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VIRGINIA RECREATIONAL FISHING DEVELOPMENT FUND
SUMMARY PROJECT APPLICATION*

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Research and data collection</td><td>PROJECT LOCATION:
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DESCRIPTIVE TITLE OF PROJECT:

Improving stock assessment of weakfish (*Cynoscion regalis*)

PROJECT SUMMARY:

Problems associated with the current stock assessment methods for weakfish include spatial difference of individual growth, stock structure, the catch rate survey spatial coverage, questionable assumptions used in the Adaptive VPA models, such as borrowed (among disparate geographic regions) length-at-age key, measurement error of catch data and constant catchability Therefore, new approaches must be developed for stock assessment of weakfish to overcome these problems We will address the above issues in our proposed 3 year work through further geospatial data synthesis, and the development of new alternative approaches to assessing the weakfish fishery. A geospatial analysis of the catch rate will help us to weight the data usage in the following stock assessment models by considering their spatial coverage and the sample design A flexible statistical catch-at-age model and a catch data-free population growth model will be developed to avoid the borrowed age-length key in the ADAPT-VPA analysis and to better answer the questions of "is the weakfish stock overfished?" and "to what extent is overfishing occurring? ".

EXPECTED BENEFITS:

The project will enable us to construct an operational stock assessment model for weakfish. There are no known status parameters (fishing mortality rate or spawning stock biomass (SSB) estimates), for current management Without knowledge of stock-based parameters, the ASMFC could be faced with future decisions involving further curtailment of commercial and recreational harvests and fishing opportunities, based on precautionary management strategies An improved stock assessment can provide an estimate of fishing mortality and SSB and corresponding thresholds (biologically safe limits). For recreational fisheries it is important that any policy regarding the establishment of recreational possession limits be based on a scientific foundation The new stock assessment approach to be developed in this study can overcome many problems associated with previous methods, which will improve the quality of the weakfish stock assessment over previous assessments Most importantly, recent stock assessments have shown there is a mismatch between the strength or signal between the fishery-independent (e g trawl survey) and fishery-dependent (catch-at-age data) within the model (ADAPT) framework. The benefit of this proposal is that it will utilize multiple model approaches to investigate the status of the weakfish stock

COSTS:

First year

VMRC Funding:	$87,194
Recipient Funding:	$26,330
Total Costs:	$113,524

Detailed budget must be included with proposal.

Title: Improving stock assessment of weakfish (*Cynoscion regalis*)

Applicant: Dr. Yan Jiao, Dr. Don Orth, Virginia Tech, and Rob O'Reilly, Virginia Marine Resource Commission

Needs

Weakfish (*Cynoscion regalis*) has formed the basis of one of the most important fisheries on the Atlantic coast for centuries, which are critical to the local economy and society. There is no current estimate of fishing mortality or spawning stock biomass because the stock assessment done by the weakfish subcommittee and Technical Committee (TC) didn't pass the peer review (ASMFC 2006, SARC 40). The stock assessment approaches used in the past appear inadequate to model the population dynamics of the weakfish and insufficient in providing the information required for proper fishery management (ASMFC 2006). There is a compelling need for an improved stock assessment given the findings of the most recent peer review.

There is a definite relationship between a stock assessment of Atlantic coast weakfish and Virginia weakfish. Right now there are no solid, scientific indicators of the status of the weakfish stock. There is no way of knowing whether the relatively small recreational and commercial fisheries coast-wide or Virginia is harming the stock. There has not been a comprehensive assessment of weakfish in many years. Weakfish is an inter-jurisdictional, migratory species. Any benefit gained from a coast-wide assessment directly benefits Virginia. Without a comprehensive stock assessment, the ASMFC will not have the ability to effectively manage the states' fisheries but will be forced (in the face of continuing declines in landings) to further restrict fishermen (a moratorium is favored by 2 states, already). Right now, the ASMFC recognizes that natural mortality is a factor, but the ASMFC does not know fishing mortality and spawning stock biomass without an improved comprehensive stock assessment. The direction of management, without an assessment, is moving towards a much reduced amount of fishing or a moratorium.

We propose to (1) conduct a detailed geospatial analysis to survey catch rates at age for consistent year-class signals; (2) explore applicability of a flexible statistical catch-at-age model to weakfish assessment; (3) develop a catch-data-free population growth model to supplement our understanding of the stock status.

Issues in the current stock assessment, such as the individual growth difference and their geospatial pattern, and the geospatial pattern of the catch rate surveys, are the top two priorities of the weakfish stock assessment recognized by the weakfish stock assessment technical committee. The analysis of the two issues will also help to understand the stock structure by analyzing the growth and morphological variation over spatial scale, which is the third research priority recognized by the TC. Weakfish stock structure has been discussed regularly in the past decade. The TC notes that difficulty in defining stocks and implementing stock-specific assessments in a mixed stock fishery would be major obstacles (ASMFC 2006). To better understanding the stock structure and the stock mixing, a further analysis on the geospatial difference of the weakfish individual growth and the meristics difference should help through a stock composition analysis (Fournier et al. 1984; Millar 1986; Millar 1990). The analysis will help us to justify the data sets in the following stock assessment model. Other issues such as the use of the ADAPT-VPA model, variation in natural mortality, the use of "borrowed" age-length key information, the discrepancy between observed Young-of-Year (YOY) trend and the stock assessment result from the VPA model, etc., were questioned by the SARC 40 peer review, and were listed as the important research needs by the TC and the peer review committee.

New approaches must be developed for stock assessment of weakfish to overcome many problems associated with the current stock assessment methods for weakfish, to improve the quality of the weakfish stock assessment, to improve the understanding, utilization, and management of this important resource in the Atlantic (e.g. ASMFC 2006, NEFSC 2004). We will address the above issues and suggestions in our proposed work through further geospatial data synthesis, and the development of new alternative approaches to assessing the weakfish fishery. A detailed analysis of the current available fishery dependent and independent surveys with specific focus on spatial and sample size justification is needed too improve the current weakfish stock assessment (ASMFC 2006). GIS mapping is needed to synthesize the data from different surveys and locations. The catch rate pattern of the catch rate over the whole geospatial distribution of the weakfish will help to better understand and quantify different data quality used in the stock assessment. The synthesized data can further be used to develop catch rate models.

Some flexible statistical models for weakfish fishery stock assessment are needed to avoid the borrowed age-length key in the ADAPT-VPA analysis and to better answer the question of "is the weakfish stock declining" (ASMFC 2006). Models under our consideration are a flexible statistical catch-at-age model, and a catch-data-free population growth model. The flexible statistical catch-at-age model can avoid the borrowed age-length key needed in the current ADAPT-VPA analysis; the catch-data-free population growth model detects the population trends over time without the use of the catch data (Hilborn 2002), which avoids the uncertainty in the catch report.

The prior assessments lack a systematic framework for the incorporation of data from different sources, lack a systematic algorithms in estimation of uncertainty and for estimating risk of overfishing and the stock being overfished. A risk-based decision-making framework for the weakfish needs to be developed. Risks of overfishing and the stock being overfished needs to be estimated with full consideration of uncertainty.

Background information

The weakfish supports one of the most valuable commercial and recreational fisheries in the western Atlantic. The fishery is critical to the local economy. Consistent landing records from the commercial fishery started in 1950, while the record from recreational fishery started in 1981. Landings have increased steadily since the early 1950s, peaked in 1981, and then declined in the mid-1990s and 2000s (ASMFC 2006).

The weakfish is distributed mainly across the northern and western part of the Atlantic but can be observed from Nova Scotia to Florida. It is a migratory population under Atlantic State Marine Fisheries Commission (ASMFC) management. Weakfish may live as long as 17 years and are known to reach 12 ponds in body weight (Goodson 1976). Age is mainly determined by observation of otoliths in current stock assessment (ASMFC 2006).

Mature weakfish spawn in riverine areas in the spring and larvae and post-larvae nurse in bays, coastal sounds, and estuaries for 1 to 2 years (90% by age 1 and 100% by age 2). Adult weakfish migrate into the ocean and migrate north in the summer and south in the winter. The continental shelf from Chesapeake Bay to Cape Lookout, North Carolina is the main wintering grounds for weakfish. Some weakfish may remain in inshore water from North Carolina southward (ASMFC 2004).

ADAPT-VPA was used in weakfish stock assessment but was criticized by the most recent peer review committee because of the ignorance of the uncertainty in the catch data. It requires catch-at-age matrix, which is derived from the age-length key sampling. The spatial variation of weakfish individual growth brings problems of using borrowed age-length key where sampling surveys were not conducted. The spatial coverage and the possible spatial correlation of the catch rate survey bring discussions about their quality among the SARC 40 peer review committee and the TC. The new geospatial analysis of the individual growth and the catch rate surveys will help to understand the geospatial pattern and the spatial correlation of these variables which provides insight of spatial dynamics of the weakfish population. The new stock assessment framework developed in this study will include a flexible stochastic age-based model which applies more realistic assumptions of the stock's population dynamics, better incorporates the model's statistical errors and provides a Bayesian estimator. The flexible age-based model can incorporate catch-at-age error, incorporate catch-per-unit of effort (CPUE) indices without aging information (so we do not need to borrow the age-length key as required by the ADAPT-VPA). The flexible age-based model can be further extended to spatially explicit model to incorporate stock structure. So, CPUE indices from different locations can be used with different stocks of weakfish. We also will develop a catch data-free population growth model based on fishery-independent and fishery-dependent surveys. This model will be used to evaluate population overall growth without separating natural mortality, fishing mortality and population intrinsic growth rate. It will help us to understand the overall trend of the population. After that, a multi-species predator-prey-environmental recruitment model will be constructed. This model will be used to evaluate the influence from other biotic and abiotic factors beyond the weakfish population itself.

Bayesian estimators have been increasingly used in assessing fisheries resources because of their abilities to provide a systematic approach for incorporating prior knowledge and data from different sources into assessments, as well as the ability to produce results that can be used directly for risk analyses of alternative management strategies. Risk will be estimated using a composite risk assessment approach based on the posterior distributions of the reference points that we will explore in this study (Jiao et al. 2005). The composite risk assessment approach fully considers uncertainty from indicator reference values (e.g., F and B) and biological reference points (e.g., F_{msy} and B_{msy}) when estimating risk of overfishing and risk of a fishery being overfished. The uncertainty of the F and B, and F_{msy} and B_{msy} will be their posterior distributions from the Bayesian stock assessment model. The current control rule used for the weakfish fishery status evaluation uses F_{target} , $F_{threshold}$ and $SSB_{threshold}$. We will look at the fishery status based on the control announced in Amendment 4 to the weakfish management plan (ASMFC 2002). B_{msy} will be estimated and the difference between SSB_{msy} and $SSB_{threshold}$ will be compared to investigate the space of further stock rebuilding. Other reference points from age-structured models will be also evaluated. This will greatly improve our understanding, utilization, and management of this important resource in the western Atlantic.

<u>Objectives and goals</u>

The objectives of this study are to synthesize the geospatial data of the weakfish growth and the catch rate; to develop a stock assessment and risk-based decision making framework to assess the weakfish fishery in the Western Atlantic; to develop a set of stock assessment models (flexible statistical catch-at-age models, catch data-free population growth rate models) to better capture the population dynamics of the weakfish; to improve our understanding, utilization, and management of the weakfish fishery; and to provide a training opportunity and research experience to a postdoctoral researcher in using quantitative modeling skills to address complex management problems in fisheries.

More specifically, we will:

I: collect, request and synthesize data

(1) obtain both biological and management-related information through literature review, meeting with relevant scientists and agencies, and by organizing a research advisory workshop in which the current weakfish stock assessment subcommittee will be invited;

(2) further evaluate and identify problems associated with the approaches currently used in the weakfish stock assessment after step (1);

(3) synthesize the growth and the catch rate data, using GIS to map them;

II: develop effective stock assessment models

(4) develop models for the geospatial data of the growth and the catch rate; evaluate the possible ways of incorporating spatial structure into the stock assessment models;

(5) develop a flexible statistical catch-at-age model to describe the population dynamics of the weakfish;

(6) develop a catch-data-free population growth rate model;

(7) develop a multi-species predator-prey-environmental recruitment model;

III: develop estimator for parameters estimation in the above models

(8) develop a Bayesian approach for estimating vital fishery parameters by incorporating both data collected from different sources and prior knowledge of the fishery derived from previous studies (ecological studies, scientists' and fishermen's experience and observations);

IV: validate models through simulation study

(9) conduct an extensive simulation study to investigate model performance with respect to model hypotheses on data quantity and quality, especially the aging data and the natural mortality assumption, and catchability assumption;

V: explain the population dynamics characteristics and analyze the stock status

(10) evaluate the population dynamics and current status of the weakfish stock; and

(11) develop a decision-making framework for risk analyses of alternative management strategies for providing management advice to government agencies and local fishing industries. This framework will consider uncertainty from different sources and identify an optimal management plan for sustainable exploitation of this important resource.

Project impacts/ Results or Benefit Expected

We are proposing some traditional and some novel approaches to assess the weakfish stock because the current methodology is failing to allow effective management of the fisheries.

Mapping and analyzing the spatial structure of the growth and the catch rate will help us to understand the stock structure, and explore the possibility of incorporating the stock structure into our stock assessment. Constructing a flexible catch-at-age model will avoid many shortcomings in the currently used weakfish age-structured model, e.g., the uncertainty of the catch will be incorporated, the length-at-age key will not need to be borrowed, and recruitment over time, fishing mortality and spawning stock biomass will be estimated as well. Developing catch-free models will help us to understand the population status, such as, is the population decreasing or not? This will complement the result from the age-structured model. Eight formulations of stock-recruitment models will be used to explore the relationship between spawning stock size and recruitment. Assuming one model is the "true model" is dangerous, which ignores model selection uncertainty and may lead to overconfidence of inferences (Jiao 2007). The finalized stock-recruitment relationship will help us to understand the productivity changes over times attribute to climate ocean oscillation or food chain dynamics. These questions will be further investigated through the stock recruitment models. The stock recruitment relationship is important and is crucial in estimating biological reference points. For example, if M is changing following high-low regimes, the productivity should follow high-low regimes also, and these should be incorporated in the F estimation and the F-based biological reference point estimation.

The project will enable us to construct an operational stock assessment model for weakfish, better understand the dynamics of weakfish in the western Atlantic and greatly improve the management of Atlantic weakfish. The new stock assessment approach to be developed in this study can overcome many problems associated with traditional methods, which will improve the quality of the weakfish stock assessment over previous assessments. This will benefit fisheries scientists, managers, and stakeholders and greatly improve the understanding, utilization, and management of this important resource in the western Atlantic.

The PI will also present this project as a case study to Ph.D. students taking the graduate course "Fisheries Population Dynamics and Modeling", which the PI will teach regularly. This will teach students updated quantitative approaches in assessing fisheries resources in the context of a current, important, U.S. Atlantic fishery issue and will help students better understand how a stock assessment can be done to address management issues in the real world.

The results will be communicated to the NMFS, ASMFC, and state management agencies through seminars, workshops and meetings. A webpage will be developed to update the progress made in the project and to receive feedback from people with different interests. Information and methods developed in the study will be downloadable for anyone who is interested in this study. Upon the completion of this project, the results will be presented to the ASMFC and NMFS for their consideration for implementing the proposed method in the management of the fisheries. Talks will also be presented at national and international conferences (e.g., American Fishery Society annual meetings), and manuscripts will be submitted to peer-reviewed journals in fisheries.

Research plan and methodology

Spatial structure analysis of the weakfish growth

GIS will be used to map the survey location, sample size and the age-specific growth difference. This will enhance our understanding of the spatial difference of the weakfish growth. Spatial difference of the individual growth (both age specific difference and the von Bertalanffy growth curve difference) of the weakfish will be analyzed through a likelihood ratio test (Cerrato 1990). No significant differences (P>0.05) in the likelihood of weakfish from different locations could be detected after fitting the model, the simplified formula for the likelihood ratio could be used

$$(1) \qquad -2Ln(Likelihood \quad ratio) = nLn\left(\frac{sum \quad of \quad square \quad residuals|H_o}{sum \quad of \quad square \quad residuals|H_a}\right),$$

Where n is the total number of fish, Ho is the null hypothesis, and Ha is the alternative hypothesis. To reject Ho, $-2Ln(Likelihood \quad ratio)$ should be larger than χ_k^2, where k is the number of degrees of freedom and equals the extra number of parameters estimated under Ha compared with Ho.

Stock mixing will be analyzed through stock composition analysis using maximum likelihood method (Fournier et al. 1984; Millar 1986; Millar 1990).

Spatial structure analysis of the weakfish CPUE

GIS will be used to map the survey location, sample size and the CPUE difference. This will enhance our understanding of the spatial difference of the weakfish catch rate and their sample size and spatial coverage. How factors such as, spatial factors and environmental factors, influence CPUE will be analyzed through Generalized Linear Mixed Model (GLMM) (Bishop et al. 2004). Other approaches currently used will also be used for comparison of the model performance.

After this analysis, we will get a conclusion on CPUE standardization and the weighting of different CPUEs based on their sample size, spatial coverage. If strong spatial correlation were detected a spatial-structured CPUE model can be developed and used in the following population dynamics models.

Development of catch-data-free model

A set of catch-data-free models will be constructed to represent the dynamics of the weakfish stock. The models will capture the overall trend of the population changes over time instead of the "true" population size. This study will help to answer the question of "is the population declining". Models such as random-walk and the kalman-filter autoregressive models have been used to analyze the trend of the population or productivity over time (Peterman et al. 2000, 2003).

The first model will be used is

$$I_{t+T_t} = I_t \lambda^{T_t} e^{\varepsilon_1}, \quad or \qquad (2)$$
$$Ln(I_{t+T_t}) = T_t Ln(\lambda) + Ln(I_t) + \varepsilon_1$$

where λ is the population growth rate; I_t is the density of the population (CPUE) at the survey year t; T_t is the time interval between year t and $t+T_t$; error ε_1 is independent and normally distributed with mean 0 and variance $\sigma^2_{\varepsilon_1}$. This model assumed constant population growth rate over time and locations, and density dependency was not considered. This is an exponential growth model, so we called it the EG model.

The second model will be used is

$$Ln(I_{t+T_t}) = T_t Ln(\lambda) + Ln(I_t) + u_t \qquad (3)$$
$$u_{t+T_t} = \phi u_t + \varepsilon_2$$

In this model, residual error u_t is modeled as a first-order autoregressive (AR(1)) process. ϕ is the autocorrelation coefficient, and error ε_2 is independent and normally distributed with mean 0 and variance $\sigma^2_{\varepsilon_2}$. This is a residual autoregressive model.

The third model will be used is

$$Ln(I_{t+T_t}) = T_t Ln(\lambda_t) + Ln(I_t) + \varepsilon_3 \qquad (4)$$
$$\lambda_{t+T_t} = \lambda_t + \varepsilon_4$$

where population growth rate λ_t is modeled as a random walk process; and errors ε_3 and ε_4 are independent and normally distributed with mean 0 and variances $\sigma^2_{\varepsilon_3}$ and $\sigma^2_{\varepsilon_4}$. This is a random walk model.

The fourth model will be used is

$$(5) \quad \begin{aligned} Ln(I_{t+T_t}) &= T_t Ln(\lambda_t) + Ln(I_t) + \varepsilon_5 \\ Ln(\lambda_{t+T_t}) &= Ln(\bar{\lambda}) + \varphi[Ln(\lambda_t) - Ln(\bar{\lambda})] + \varepsilon_6 \end{aligned}$$

where population growth rate λ_t is modeled as a first-order autoregressive process, and φ is the autocorrelation coefficient. This is a Kalman-Filter autoregressive model.

The fifth model will be used is

$$(6) \quad \begin{aligned} &Ln(I_{t+T_t}) = T_t Ln(\lambda_t) + Ln(I_t) + \varepsilon_7 \\ &\lambda_t \in N(a,b) \\ &a \in U(c,d) \end{aligned}$$

where error ε_7 is independent and normally distributed with mean 0 and variance $\sigma^2_{\varepsilon_7}$. λ_t is modeled to follow a hierarchical distribution, i.e., a, the mean of λ follows a uniform distribution between c and d, and $N(a,b)$ is truncated to make sure that λ has positive values. This is a Bayesian hierarchical exponential growth model.

The sixth model will be used is

$$(7) \quad \begin{aligned} Ln(I_{t+T_t}) &= T_t Ln(\lambda) + Ln(I'_t) + \varepsilon_8 \\ Ln(I_t) &= Ln(I'_t) + \varepsilon_9 \end{aligned}$$

where error ε_8 and ε_9 are independent and normally distributed with mean 0 and variance $\sigma^2_{\varepsilon_8}$ and $\sigma^2_{\varepsilon_9}$. I_t is modeled as a measurement error model (Jiao et al. 2006).

All the CPUE data will be analyzed using the models described above. These models will be compared based on Deviance Information Criteria (DIC). If the DICs differ greatly, one of the models with lowest DIC will be used for population projection; if the DICs are close, a model averaging approach may be used to summarize the population trends using all the models by incorporating model selection uncertainty (Jiao 2007).

Development of flexible statistical catch-at-age stock assessment model

A flexible stochastic age-based model will be constructed to represent the dynamics of the weakfish stock. The model will consist of five sub-models including: (1) a stock-recruitment model (not built in the general mode here because of the dramatic changes of weakfish recruitment and the huge impact of model assumptions); (2) a number-at-age model; (3) a series of observational models that describes the relationship between stock abundance and the abundance indices observed in the fishery and/or fisheries-independent surveys (age structured or not, "borrowed" age-length data will not be used); (4) a series of observational models that describe the relationship between observed and predicted size composition data collected in the fishery and/or fisheries-independent surveys; and (5) a series of observational models that describe the relationship between observed and predicted catch. A model stock will be generated and driven by observed catches and fine-tuned with the data observed from the fishery using a Bayesian estimator described in the statistical estimation section.

(8) $\hat{R} = f(spawner)$ $\hat{R}$ is the predicted recruitment

(9) $\hat{N}_{year,age} = f(N_{year-1,age-1}, M_{year-1,age-1}, F_{year-1,age-1})$ $\hat{N}_{year,age}$ is the predicted population size at certain year and age; M and F are natural mortality and fishing mortality separately. M is often assumed to be constant among ages and years.

(10) $\hat{I}_{year.age} = f(N_{year,age})$ if age composition information is available for the CPUE data;

$\hat{I}_{year} = f(N_{year})$ if age composition information is not available for the CPUE data.

$\hat{I}$ is the predicted CPUE. In this equation, a constant catchbility model and a time-varying catchability model will both be used. We will justify which one works better for the weakfish fishery based on the goodness of fit.

(11) $\hat{p}_{year,age} = f(N_{year.age}, F^{*}_{yecar.age}, M_{yea.age})$

F^{*} is the fishing mortality from the survey; $\hat{p}_{year,age}$ is the predicted proportion at certain age and year. If the survey is from the fishery, then $F^{*} = F$ from the fishery; if not $F^{*} \neq F$.

(12) $Catch\Big|_{predicted} = f(F_{year.age}, M_{year,age}, N_{year.age})$

As in equation (3), catch can be age-structured if age-structured information is available; it can be non age-structured if no age information available.

A modeled stock will be generated and driven by observed catches and fine-tuned with the data observed from the fishery using a frequentist method and a Bayesian estimator described in the statistical estimation section. When some model equations, such as a time-varying auto-correlated catchability model, are used, a Bayesian estimator will have to be used (De Valpine and Hasting 2002).

The dynamics of the weakfish stock will be described by the stock-recruitment model, together with a number-at-age model, which can be derived from two commonly used models in fisheries, the catch equation and the exponential survival equation (Ricker 1975, Hilborn and Walters 1992). The predicted numbers-at-age, catch-at-age, and stock abundance will be related to observed catch and CPUE data in the fishery and to observed numbers-at-age and abundance index observed in the fishery-independent survey by formulating an appropriate objective function, which will be decided in the section of the statistical estimator. By optimizing the objective function, we can estimate the model parameters, and thus the dynamics of the weakfish stock.

Development of stock recruitment model

The stock-recruitment relationship is always one of the most difficult and controversial relationships to be identified or assumed in stock assessment. It will be done separately after the flexible age-structured stock assessment model. Eight mathematical models will be developed to simulate the recruitment dynamics, which include a Ricker model, a Beverton-Holt model, a hierarchical Ricker model, an auto-regressive residual model, a random walk Kalman filter model, an auto-regressive Kalman filter model, a measurement error Ricker model, and a predator-prey-environmental recruitment model (Quinn and Deriso 1999; Peterman et al. 2003). The implications of using the different recruitment estimation approaches will be evaluated. Other approaches identified in the study will also be considered. These models will be compared based on Deviance Information Criteria (DIC). If the DICs differ greatly, one of the models with lowest DIC will be used for population projection; if the DICs are close, a model averaging approach may be used (Jiao 2007).

Development of catch data free population growth model

We will also develop a set of catch data-free population growth models. Models include: an exponential growth model, an auto-regressive residual model, a random walk population growth model, an auto-regressive population growth model, and a hierarchical exponential population growth model. The models will be used to estimate the overall trends of the population based on cpue survey data only. These models will be compared based on DIC. If the DICs differ greatly, one of the models with lowest DIC will be used for population projection; if the DICs are close, a model averaging approach may be used (Jiao 2007). By doing this, assumptions regarding natural mortality, fishing mortality, aging, and catchability will be avoided. It will help us to understand the overall trend of the population.

Statsitical estimator

We will mainly use a Bayesian approach to fit the model to data collected from different sources because of the use of state-space time-series models (such as the process error in the equation 2 and the time varying catchability model in equation 3). A Bayesian estimator will have to be used for these time-series models (De Valpine and Hasting 2002). We will also use the frequentist method when only the observation errors are considered. A main difference between Bayesian approaches and frequentist methods is in the interpretation of uncertainty associated with modeling (Berger 1985). Bayesians believe that model parameters are random and uncertainties in the parameter estimation reflect the likelihood of a hypothesis that a parameter has a certain value (Hilborn et al. 1993). This enables the results of Bayesian stock assessment, the posterior distributions of model parameters, to be used directly in risk analyses of alternative management strategies. The Bayesian approach has been increasingly used in stock assessment because of this (McAllister and Kirkwood 1998, Chen et al. 2004).

The Bayesian approach uses a probability rule (Bayes' theorem) to calculate a "posterior distribution" from the observed data and a "prior distribution", which summarizes the prior knowledge of the parameters (McAllister and Kirkwood 1998, Gelman et al 2004). A normal distribution function

$$P(Y,X\mid\beta,\sigma)=\frac{1}{\sqrt{2\pi}\sigma}\exp(-\frac{[Y-f(X,\beta)]^2}{2\sigma^2}) \tag{13}$$

will be used for log-transformed catch, CPUE data and the predicted stock abundance. The t distribution has been shown to be robust to atypical errors (Hilborn and Walters 1992, Quinn and Deriso 1999, Chen et al. 2000). We will move to the t distribution if the results are sensitive to the normal distribution assumed. For numbers-at-age/length and catch-at-age/length data, the above distribution is inappropriate. A modified multinomial function (Fournier et al. 1990), weighted by the effective sample size, τ_t (i.e., independent samples actually measured for estimating age/length compositions), will be used to describe the differences between observed and predicted numbers-at-age/length and catch-at-age/length:

$$P(X\mid\beta)=\frac{1}{\sqrt{2\pi P^{Obs}_{a,t}(1-P^{Obs}_{a,t})+0.1/n}}\exp\left[\frac{-\tau_t(P^{Obs}_{a,t}-P^{Pred}_{a,t})^2}{2[P^{Obs}_{a,t}(1-P^{Obs}_{a,t})+0.1/n]}+0.01\right], \tag{14}$$

where X is the catch-at-length or catch-at-age composition data from the fishery or from a fishery-independent survey, n is the number of age/length classes. The term 0.01 increases the size of the distribution's tails, and reduces the influence of outliers. The term $0.1/n$ prevents the variance from tending to zero as the observed value tends to zero, reducing the influence of observed outliers with small probability (Fournier et al. 1990).

The normal distribution function will also be used for log-transformed CPUE data in the catch data-free population growth models and in the log-transformed recruit data in the recruitment models. We will move to the t distribution if the results are sensitive to the normal distribution assumed.

Data required in the assessment and their availability

Information relating to weakfish and its fishery has been collected by the NEFSC, ASMFC, local agencies and research institutes of the coastal states of the northwestern Atlantic (e.g., Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia and North Carolina). The information required by the stock assessment model described above comes from two types of sources: fishery-dependent and fishery-independent. The above information has been discussed in ASMFC (2006) and NEFSC (2003) stock assessment documents and is available to this project. Original data will be requested through Rob O'Reilly, who is working at the Virginia Marine Resources Commission and has been involved in weakfish stock assessment for many years.

Other information required by the proposed stock assessment framework includes data describing the relationship between length and maturation, age/length-specific fishing vulnerability, length-weight relationship, age/length-specific fecundity, and maximum and minimum legal sizes, release mortality etc. These data have been collected by ASMFC, NMFS, state agencies of the northwestern Atlantic, and by academics, and will be available to this project.

Two types of prior distribution are commonly used in a Bayesian stock assessment: non-informative and informative priors (Scheweder 1998, Gelman et al 2004). A uniform distribution is usually used for a non-informative prior, the lower and upper boundaries of which are based on biological theories or knowledge of fish stocks (Hilborn et al. 1993). An informative prior is usually defined by a normal or log-normal distribution function with mean and variance determined based on existing knowledge of fisheries.

Whether a parameter will have a non-informative or informative prior will be determined by the reliability and details of our prior knowledge about the parameter. Prior knowledge will come from different sources, including weakfish fishermen's experience, results derived from previous studies of the weakfish fishery, and knowledge of the parameters for similar species and fisheries.

Harvest control rule and fishery status evaluation

Amendment 4 of the management plan for weakfish uses an overfishing definition with a fishing mortality target of $F_{target} = F_{30\%} = 0.31$, a fishing mortality threshold of $F_{threshold} = F_{20\%} = 0.5$, and a spawning stock biomass threshold of $SSB_{threshold} = SSB_{20\%} = 31.8$ million pounds. An F greater than 0.5 equals overfishing and a SSB less than 31.8 million pounds equals overfished (Figure 1).

The current stock status evaluation approach did not consider uncertainty involved in the indicator reference values (e.g., F, B) and biological reference values (e.g., F_{msy}, SSB_{1995}) that are compared. Stock status will also be evaluated by a risk assessment in this study. Risk in statistics is determined as the probability that the observed value will be larger or smaller than some reference value. In this study, risk is determined to be the probability of fishing mortality (F) in a certain year (t) being larger than an F based reference point, such as $F_{threshold}$. Risk is $P(F > F_{threshold})$ when $F_{threshold}$ is used (here) as a reference point; $P(SSB < SSB_{threshold})$ when $SSB_{threshold}$ (spawner population abundance of a certain year) is used as a reference value. A previously described estimation algorithm (Jiao et al. 2005) will be used to calculate the composite risk in the proposed study. This method will let uncertainty involved in decision-making full considered.

Other F and B based reference points will be considered to decide the fishery status on overfishing (F-based) and overfished (B-based) except threshold above for further improvement of the current status evaluation of the weakfish fishery. Other F-based reference points include F_{msy}, $F_{\max}$ and $F_{0.1}$, $F\%$; other B-based reference points include SSB_{msy}. New reference points (beyond those of Amendment 4) are necessary and are important for helping us better understand the fishery status. The biological reference point estimation will be linked to the natural mortality variation regimes and the productivity changes overtime. Our management will be improved by linking the management with the natural variation of the population itself even though the variation may be caused by the climate ocean oscillation or because of food chain dynamics.

Simulation and sensitivity study

This study involves using the proposed model to fit different sets of weakfish observation data and the estimate model parameters that characterize the weakfish population dynamics. The parameters will be compared with the default parameters which are estimated when all the data are used. We will have specific focus on the influence of MRFSS data since they have been treated as very uninformative but was regarded as one of the better data sources because of its wider spatial coverage in the weakfish stock assessment (NRC 2006, ASMFC 2006), and the aging error, natural mortality assumption, and catchability assumption (ASMFC 2006). Impacts of having assumptions of random errors and autocorrelated errors on the formulation of likelihood functions and subsequent parameter estimation will be compared. Other important factors identified during the study will also be investigated. We will evaluate the management consequences with respect to the above factors to inform fisheries managers the relative risks associated with any choice.

Uncertainty caused by aging error will be analyzed through a simulation study. Generated "true" length-age key data based on the statistical catch-at-age model will be added with random error of different levels. We will then use the generated data with error to estimate important parameters and population size to investigate the influence of the aging error in the weakfish stock. At the same time, we will investigate the performance of using the non-age-structured catch-at-age data and CPUE and survey indices data when deriving the estimator in the flexible statistical catch-at-age model. The aim of this comparison is to explore whether using non-age structured catch and CPUE data can decrease the impact of the aging error when a statistical catch-at-age model is used.

The model and statistical approach will be modified based on the simulation and sensitivity analysis results to ensure that the modelling results can capture the weakfish stock dynamics and are not too sensitive to errors in the data and some subjective hypotheses. Possible modification methods include considering both data quality (variance from survey and fishermen's and scientists' experience) and model fit if one data set shows a contrary trend or causes a moderate to highly different result (Polacheck et al. 1997, Richards 1991). Robustness of the reference points and robustness of the estimated risks when different reference points are used will be both investigated. The assessment model and statistical approach fine-tuned in the study will be suggested to the weakfish stock assessment panel.

We expect to complete the work in 3 years (see the timeline in Table 1).

Location of the project

The project will be done in the Department of Fisheries and Wildlife Sciences, College of Natural Resources, Virginia Polytechnic Institute and State University.

Monitoring of project performance

Dr. Yan Jiao will oversee the completion of this project and will supervise the postdoctoral and the Ph.D. student and all program coding and modeling analyses. Dr. Jiao will monitor the progress of the project and will oversee the preparation of the semiannual project status reports and the final project report. Dr. Donald Orth and Rob O'Reilly will work with the research team on a regular basis, both reviewing ongoing work and discussing future steps. All members of this team will be involved in the planning of model approaches, data analyses, the interpretation of results, and the preparation and editing of manuscripts and the final report.

Please see the timetable (Table 1) for detailed information on duty and timelines.

Participation by persons or groups other than the applicant

We will collaborate with the Virginia Marine Resources Commission to discuss our project progress and results. Scientists who have previously worked on weakfish at the state agencies have been contacted for comments regarding this proposal and will be regularly contacted to review the project's progress. Weakfish stock assessment subcommittee members, e.g., Desmond M. Kahn, Jim Uphoff, Victor Crecco, etc., will be invited to attend a weakfish stock assessment workshop in Blacksburg, VA. We expect 6 of them can attend it each year. Their experience and knowledge about Atlantic fisheries, the fishing industry, and the data will help ensure the success and quality of the project. This project will also involve the Leader of the National Marine Fisheries Services Recruiting Training and Research Unit at the Virginia Tech for student training purposes.

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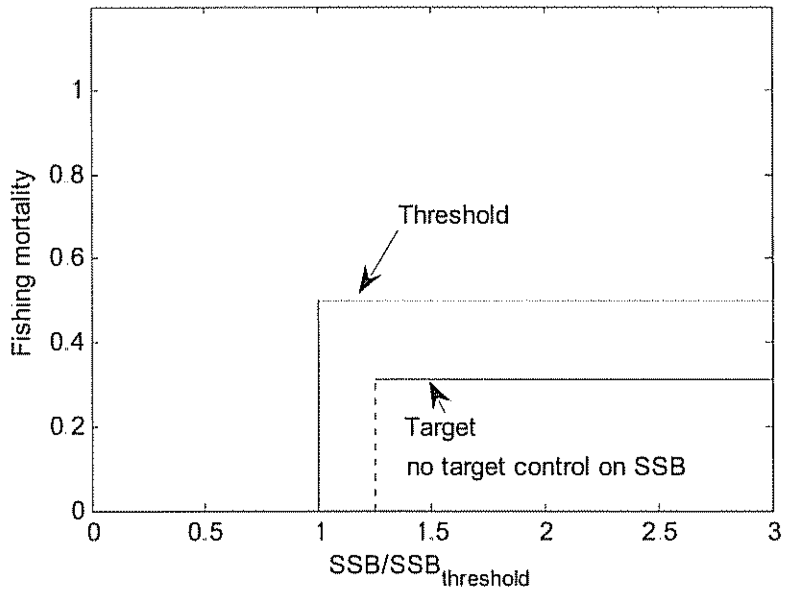
Table 1. Timetable (01/01/2008 – 12/31/2010)

Project component	**Responsible persons**	**3**	**6**	**9**	**12**	**3**	**6**	**9**	**12**	**3**	**6**	**9**	**12**
1) Literature search; recruit a postdoc	Jiao, Orth, O'Reily	✓											
2) Request the growth survey and catch rate data; organize a weakfish research advising workshop to incorporate the weakfish stock assessment subcommittee's input	O'Reily, Orth and Jiao	✓				✓				✓			
3) Synthesize the growth survey and catch rate data using GIS	Ph.D.		✓	✓	✓								
4) Quantitative analysis of the spatial structure of the growth	Ph.D.				✓	✓	✓	✓	✓				
5) Develop database and submodels that describe different fishery processes	all members		✓										
6) Develop statistical estimators for the catch-data free model	Jiao, Ph.D.					✓	✓			✓	✓		
7) Develop model averaging approach for the catch-data free model	Jiao, Ph.D.											✓	✓
8) Develop estimators for the flexible statistical catch-at-age model	Jiao, postdoc			✓	✓								
9) Develop and debug computer program codes for the models	postdoc, Ph.D.			✓	✓	✓	✓	✓			✓		
10) Estimate the dynamics of the weakfish fishery using the data and constructed model, estimator	postdoc, Jiao				✓	✓	✓						
11) Risk assessment to evaluate weakfish fishery status	postdoc, Jiao						✓	✓					
12) Sensitivity analysis to aging data and test model tuning method versus sensitivity on data sources and other important assumptions	postdoc, Jiao								✓	✓			
13) test natural mortality assumption	postdoc, Jiao									✓			
14) test catchability assumption	postdoc, Jiao						✓	✓		✓			
15) model averaging different catchability models	postdoc, Jiao							✓	✓	✓			
16) Estimate the dynamics of the weakfish fishery using the further tuned model	postdoc, Jiao										✓	✓	
17) Evaluate and conclude the project	all members											✓	✓
Project Disseminations													
1) Set up a website for the project	Postdoc, Jiao	✓											
2) Update the project website	Postdoc, Jiao		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3) Present results to Virginia MRC and ASMFC if possible	all members							✓					
4) Present results at national and international conferences	all members							✓			✓		
5) Submit papers to peer-reviewed journals	all members							✓					✓

Figure 1: Fishery status shown as overfishing risk and overfished risk using the weakfish Amendment 4 (2002) control rule.



Budget and budget justification

SPONSOR: VSRFDF
PRINCIPAL INVESTIGATOR: Y. Jiao
PERFORMANCE PERIOD: 1/1/08 - 12/31/10

	YEAR 1				YEAR 2				YEAR 3				TOTALS		
NAME/POSITION		SPONSOR		VT		SPONSOR		VT		SPONSOR		VT	SPONSOR	VT	TOTAL
1. Y. Jiao (CY)	10%	$7,265	0%	$0	10%	$7,737	0%	$0	10%	$8,240	0%	$0	$23,242	$0	$23,242
2. D. Orth (AY)	5%	$6,552	0%	$0	5%	$6,978	0%	$0	5%	$7,431	0%	$0	$20,961	$0	$20,961
3. GRA - Step 12	66%	$13,677	0%	$0	100%	$21,345	0%	$0	100%	$21,985	0%	$0	$57,007	$0	$57,007
4. Post Doc (TBN)	50%	$17,595	0%	$0	100%	$37,477	0%	$0	60%	$23,948	0%	$0	$79,020	$0	$79,020
TOTAL PERSONNEL SALARIES		$45,089		$0		$73,537		$0		$61,604		$0	$180,230	$0	$180,230
FRINGE BENEFITS															
FACULTY & SPEC. RES. FAC.		$10,844		$0		$18,388		$0		$13,756		$0	$42,988	$0	$42,988
SMR/WAGES		$0		$0		$0		$0		$0		$0	$0	$0	$0
GRA		$1,504		$0		$2,348		$0		$2,418		$0	$6,270	$0	$6,270
Classified		$0		$0		$0		$0		$0		$0	$0	$0	$0
TOTAL FRINGE BENEFITS		$12,348		$0		$20,736		$0		$16,174		$0	$49,258	$0	$49,258
TOTAL SALARIES & FRINGES		$57,437		$0		$94,273		$0		$77,778		$0	$229,488	$0	$229,488
TUITION & ACAD. FEE - AY		$5,318		$0		$8,783		$0		$9,574		$0	$23,675	$0	$23,675
TRAVEL - Blacksburg 6 person 1 time		$5,000				$5,000				$5,000			$15,000		$15,000
TRAVEL - VMRC 1 person 3 times		$2,000		$0		$2,000		$0		$2,000		$0	$6,000	$0	$6,000
TRAVEL - AFS Conference						$1,500				$1,500			$3,000		$3,000
MATERIALS & SUPPLIES (Computer)		$0		$2,000		$0		$220		$0		$220	$0	$2,440	$2,440
CONTRACTUAL SERVICES (MATLAB ($1500) and ADMB ($700))		$0		$2,200		$0		$0		$0		$0	$0	$2,200	$2,200
TOTAL DIRECT COSTS		$69,755		$4,200		$111,556		$220		$95,852		$220	$277,163	$4,640	$281,803
INDIRECT COSTS @ 56.8%		$18,300		$1,193		$0		$0		$0		$0	$18,300	$1,193	$19,493
INDIRECT COSTS @ 58.5%		$18,848		$1,229		$60,122		$112		$44,002		$112	$122,972	$1,453	$124,425
VSRFDF Allowed Indirect @ 25% TDC		$17,439				$27,889				$23,963			$69,291	$0	$69,291
WAIVED INDIRECT		($37,148)		$19,709		($60,122)		$32,233		($44,002)		$20,039	($141,272)	$71,981	($69,291)
TOTAL COSTS		$87,194		$26,330		$139,445		$32,565		$119,815		$20,371	$346,454	$79,267	$425,721

FRINGE RATE SCHEDULE (provisional-ONR approved)	7/1/05 - 6/30/07	On or after 7/1/07
Regular Faculty	33%	32.00%
Special Research Faculty	36%	35.50%
Part-Time Faculty	16%	16.25%
SMR/WAGES	8%	8.50%
GRA	9%	11.00%
CLASSIFIED	44%	45.50%

BUDGET NARRATIVE (YEAR 1)—Jiao
(Budget is based on a start date of 1 Jan. 2008)

1) Personnel:

Salaries: **$ 45,089**

Note: Virginia Tech accounting for salaried personnel on the basis of percentage-of-effort, not on a per-hour basis; this method of accounting is in according with OMB Circular A-21, Cost Principle for Education Institutions. Any hours reflected in the proposal for these personnel have been shown for the convenience of the Sponsor. These hourly rates are not auditable either as proposed or as incurred hours. The conversion has been made by applying a standard 2,080 hour year to the cost estimated by using percentage-of-effort to determine the total salary cost.

Dr. Jiao 10% year time salary; Dr. Orth 5% year time salary; and Ph.D. 66% (2 semesters research associate support) and Postdoc 50% year salary.

Dr. Jiao will oversee the project progress, management the budget; both Dr. Jiao and Dr. Orth will help the postdoctoral fellow and the Ph.D. student to construct the model.

Fringe Benefits (Includes FICA, workers compensation, unemployment compensation, medical insurance, group life insurance, employee retirement compensation, faculty and staff fee waivers, and educational leave): $12,347

Postdoc Research Associate: fringe rate = 36.5%
Tenure faculty: fringe rate = 32%
Graduate student: fringe rate = 11%

2) Travel: $7,000

VT and VMRC around trip 1 persons 3 times =$2,000
Weakfish workshop, 6 people from the weakfish subcommittee travel to Blacksburg, =$5,000

3) Equipment and Furniture: $2,000 (cost share from Virginia Tech)

1 new computer $2,000

4) Material and Supplies: $2,200 (cost share from Virginia Tech)

1 individual license of MATLAB ($1,500)
1 individual license of ADMB ($700)

5) Other Costs: $5,318 (student tuition)

Total Direct Costs = $69,755 (VMRC) + $4,200 (Virginia Tech cost share)

6) Indirect Costs: $17,439 (VMRC) + $19,709 + $2,422 (Virginia Tech cost share)

VMRC Indirect Rate @ 25%
Virginia Tech Indirect Rate @ 56.8% (before July 2008) and 58.5% (after July 2008)

Total Costs: $87,194 (VMRC) + $26,330 (Virginia Tech cost share)

BUDGET NARRATIVE (YEAR 2)—Jiao
(From Jan 1, 2009 to December 31, 2009)

1) Personnel:

Salaries: **$ 73,537**

Dr. Jiao 10% year time salary; Dr. Orth 5% year time salary; and Ph.D. 100% and Postdoc 100% year salary.

Dr. Jiao will oversee the project progress, management the budget; both Dr. Jiao and Dr. Orth will help the postdoctoral fellow and the Ph.D. student to construct the model.

Fringe Benefits: $20,736

Postdoc Research Associate: fringe rate = 36.5%
Tenure faculty: fringe rate = 32%
Graduate student: fringe rate = 11%

2) Travel: $8,500

VT – VMRC -ASMFC around trip 2 persons 2 times =$2,000
AFS annual conference meeting 2 person 1 trip = $1,500
Weakfish workshop, 6 people from the weakfish subcommittee travel to Blacksburg, =$5,000

3) Equipment and Furniture: $0
4) Material and Supplies: $220 (Virginia Tech cost share)
Software maintenance
5) Other Costs: $8,783 (student tuition)

Total Direct Costs = $111,556 (VMRC) + $220 (Virginia Tech cost share)

6) Indirect Costs: $27,889 (VMRC) + $32,233 + $112 (Virginia Tech cost share)
VMRC Indirect Rate @ 25%
Virginia Tech Indirect Rate @ 58.5%

Total Costs: $139,445 (VMRC) + $32,565 (Virginia Tech cost share)

BUDGET NARRATIVE (YEAR 3)—Jiao
(From Jan 1, 2010 to December 31, 2010)

1) Personnel:

Salaries: **$ 61,604**

Dr. Jiao 10% year time salary; Dr. Orth 5% year time salary; and Ph.D. 100% and Postdoc 60% year salary.

Dr. Jiao will oversee the project progress, management the budget; both Dr. Jiao and Dr. Orth will help the postdoctoral fellow and the Ph.D. student to construct the model.

Fringe Benefits: $16,174

Postdoc Research Associate: fringe rate = 36.5%
Tenure faculty: fringe rate = 32%
Graduate student: fringe rate = 11%

2) Travel: $8,500

VT – VMRC -ASMFC around trip 2 persons 2 times =$2,000
AFS annual conference meeting 2 person 1 trip = $1,500
Weakfish workshop, 6 people from the weakfish subcommittee travel to Blacksburg, =$5,000

3) Equipment and Furniture: $0

4) Material and Supplies: $220 (Virginia Tech cost share)

Software maintenance

5) Other Costs: $9,574 (student tuition fee)

Total Direct Costs = $95,852 (VMRC) + $220 (Virginia Tech cost share)

6) Indirect Costs: $23,963 (VMRC) + $20,039 +$112 (Virginia Tech cost share)

VMRC Indirect Rate @ 25%
Virginia Tech Indirect Rate @ 58.5%

Total Costs: $119,815 (VMRC) + $20,371 (Virginia Tech cost share)