros

- Explicitly accounts for mechanisms affecting time-varying catchability
- Requires less data than state space methods
- Requires fewer parameters than state space methods and incorporates information from meta-analysis

- Can be incorporated into stock projections
- Having mechanisms make results easier to explain to others
- Density dependence has theoretical and empirical support across a wide range of fish stocks

5.1.5.3 Cons

- Density-dependent process assumed constant over time
- May performs poorly if catchability is not density-dependent of if other factors dominate changes in catchability.
- Inference to other stocks can be questioned

5.1.6 Combinations of methods

In principle, any of the above methods can be combined (Wilberg et al., 2009).

5.1.6.1 Data needs

- Determined by the methods being combined

5.1.6.2 Pros

- Allows for mixing of mechanistic and descriptive approaches
- Can incorporate data from meta-analysis
- Different methods can be applied to different indices (or time periods) in the same assessment

5.1.6.3 Cons

- Depends on rest of assessment model being correctly specified
- Requires more data than use of a single method

5.2 Recommendations regarding application to southeast fisheries

1. Time-varying catchability is a common and important phenomenon, with strong theoretical and empirical support. It should be considered in future southeast stock assessments.
    a. Methods should be flexible among assessments because no one method will be best for all cases.
    b. It is important to consider effects of density-dependent and density-independent (e.g., technology creep) mechanisms on catchability, which can be done using a descriptive or mechanistic approach.
2. Information should be compiled during the data workshop regarding time-varying catchability.
    a. Information may be derived from the fisherman discussion summary from the SEDAR catchability workshop, provided by fishermen attending stock assessment meetings, or from ongoing fishermen interviews.
    b. Explore potential mechanisms (technology, behavior, management/ regulations) and when they occurred.
3. For all species:

a. Evaluate time-varying catchability as part of the assessment.

b. Methods that can be used will depend on available data, but may include mechanistic or descriptive techniques.

4. For species with limited data, and in the absence of a contrary justification:

   a. Generally assume density-dependent catchability as a null hypothesis, because it will be difficult to estimate time-varying catchability in data-poor situations, and data are available for density-dependent effects from previous meta-analyses.

   b. Use meta-analysis (e.g., Gulf of Mexico, Harley et al. 2001) to inform either (I) selection of parameter values or (II) specification of a Bayesian prior.

   c. Explore density-independent factors that might contribute to a time trend in catchability.

6 Future Directions for Research and Methods

The group supports the many recommendations in earlier SEDAR reports relating to improving our understanding of how catchability has changed in the various fisheries, including:

- Enhancement of fishery independent surveys,
- Compilation and evaluation of historical data sources to aid in refining estimates of catchability including logbooks from individual fishermen or headboat operators, and
- Collection of more detailed effort information for catch rate analyses (e.g., finer spatial and temporal resolution, information on targeting, gear changes).

The group further recommends SEDAR assessments include terms of reference that focus specifically on describing how changes in catchability may have affected each index of abundance used in the assessment, the degree to which these changes may be accounted for during the standardization process, and how best to model the changes in the catchability that cannot otherwise be accounted for.

Finally, the group recognized that the state of the art for modeling catchability has not reached an end point; further theoretical and empirical study is clearly warranted. In particular, the group recommends:

- Testing the performance of alternative catchability models more thoroughly through simulation studies tailored to reflect the fisheries and data sets characteristic of the Southeastern United States,
- Expanding multispecies empirical analyses to include more species from the Southeastern U.S.,
- Expanding multispecies empirical analyses to other areas in the Southeastern U.S. To date, work has focused on stocks in the Gulf of Mexico, and
- Organizing a follow-up catchability workshop in three to five years or establishing a permanent technical working group that meets periodically to review a variety of assessment-related topics including catchability.

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