



## VIRGINIA RECREATIONAL FISHING DEVELOPMENT FUND SUMMARY PROJECT APPLICATION\*

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<b>PRIORITY AREA OF CONCERN:</b> Research and data collection	<b>PROJECT LOCATION:</b> Department of Fisheries and Wildlife Sciences Virginia Polytechnic Institute and State University VA, 24061-0321								
<b>DESCRIPTIVE TITLE OF PROJECT:</b> Improving stock assessment of weakfish ( <i>Cynoscion regalis</i> )									
<b>PROJECT SUMMARY:</b> <p>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 length-at-age keys borrowed among disparate geographic regions, 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 geospatial data synthesis and the development of new approaches to assessing the weakfish fishery. A geospatial analysis of catch rates will help us to weight the data used in subsequent 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 need for borrowed age-length keys (such as used in ADAPT-VPA analysis), and to better answer the questions of “is the weakfish stock overfished?” and “to what extent is overfishing occurring?”.</p>									
<b>EXPECTED BENEFITS:</b> <p>The project will provide Virginia and other states with a more relevant quantitative understanding of the current status of the weakfish stock. A successful stock assessment will help to reduce the uncertainty in current management efforts by the VMRC and ASMFC. Fishermen need to know whether current regulations are improving the weakfish stock, and whether a long-time recovery plan is necessary. If a recovery plan is necessary a good stock assessment can lead the recovery effort, and provide guidance on useful conservation steps. There are no known status parameters (fishing mortality rate or spawning stock biomass (SSB) estimates) for current management. Without this knowledge, the ASMFC could be forced to curtail future fishing opportunities just as a precautionary measure. An improved stock assessment can provide an estimate of fishing mortality, SSB and corresponding thresholds (biologically safe limits). For recreational fisheries it is important that any policy regarding the establishment of 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. This proposal will utilize multiple model approaches to investigate the status of the weakfish stock.</p>									
<b>COSTS:</b> <table style="margin-left: 100px; border-collapse: collapse;"> <tr> <td style="text-align: right;">Year Three</td> <td></td> </tr> <tr> <td style="text-align: right;"><b>VMRC Funding:</b></td> <td style="border: 1px solid black; padding: 2px;">\$111,356</td> </tr> <tr> <td style="text-align: right;"><b>Recipient Funding:</b></td> <td style="border: 1px solid black; padding: 2px;">\$25,170</td> </tr> <tr> <td style="text-align: right;"><b>Total Costs:</b></td> <td style="border: 1px solid black; padding: 2px;"><b>\$136,526</b></td> </tr> </table>		Year Three		<b>VMRC Funding:</b>	\$111,356	<b>Recipient Funding:</b>	\$25,170	<b>Total Costs:</b>	<b>\$136,526</b>
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<b>Detailed budget must be included with proposal.</b>									

## Budget and budget justification

PRINCIPAL INVESTIGATOR: Yan Jiao

SPONSOR: VA Saltwater Recreational Fishing Development Fund

PERFORMANCE PERIOD: 1/1/08 - 12/31/10

NAME/POSITION	YEAR 1 (2008)		YEAR 2 (2009)		YEAR 3 (2010)		TOTAL								
	SPONSOR	VA TECH	SPONSOR	VA TECH	SPONSOR	VA TECH	SPONSOR	VA TECH	Grand Total						
1. Jiao, Yan - CY	10%	\$7,265	0%	\$0	10%	\$7,194	0%	\$0	10%	\$8,065	0%	\$0	\$22,524	\$0	\$22,524
2. Orth, Donald J. - AY	5%	\$6,552	0%	\$0	2%	\$2,583	0%	\$0	2%	\$2,606	0%	\$0	\$11,741	\$0	\$11,741
3. GRA - Step 12	66%	\$13,677	0%	\$0	100%	\$21,106	0%	\$0	100%	\$21,848	0%	\$0	\$56,631	\$0	\$56,631
4. TBN Post Doc - CY (SRF)	50%	\$17,595	0%	\$0	100%	\$37,477	0%	\$0	60%	\$24,107	0%	\$0	\$79,179	\$0	\$79,179
<b>TOTAL PERSONNEL SALARIES</b>		<b>\$45,089</b>		<b>\$0</b>		<b>\$68,360</b>		<b>\$0</b>		<b>\$56,626</b>		<b>\$0</b>	<b>\$170,075</b>	<b>\$0</b>	<b>\$170,075</b>
<b>FRINGE BENEFITS:</b>															
FACULTY; RESEARCH FACULTY		\$10,844		\$0		\$17,688		\$0		\$12,923		\$0	\$41,455	\$0	\$41,455
SMR/WAGES		\$0		\$0		\$0		\$0		\$0		\$0	\$0	\$0	\$0
GRA		\$1,504		\$0		\$1,425		\$0		\$1,475		\$0	\$4,404	\$0	\$4,404
CLASSIFIED		\$0		\$0		\$0		\$0		\$0		\$0	\$0	\$0	\$0
<b>TOTAL FRINGE BENEFITS</b>		<b>\$12,348</b>		<b>\$0</b>		<b>\$19,113</b>		<b>\$0</b>		<b>\$14,398</b>		<b>\$0</b>	<b>\$45,859</b>	<b>\$0</b>	<b>\$45,859</b>
<b>TOTAL SALARIES AND FRINGES</b>		<b>\$57,437</b>		<b>\$0</b>		<b>\$87,473</b>		<b>\$0</b>		<b>\$71,024</b>		<b>\$0</b>	<b>\$215,934</b>	<b>\$0</b>	<b>\$215,934</b>
EQUIPMENT		\$0		\$0		\$0		\$0		\$0		\$0	\$0	\$0	\$0
TUITION - AY		\$5,318		\$0		\$8,728		\$0		\$9,561		\$0	\$23,607	\$0	\$23,607
MATERIALS AND SUPPLIES		\$0		\$2,000		\$0		\$550		\$0		\$580	\$0	\$3,130	\$3,130
Computer & software															
TRAVEL		\$7,000		\$0		\$8,500		\$0		\$8,500		\$0	\$24,000	\$0	\$24,000
Domestic		\$7,000		\$0		\$8,500		\$0		\$8,500		\$0			
International		\$0		\$0		\$0		\$0		\$0		\$0			
CONTRACTUAL SERVICES		\$0		\$2,200		\$0		\$0		\$0		\$0	\$0	\$2,200	\$2,200
SUBCONTRACTORS		\$0		\$0		\$0		\$0		\$0		\$0	\$0	\$0	\$0
<b>TOTAL DIRECT COSTS</b>		<b>\$69,755</b>		<b>\$4,200</b>		<b>\$104,701</b>		<b>\$550</b>		<b>\$89,085</b>		<b>\$580</b>	<b>\$263,541</b>	<b>\$5,330</b>	<b>\$268,871</b>
<b>TOTAL INDIRECT (full, not in calculation)</b>	MTDC	58.5%	<b>\$37,148</b>	<b>\$2,421</b>	<b>\$56,144</b>	<b>\$322</b>	<b>\$46,522</b>	<b>\$339</b>	<b>\$139,814</b>	<b>\$3,082</b>	<b>\$142,896</b>				
Sponsored allowed	TDC	25.0%	<b>\$17,439</b>	<b>\$0</b>	<b>\$26,175</b>	<b>\$0</b>	<b>\$22,271</b>	<b>\$0</b>							
<b>UNRECOVERED INDIRECT AS COST SHARE</b>				<b>\$19,709</b>		<b>\$29,969</b>		<b>\$24,250</b>		<b>\$0</b>		<b>\$73,928</b>	<b>\$73,928</b>		
<b>TOTAL COSTS</b>		<b>\$87,194</b>		<b>\$26,330</b>		<b>\$130,876</b>		<b>\$30,841</b>		<b>\$111,356</b>		<b>\$25,170</b>	<b>\$329,427</b>	<b>\$82,341</b>	<b>\$411,767</b>

required cost share 25%

25.00%

TABLE 1	7/1/07 - 6/30/08	On or After 7/1/08
FRINGE RATE SCHEDULE (ONR approved)		
Regular Faculty	32.50%	35.25%
Special Research Faculty	35.25%	38.00%
Part Time Faculty	21.50%	27.00%
SMR/WAGES	7.00%	6.75%
GRA	7.00%	6.75%
CLASSIFIED	45.00%	49.00%

**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 socially and economically important fisheries on the Atlantic coast. Currently there is no estimate of fishing mortality or spawning stock biomass because the stock assessment done by the weakfish subcommittee and Technical Committee (TC) did not pass 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.

A definite relationship exists between the stock status of Atlantic coast weakfish and Virginia weakfish, since this is a migratory, interjurisdictional species managed as a coast-wide unit stock. Right now there are no solid, scientific indicators of the status of the weakfish stock. There is no way of knowing whether the current relatively small recreational and commercial fisheries, along the Atlantic coast or in Virginia, are harming the stock. There has not been a comprehensive assessment of weakfish in many years. 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 (e.g. predation) is a factor of overall weakfish mortality, but the ASMFC will not know the extent of fishing mortality or magnitude of spawning stock biomass without an improved comprehensive stock assessment. The direction of ASMFC management, in the absence of an assessment, is moving towards lower harvest “caps” for the commercial fishery, and lower bag limits for the recreational fishery. However, this measure is ad hoc and not scientifically based.

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 understand the stock structure and stock mixing, a stock composition analysis should further help to understand geospatial differences of weakfish individual growth and meristic (Fournier et al. 1984; Millar 1986; Millar 1990). The analysis will assist in evaluating and justifying the use of different data sets in the subsequent 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) trends 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 methods; to improve the quality of the weakfish stock assessment, and 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 approaches to assessing the weakfish fishery. A detailed analysis of the currently available fishery-dependent and fishery-independent surveys, with specific focus on spatial and sample size justification, is needed to 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 over the entire geospatial distribution of weakfish will help to better understand and quantify differences in data quality used in the stock assessment. The synthesized data can then be used to develop catch rate models.

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

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

### **Summary of first year accomplishments**

In our first year of data and modeling analysis, we found that: 1) population growth rate varies over time with a declining trend after mid-1990s; 2) a time-varying population growth model works better than a constant population growth model; 3) catch rate standardization is needed before the abundance indices can be used in the stock assessment. We found that survey season (month) and location (longitude and latitude) may be particularly important factors influencing the catch rate. Spatial autocorrelation is significant in some surveys, such as the SEAMAP trawl survey. Without standardization to eliminate the influence of these factors, an abundance index using arithmetic or geometric mean catch rates can be misleading. We recommend using either a Generalized Linear Model or Generalized Additive Model to standardize the catch rate survey data. A working document with the results of our analysis on catch rate standardization of state surveys and coast-wide surveys (MRFSS, SEAMAP, and NMFS) using Generalized Linear Models and/or Generalized Additive Models has been submitted to VMRC and to ASMFC. This analysis has been under consideration for use by the current weakfish stock assessment subcommittee. We received \$5000 from the ASMFC for this proposal.

### **Summary of second year accomplishments**

The second year (as of January 2009) continues the progress of our first year's work, with the additional data sets we have since received and the continuing model analysis. We have found that: 1) An individual growth model of weakfish can be influenced substantially by the measurement error of the fish age. It is recommended to incorporate measurement error when developing the age-length relationship and transforming the length-frequency distribution of a subpopulation to an age-frequency distribution. 2) Individual fish growth rates of weakfish have high spatial and temporal variation, which needs to be considered in the development of age-structured models when survey data are unavailable for some years or states, and need to be interpolated. 3) A flexible statistical catch-at-age model is needed for weakfish stock assessment rather than a classical VPA or statistical catch-at-age model, because a high percentage of the age-length relationships used by states are actually 'borrowed' from neighboring states rather than calculated with in-state data. Details of the work accomplished in the last one year and three months are given in Appendix 1.

### **Background information**

Consistent landing records from the commercial weakfish fishery started in 1950, and records from the 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).

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

Mature (90% by age 1 and 100% by age 2) weakfish spawn in estuarine and near-coastal waters, from spring through early fall, with peak spawning occurring, in Virginia, in late May. In Virginia, young of the year remain in these areas during their first summer then move offshore and migrate south to overwinter, in late fall. Adult weakfish migrate into the ocean and migrate north in the summer and south in the late fall. 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 uncertainty in the catch data. ADAPT-VPA requires a catch-at-age matrix, which is derived from only some states samples of the commercial fisheries. Virginia has been a top provider of these biological data (length, weigh and sex, since 1989 and age data since 1998). The spatial variability of weakfish individual growth creates the problem of using borrowed age-length keys where age-length sampling surveys were not conducted. Disparities in spatial coverage and the possible spatial autocorrelation of catch rates raised issues of data quality among the SARC 40 peer review committee and the TC. The new geospatial analysis of individual growth together with the survey catch rates will improve understanding of the geospatial pattern and correlation of these variables, and provides insight on the 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, and 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 models to incorporate stock structure. Therefore, 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 intrinsic population 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 of overfishing (fishing mortality  $F$  larger than  $F$ -based biological reference point) the fishery and the stock to be overfished (Biomass  $B$  smaller than  $B$ -based biological reference point) 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; Jiao et al. 2009). The composite risk assessment approach fully considers uncertainty from indicator reference values (e.g.,  $F$  and  $B$ ) and biological reference points (e.g.,  $F_{msy}$ , fishing mortality as the maximum sustainable yield ( $MSY$ ) and  $B_{msy}$ , biomass at  $MSY$ ) when estimating risk of overfishing and risk of a fishery being overfished. The uncertainty of  $F$  and  $B$ , and of  $F_{msy}$  and  $B_{msy}$  will be given by the posterior distributions of these parameters in the Bayesian stock assessment model. The current control rule (a guideline that determines the overfishing and overfished conditions of a stock) for weakfish fishery status evaluation uses  $F_{target}$  (target fishing mortality level, a biological reference point that is lower than  $F_{threshold}$ , and is used to against uncertainty of  $F_{threshold}$ ),  $F_{threshold}$  (a threshold level of the fishing mortality that we try to avoid) and  $SSB_{threshold}$  (a threshold level of the spawning stock biomass ( $SSB$ ) that we try to avoid). We will examine fishery status based on the control rule provided 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 margin for 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.

## **Objectives and goals**

The objectives of this study are 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 weakfish, and to improve our understanding, utilization, and management of the weakfish fishery.

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 to 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;

- (3) synthesize growth and catch rate data, and use GIS to map them;
- II:** develop effective stock assessment models
  - (4) develop models for the geospatially referenced growth and catch rate data; 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 recruitment model after comparison among models;
- III:** develop estimators for parameter 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 a 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 assumptions, and catchability assumptions;
- V:** explain the population dynamics characteristics and analyze the stock status to
  - (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, to advise 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 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 whether the population is decreasing or not. This will complement the result from the age-structured model. Eight stock-recruitment models will be examined to explore the relationship between spawning stock size and recruitment. The use of eight models counters the danger of assuming that any one model is the "true", which ignores uncertainty in model selection and may lead to overconfidence in the inferences of the model (Jiao et al. 2008 and 2009). The finalized stock-recruitment relationship will help us to understand productivity changes over time that may be caused by climate/ocean oscillation or food chain dynamics. These questions will be further investigated through the stock recruitment models. The stock recruitment relationship 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 changes 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. 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 and important U.S. Atlantic fishery, and will help students better understand how a stock assessment is 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 of the project and receive feedback from stakeholders and interested parties. Information and methods developed in the study will be downloadable for anyone who is interested in this study. Upon completion of this project, the results will be presented to the ASMFC and NMFS for their consideration for implementing the proposed methods in the fisheries management. Presentations will be given 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 weakfish growth**

GIS will be used to map the survey location, sample size, and age-specific growth differences. Spatial differences of weakfish individual growth (both age-specific differences and growth curve differences) will be analyzed through a likelihood ratio test (Cerrato 1990). A simplified likelihood ratio formula may be used, e.g.:

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

where  $n$  is the total number of fish,  $H_o$  is the null hypothesis (for example: fish grow at the same rate everywhere), and  $H_a$  is the alternative hypothesis (for example: weakfish grow faster further south than north). To reject  $H_o$ ,  $-2Ln(\text{Likelihood ratio})$  should be larger than  $\chi_k^2$ , where  $k$  is the number of degrees of freedom and equals the extra number of parameters estimated under  $H_a$  compared with  $H_o$ .

Individual growth for a given area (for example, a state’s waters) can be simulated based on available age-length data. For areas that do not have individual growth data available, a hierarchical individual growth model (Gelman et al. 2004) will be developed, which can be written as:

$$(2) \quad \begin{aligned} L_{s,t} &= L_{s,\infty}(1 - e^{-k_s(t_s - t_{s,0})}) \\ L_{s,\infty} &\sim N(\bar{L}_\infty, \sigma_{L_\infty}^2) \\ k_s &\sim N(\bar{k}, \sigma_k^2) \\ t_{s,0} &\sim N(\bar{t}_0, \sigma_{t_0}^2) \end{aligned}$$

where  $L_\infty$ ,  $k$ , and  $t_0$  are parameters in the von Bertalanffy growth model, and subscript  $s$  represents specific spatial parameters. The hierarchical population structure is developed in this



model through a multi-level prior (Wikle 2003; Gelman et al. 2004) of spatial-specific parameters in the individual growth model.

### **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. The Generalized Linear type of models (including Generalized Linear Model (GLM), Generalized Additive Models (GAM) and Generalized Linear Mixed Model (GLMM)) (Bishop et al. 2004) will be used to analyze how spatial distributions of catches (and potentially spatial autocorrelation of catches), as well as environmental factors, influence CPUE. Other modeling approaches that are currently used by management agencies will be examined for comparison with the performance of the GLMs.

From this analysis, we will obtain a conclusion on CPUE standardization and the weighting of different CPUEs based on their sample size and spatial coverage. If strong spatial correlation is detected a spatial-structured CPUE model can be developed and used in the subsequent 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 temporal trends of population or productivity (Peterman et al. 2000, 2003).

The first model will be:

$$(3) \quad \begin{aligned} I_{t+T_t} &= I_t \lambda^{T_t} e^{\varepsilon_1}, \quad \text{or} \\ \ln(I_{t+T_t}) &= T_t \ln(\lambda) + \ln(I_t) + \varepsilon_1 \end{aligned}$$

where  $\lambda$  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  $t+T_t$ ; and error  $\varepsilon_1$  is independent and normally distributed with mean 0 and variance  $\sigma_{\varepsilon_1}^2$ . This model assumes constant population growth rate over time and locations, and density dependency is not considered. This is an exponential growth model (EG model).

The second model will be:

$$(4) \quad \begin{aligned} \ln(I_{t+T_t}) &= T_t \ln(\lambda) + \ln(I_t) + u_t \\ u_{t+T_t} &= \phi u_t + \varepsilon_2 \end{aligned}$$

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

The third model will be:

$$(5) \quad \begin{aligned} \ln(I_{t+T_t}) &= T_t \ln(\lambda_t) + \ln(I_t) + \varepsilon_3 \\ \lambda_{t+T_t} &= \lambda_t + \varepsilon_4 \end{aligned}$$

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

The fourth model will be:

$$(6) \quad \begin{aligned} Ln(I_{t+T_t}) &= T_t Ln(\lambda_t) + Ln(I_t) + \varepsilon_5 \\ Ln(\lambda_{t+T_t}) &= Ln(\bar{\lambda}) + \varphi[Ln(\lambda_t) - Ln(\bar{\lambda})] + \varepsilon_6 \end{aligned}$$

where population growth rate  $\lambda_t$  is modeled as a first-order autoregressive process, and  $\varphi$  is the autocorrelation coefficient. This is a Kalman-Filter autoregressive model.

The fifth model will be:

$$(7) \quad \begin{aligned} Ln(I_{t+T_t}) &= T_t Ln(\lambda_t) + Ln(I_t) + \varepsilon_7 \\ \lambda_t &\in N(a, b) \\ a &\in U(c, d) \end{aligned}$$

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

The sixth model will be:

$$(8) \quad \begin{aligned} Ln(I_{t+T_t}) &= T_t Ln(\lambda) + Ln(I'_t) + \varepsilon_8 \\ Ln(I_t) &= Ln(I'_t) + \varepsilon_9 \end{aligned}$$

where error  $\varepsilon_8$  and  $\varepsilon_9$  are independent and normally distributed with mean 0 and variance  $\sigma_{\varepsilon_8}^2$  and  $\sigma_{\varepsilon_9}^2$ .  $I_t$  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 the Deviance Information Criteria (DIC). If the DICs differ greatly, one of the models with the 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 and incorporating model selection uncertainty (Jiao et al. 2008 and 2009).

### Development of a 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.

$$(9) \quad \hat{R} = f(\text{spawner}) \quad \hat{R} \text{ is the predicted recruitment}$$

$$(10) \quad \hat{N}_{year,age} = f(N_{year-1,age-1}, M_{year-1,age-1}, F_{year-1,age-1})$$

$\hat{N}_{year,age}$  is the predicted population size at a given year and age;  $M$  and  $F$  are natural mortality and fishing mortality.  $M$  is assumed to be constant among ages and years.

$$(11) \quad \hat{I}_{year,age} = f(N_{year,age})$$

if age composition information is available for the CPUE data; or  $\hat{I}_{year} = f(N_{year})$  if age composition information is not available for the CPUE data.  $\hat{I}$  is the predicted CPUE. In this equation, a constant catchability 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.

$$(12) \quad \hat{p}_{year,age} = f(N_{year,age}, F_{year,age}^*, M_{year,age})$$

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

$$(13) \quad Catch|_{predicted} = f(F_{year,age}, M_{year,age}, N_{year,age})$$

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.

The model described above can be extended as a spatial catch-at-age model through hierarchical structuring, as we proposed in the section on spatial structure analysis of weakfish growth. Equations 10 to 13 can then be written as:

$$(14) \quad \begin{aligned} \hat{N}_{s,year,age} &= f(N_{s,year-1,age-1}, M_{s,year-1,age-1}, F_{s,year-1,age-1}) \\ \hat{I}_{s,year,age} &= f(N_{s,year,age}) \\ \hat{p}_{s,year,age} &= f(N_{s,year,age}, F_{s,year,age}^*, M_{s,year,age}) \\ Catch_s|_{predicted} &= f(F_{s,year,age}, M_{s,year,age}, N_{s,year,age}) \end{aligned}$$

where subscript  $s$  represents specific spatial parameters. The hierarchical population structure will be developed through multi-level priors of spatial-specific parameters in the spatial catch-at-age model. A modeled 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.

The dynamics of the weakfish stock will be described by the stock-recruitment model, together with a numbers-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). 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 the 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 following the flexible age-structured stock assessment model. Eight mathematical models will be developed to simulate the recruitment dynamics: 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). Other approaches that may be identified in course of the study will also be considered. These models will be compared based on the Deviance Information Criteria (DIC). If the DICs differ greatly, one of the models with the lowest DIC will be used for population projection; if the DICs are close, a model averaging approach may be used (Jiao et al. 2008 and 2009).

Recruitment modeling responses to environmental factors such as water temperature; the North Atlantic Oscillation, and predator-prey relationships (striped bass, menhaden, etc) were included in the previous proposal of this project. Meanwhile, the 2006 stock assessment committee had developed a predator-prey model. We therefore added the predator-prey-environmental recruitment model (listed above) to investigate possible factors other than spawner stock that influence the recruitment dynamics of weakfish. This is one of the primary recruitment models to be included in the comparison. The environment and biotic factors other than predation may or may not contribute significantly to recruitment variation. A final selection of the best recruitment model will be decided after comparing all models.

### Statistical estimator

We will mainly use a Bayesian approach to fit the model to data collected from different sources. State-space time-series models (such as equation 2, which comprises process error, and equation 3, which comprises time-varying catchability) explicitly require a Bayesian estimator (De Valpine and Hasting 2002). We will also use the frequentist method when only observation errors are considered. The principal 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, i.e., 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 advantage (McAllister and Kirkwood 1998, Chen et al. 2004).

The Bayesian approach uses a probability rule (Bayes' theorem) to calculate a "posterior" distribution of model parameters from the combination of observed data and a "prior" distribution, i.e., a summary of the prior knowledge about the parameters (McAllister and Kirkwood 1998, Gelman et al 2004). Two types of prior distribution are commonly used in a Bayesian stock assessment: non-informative and informative priors (Scheweder 1998, Gelman et al 2004). Whether a parameter will have a non-informative or informative prior will be determined by the reliability and details of prior knowledge, which may come from various sources including fishermen's experience, previous studies of the fishery, and knowledge of similar species and fisheries. If a non-informative prior must be used it is usually applied as a uniform distribution, the lower and upper boundaries of which are based on biological theory or knowledge of fish stocks (Hilborn et al. 1993).

Normal distribution function (bell curve)

$$(15) \quad P(Y, X | \beta, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{[Y - f(X, \beta)]^2}{2\sigma^2}\right)$$

will be used for log-transformed catch, CPUE data and the predicted stock abundance. If data prove to be sensitive to the normal distribution we will switch to the  $t$  distribution, which is similarly shaped but more robust to atypical errors (Hilborn and Walters 1992, Quinn and Deriso

1999, Chen et al. 2000) 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,  $\tau_t$  (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

$$(16) \quad P(X | \beta) = \frac{1}{\sqrt{2\pi P_{a,t}^{Obs} (1 - P_{a,t}^{Obs}) + 0.1/n}} \exp \left[ \frac{-\tau_t (P_{a,t}^{Obs} - P_{a,t}^{Pred})^2}{2[P_{a,t}^{Obs} (1 - P_{a,t}^{Obs}) + 0.1/n]} + 0.01 \right],$$

where  $X$  is the catch-at-length or catch-at-age composition data from the fishery or from a fishery-independent survey, and  $n$  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 and/or  $t$  distribution functions will also be used for log-transformed CPUE data in the catch-data-free population growth models and for log-transformed recruit data in the recruitment models.

### 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 Atlantic coastal states (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 sources of information have been discussed in ASMFC (2006) and NEFSC (2003) stock assessment documents and are available to this project. Original data will be requested by Rob O'Reilly, who works at the Virginia Marine Resources Commission and has been involved in weakfish stock assessment for many years.

Other information required for 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, and release mortality. These data have been collected by ASMFC, NMFS, state agencies and academic researchers, and will be available to this project.

### Harvest control rule and fishery status evaluation

Amendment 4 to 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

$$F_{threshold} = F_{20\%} = 0.5, \text{ and a spawning stock biomass threshold of } SSB_{threshold} = SSB_{20\%} = 31.8$$

million pounds. Thus, an  $F$  greater than 0.5 means overfishing is ongoing and a  $SSB$  less than 31.8 million pounds means the stock has been overfished (Figure 1).

The current stock status evaluation approach did not consider the uncertainty involved in these indicator reference values (e.g.,  $F$ ,  $B$ ) and biological reference values (e.g.,  $F_{msy}$ ,  $SSB_{1995}$ ).

Our proposed study will fulfill this requirement. Stock status will also be evaluated in terms of a risk assessment in this study. Risk in statistics is defined as the probability that the observed value will be larger or smaller than a given reference value. In this study, risk is determined to be the probability of fishing mortality ( $F$ ) in a given 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 as a reference point;

$P(SSB < SSB_{threshold})$  when  $SSB_{threshold}$  (spawner population abundance of a given 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 enable uncertainty to be fully considered in decision-making process.

Other  $F$  and  $B$  based reference points will be considered to analyze the fishery status in terms of overfishing (F-based) and overfished (B-based), such as  $F_{msy}$ ,  $F_{max}$  and  $F_{0.1}$ ,  $F_{\%}$ , and  $SSB_{msy}$ . Threshold values for reference points will be evaluated to further improve current status assessments of the weakfish fishery.

When estimating  $F_{msy}$  based on Shepherd (1982), the age-structured model result will be used to develop a stock-recruitment relationship. To develop an age-structured model individual growth for each area can be simulated based on the data estimates; however for areas without individual growth data available, a hierarchical individual growth model will be developed. If the hierarchical structured model is selected as the operational model for further stock assessment then in parallel, the hierarchical individual growth model should be used for the whole population.

New reference points (beyond those of Amendment 4) are necessary and are important for helping to improve our understanding of the fishery's status. Biological reference point estimation will be linked to the regimes of natural mortality variation and the productivity changes over time. Management will be improved by linking the management process with natural variations of the population, such as those caused by climate / ocean oscillations or food chain dynamics.

### **Simulation and sensitivity study**

This study involves using the proposed model to fit different sets of weakfish observation data and model parameters that characterize the weakfish population dynamics. We will have specific focus on the influence of the aging error, natural mortality assumption, and catchability assumption (ASMFC 2006). We will investigate the influence of Marine Recreational Fisheries Statistics Survey (MRFSS) data since they, which have previously been treated as very uninformative but was are regarded as one of the better data sources because of its wider spatial coverage in the weakfish stock assessment (NRC 2006, ASMFC 2006). The impacts of using either random error assumptions or autocorrelated error assumptions on the formulation of likelihood functions and subsequent parameter estimation will be compared. We will evaluate the management consequences of the above factors to inform fisheries managers about the relative risks associated with any choice.

Uncertainty caused by aging error will be analyzed through a simulation study. Simulated "true" length-age data based on the statistical catch-at-age model will be augmented with different levels of random error. We will then estimate stock parameters and population size from these simulated data with error, and investigate the influence of aging error on the weakfish stock by evaluating the difference between parameters calculated with and without aging error. The estimated probabilities of aging bias will be linked to the converted catches-at-age, and the corresponding bias in the result will be analyzed as a sensitivity factor. With this analysis, we will be able to determine how sensitive the stock assessment result is to bias caused by the aging method. At the same time, we will investigate the performance of using non-age-structured catches, CPUEs, 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 aging error when a statistical catch-at-age model is used.

The modelling and statistical approaches may be modified based on the simulation and sensitivity analysis results to ensure that the models effectively capture the weakfish stock dynamics and are not too sensitive to errors in the data and or assumptions of hypotheses. Possible modifications may include considering both data quality (variance from surveys and fishermen's and scientists' experience) and model fit if one data set shows a contrary trend or causes divergent results (Polacheck et al. 1997, Richards 1991). Robustness of the reference points and robustness of the estimated risks when different reference points are used will both be investigated. The resulting assessment model and statistical approach fine-tuned in this study will be presented and recommended 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 carried out 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 fellow and the Ph.D. student, as well as 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 in regular communication to review the project's progress. Weakfish stock assessment subcommittee members, e.g., Dr. Jeff Brust (Chair of the stock assessment subcommittee), Dr. Desmond Kahn (DE Dept. Natural Resources), Jim Uphoff (MD Dept. Natural Resources), Dr. Victor Crecco (CT Dept. Environmental Protection), 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. Dr. Jiao, the project leader, has attended the weakfish subcommittee meeting on January 7-8, 2008, and the weakfish data workshop organized by ASMFC in July 2008. This project will also involve Dr. Jim Berkson, the leader of the NMFS Recruiting Training and Research Unit at Virginia Tech, for student training purposes.

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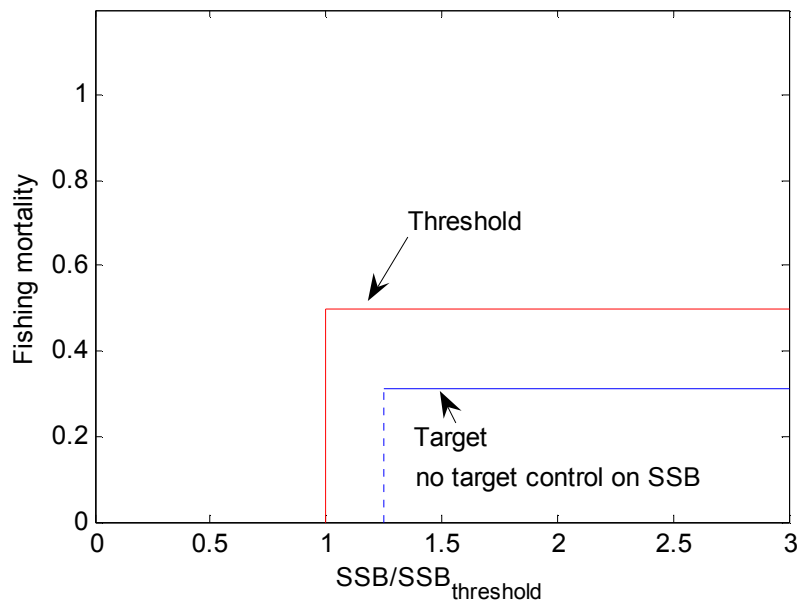
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**Table 1. Timetable (01/01/2008 – 12/31/2010)**

<b>Project component</b>	<b>Responsible persons</b>	<b>3</b>	<b>6</b>	<b>9</b>	<b>12</b>	<b>3</b>	<b>6</b>	<b>9</b>	<b>12</b>	<b>3</b>	<b>6</b>	<b>9</b>	<b>12</b>
1) Literature search; recruit a postdoc	Jiao, Orth, O'Reilly	✓											
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'Reilly, 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											✓	✓
<b>Project Disseminations</b>													
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 NARRATIVE (YEAR 1)—Jiao, Orth and O'Reilly  
(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 accordance 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, Orth and O'Reilly  
(From Jan 1, 2009 to December 31, 2009)

**1) Personnel:**

Salaries: **\$ 68,536**

Dr. Jiao 10% year time salary; Dr. Orth 2% 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: \$19,113

Postdoc Research Associate: fringe rate = 35%

Tenure faculty: fringe rate = 35.25%

Graduate student: fringe rate = 6.75%

**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: \$550 (Virginia Tech cost share)**

Software maintenance

**5) Other Costs: \$8,728 (student tuition)**

**Total Direct Costs = \$104,701 (VMRC) + \$550 (Virginia Tech cost share)**

**6) Indirect Costs: \$26,175 (VMRC) + \$29,969 + \$322(Virginia Tech cost share)**

VMRC Indirect Rate @ 25%

Virginia Tech Indirect Rate @ 58.5%

**Total Costs: \$130,876 (VMRC) + \$30,841 (Virginia Tech cost share)**

BUDGET NARRATIVE (YEAR 3)—Jiao, Orth and O'Reilly  
(From Jan 1, 2010 to December 31, 2010)

**1) Personnel:**

Salaries: **\$ 56,626**

Dr. Jiao 10% year time salary; Dr. Orth 2% 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: \$14,398

Postdoc Research Associate: fringe rate = 35%

Tenure faculty: fringe rate = 35.25%

Graduate student: fringe rate = 6.75%

**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: \$580 (Virginia Tech cost share)**

Software maintenance

**5) Other Costs: \$9,561 (student tuition fee)**

**Total Direct Costs = \$89,085 (VMRC) + \$580 (Virginia Tech cost share)**

**6) Indirect Costs: \$22,271 (VMRC) + \$24,250 +\$339(Virginia Tech cost share)**

VMRC Indirect Rate @ 25%

Virginia Tech Indirect Rate @ 58.5%

**Total Costs: \$111,356 (VMRC) + \$25,170 (Virginia Tech cost share)**

## **Appendix 1: Summary of the first 15 months accomplishments (1/1/2008 ~ 3/30/2009)**

The overall scope of first and second year (3 months) accomplishments is summarized on page 3. The following are descriptions of specific tasks completed and undertaken.

### **Data sets received:**

A “weakfish data CD” has been received that provides historical data used for previous stock assessments. This data CD comprises three parts: biological survey (fishery-independent) data, harvest (commercial) data, and biological indices.

Catch rate survey data have been received with help of the ASFMC from the state agencies in RI, NJ, DE (adult and juvenile surveys), MD (adult and juvenile surveys), NC (adult and juvenile surveys), CT, NY, and VA; and from the coast-wide SEAMAP, NMFS, and MRFSS surveys.

The PI, Dr. Yan Jiao participated in the two weakfish data workshops in 2008, and attended the weakfish Stock Assessment Subcommittee (SAS) meeting on April 1, 2009. At these meetings the catch and bycatch data were updated and made available to the weakfish stock assessment improvement project.

### **Progress and project tasks have been completed for this period**

In the last 15 months, we have attended two weakfish stock assessment subcommittee meetings (January 7-8, 2008, October 28, 2008, and April 1, 2009), and a weakfish data workshop (July 14-17, 2008). Dr. Jiao, the Principal Investigator, has been an invited member of the weakfish SAS since fall of 2008, and will attend the next stock assessment meeting in June 2009. At these meetings Dr. Jiao gave presentations on our project and collaborated with the subcommittee to share data and research objectives for improving the weakfish stock assessment. Some of our project results are being used for the next weakfish stock assessment led by the Atlantic States Marine Fisheries Commission.

**The following project tasks on data request, and synthesis have been completed:** (1), Multi-year data on commercial and recreational catches and discards, as well as survey indices of relative abundance and sex-age-length-weight relationships, have been received by the principal investigator for all Atlantic coast states which harvest weakfish, and they have been updated twice based on the progress of the current SAS stock assessment data workshops. (2), A post-doctoral researcher, Andreas Winter, has been hired at Virginia Tech to focus on spatial analyses of the weakfish catch and survey data. (3), Undergraduate students, Rich Pendleton and Jon Yu have been contracted through the department work-study program at Virginia Tech to prepare initial summaries of the data sources, and compare differences in individual growth of weakfish reported from different states. (4), Two graduate students have been trained to participate in components of the project that relate to their research backgrounds. Hao Yu participated in the Catch Rate Standardization research together with Andreas Winter. Qing He participated in the application of AdaBoost in analyzing high % zero catch issues using SEAMAP survey data as an example.



**The following project tasks on modeling analyses are accomplished or in progress:**

(1), We have completed the random-walk population growth state-space surplus production model (RWSSSPM).

Currently used population dynamics models usually assume that population growth rate is constant. But in reality, it varies because of climate changes and/or fluctuations in predation intensity. The RWSSSPM model allows us to evaluate a population growth rate that is changing over time, which is an important consideration for weakfish. Our modeling results showed that the RWSSSPM model fit the data better than a commonly used surplus production model with a constant population growth (low DIC value), with population growth rate of weakfish varying over time and the recent population growth rate decreasing (Figure A1).

(2), We have completed catch rate modeling analyses for the 3 coast-wide and 11 state-agency survey databases received. The catch rates are modeled with generalized linear models (GLM) and generalized additive models (GAM) using a delta-lognormal approach. The delta-lognormal approach is a two-step method that separately models the presence vs. absence of weakfish in all catch samples, and the weakfish catch numbers in those samples that caught at least one. This method is particularly useful for data that have many ‘zero’ catches, which are difficult to fit to a single distribution.

The analyses are motivated by the need to standardize catch rates. Currently, the geometric mean of a survey catch rate is used as the Catch-per-Unit Effort (CPUE) or abundance index for weakfish stock assessment. However, the catch rate of weakfish in a trawl survey is potentially influenced by many factors. For example, in the New Jersey survey dataset we found that besides year, which is the variable of interest, month, latitude, longitude, tow depth and tow duration were statistically significant factors influencing the catch rate of weakfish. Before using the survey dataset for stock assessment as an indicator of yearly population abundance, the influence of these other factors therefore needs to be excluded. Figure A2 shows that the New Jersey weakfish catch rate is highly correlated with the month. If a survey in a given year only happens in the fall season, while in other years the survey is year-round, then the year with the survey only in the fall will be highly biased. Figure A2 also shows that catch rate is correlated with longitude and latitude. If a survey in a given year occurs only in the southwest sector of New Jersey waters, while in the other years the survey is distributed throughout the state waters, then the year with the survey only in the southwest would again be highly biased. Standardizing catch rates by including factors such as month and longitude / latitude in a GLM or GAM, then subtracting their influence, allows for these biases to be removed and the yearly trend alone to be estimated.

Longitude and latitude are particularly important factors because of the effect of spatial autocorrelation. Catch samples taken in locations that are close together are likely to have similar numbers of fish, i.e., they are autocorrelated. However, statistical catch models are based on the assumption that data from all locations are independent. Violating this assumption may result in bias when catches from nearby locations are included in the database, which are not independent. Table A1 shows that in many years of the SEAMAP trawl survey catch numbers were ‘clustered’, i.e., they had significant spatial autocorrelation. Results were similar for the other surveys. The GLM and GAM catch rate standardizations therefore included longitude and latitude for every survey in which they were recorded. Other variables commonly recorded in the surveys were sampling depth, tow or set duration, temperature, salinity, and dissolved oxygen.

GLM and GAM catch rate standardizations were compared for each applicable<sup>1</sup> survey using the Akaike Information Criterion (AIC). GAM, which allows for non-linear fitting, was found to have a lower AIC than GLM in nearly every case (Table A2) and was therefore selected as the preferential model. Further analyses in progress will compare the  $R^2$  values and standard errors of the models. Both GAM and GLM catch rate standardizations were found to increase the consistency in year-to-year abundance trends among surveys. For example, Figure 3A shows plots of yearly catch rates from the NMFS survey vs. the NJ survey, and the MRFS survey vs. the NJ survey, over the range of years in which they overlapped (1988 to 2006). Pair-wise correlations between surveys were not strong when all years were included. However, when only high- or low-catch years were included (black circles in Fig. 3A) NJ data had a positive relationship with MRFSS data, and a negative relationship with NMFS data, and these relationships were much stronger with GAM-standardized catch rates than with geometric means of the catch rates. The results suggest that exceptionally strong or weak yearly catches occur in relation to environmental conditions, and are likely to be positively or negatively in phase among different areas along the coast, while mediocre yearly catches are haphazard.

A working document with these analyses has been sent to SAS and ASFMC for use in the next stock assessment of weakfish.

(3), We are working on juvenile index and abundance index long-term trend analyses through hierarchical models.

We are developing models to elucidate the overall trend of weakfish population abundance over time. Because each state has its own survey, with differences in survey methods and spatial locations, abundance trends from different states can be different, and none are by themselves representative of the entire weakfish population along the Atlantic coast. We are using two methods to analyze the overall population trend through time. The first method is to synthesize all survey data from all states in a single generalized linear or generalized additive model (as described above) and add the state as a fixed variable in the model. The second method is to use a hierarchical model. In this model, the overall Atlantic population is treated as a super-population, wherein each state is treated as a hierarchically structured subsample of the population. The resulting structured trend of the super-population will then be representative of the whole population. Development of this analysis is currently in progress.

(4), We are working on quantitative analysis of the spatial structure of individual fish growth, based on the biological survey data from different states. The purpose of this analysis is to obtain more accurate and more justifiable estimates of biological parameters that may need to be “borrowed” from one state to another; for example growth rates that are needed to forecast a state’s population trend, but have only been measured in a neighboring state.

Initial work consisted of synthesizing the various age-length data sets from each state. Age-length frequency distributions have been calculated for each data set to evaluate which states may have the most comparable weakfish populations. Survey data, and especially fishery data, may include several gear types such as trawls, fish traps, pound nets and gillnets, seasons defined as ‘early’ or ‘late’, and span 3 or 4 years of data collection. Different gear types tend to catch different size distributions of fish, resulting in apparent growth function differences. One consistent trend that has been detected among age-length distributions of various states is a disjunction in the age-length relationship between weakfish >600-650 mm total length, and those

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<sup>1</sup> Some surveys comprised only categorical data, in which case calculating either a GLM or a GAM is identical.

<600-650 mm (Figure A4). A new graduate student is presently being recruited to analyze weakfish age-length distributions. Approaches to the analysis include bootstrapping lengths at age per dataset to measure variability of the growth functions, and using likelihood ratio tests to determine the significance of differences in growth, or sizes at age, among the different states.

Table A1: Moran's Index results for spatial autocorrelation of SEAMAP annual survey trawl catches.

Year	catch numbers per trawl		
	Z score	<i>p</i>	distribution
1990	4.72	< 0.01	clustered
1991	0.49		random
1992	-0.46		random
1993	3.77	< 0.01	clustered
1994	0.20		random
1995	4.95	< 0.01	clustered
1996	2.81	< 0.01	clustered
1997	0.54		random
1998	-0.03		random
1999	-0.97		random
2000	2.72	< 0.01	clustered
2001	-0.64		random
2002	-0.16		random
2003	4.49	< 0.01	clustered
2004	1.72	< 0.01	clustered
2005	8.69	< 0.01	clustered
2006	2.28	< 0.01	clustered

Table A2. Comparison of AIC from GLM and GAM for surveys in which both models were used. The lowest AIC by row (for positive catch or presence/absence) is highlighted in yellow.

Surveys	GAM		GLM	
	Positive catch	Present/Absent	Positive catch	Present/Absent
MRFS	11628.0	10206.5	12433.3	11998.2
NMFS	3793.7	1454.7	4114.3	1684.7
SEAMAP	7580.2	5260.9	7695.5	5741.7
NJ	4351.8	2683.6	4459.0	2895.0
DE 30 ft.	5368.0	1358.4	5466.9	1429.9
CT	2547.5	2028.3	2576.0	2171.8
DE 16 ft.	14766.8	4216.0	14680.9	4343.2
VIMS	27277.8	15451.7	27541.2	16781.5
NC juv.	4764.1	*	4837.9	*
NC gill.	1902.0	2414.4	1928.0	2524.7

\* Not used because no zero catches were recorded.

Figure A1: The estimated population growth rate variation from a time-varying population growth model. The hard line is the posterior mean of the population growth rate; the dotted lines the 95% credible interval of the population growth rate.

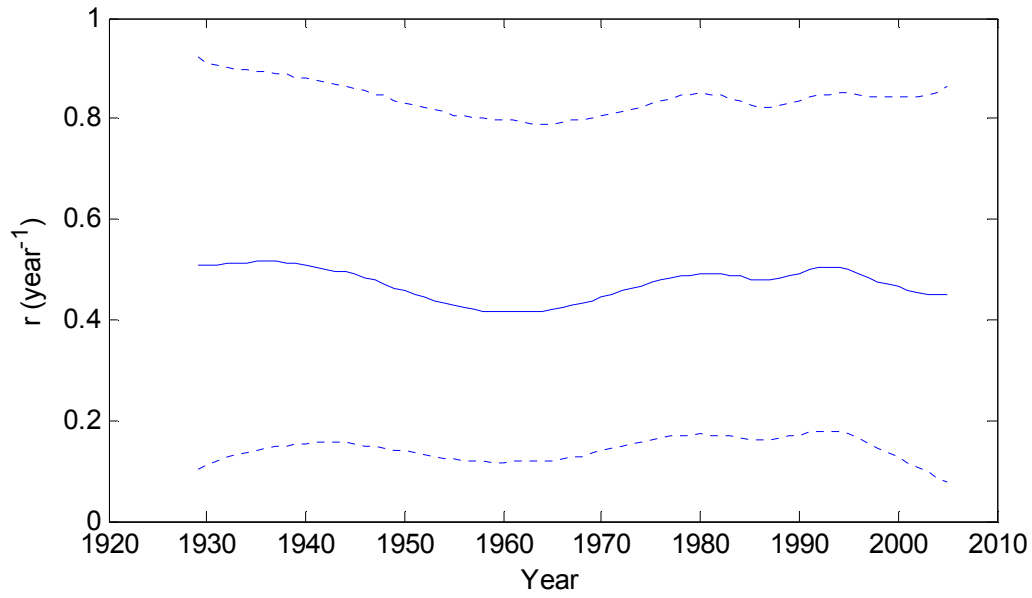


Figure A2: A comparison of CPUE yearly trend from the New Jersey trawl survey, based on four different methods. GLM: generalized linear model; GAM: generalized additive model.

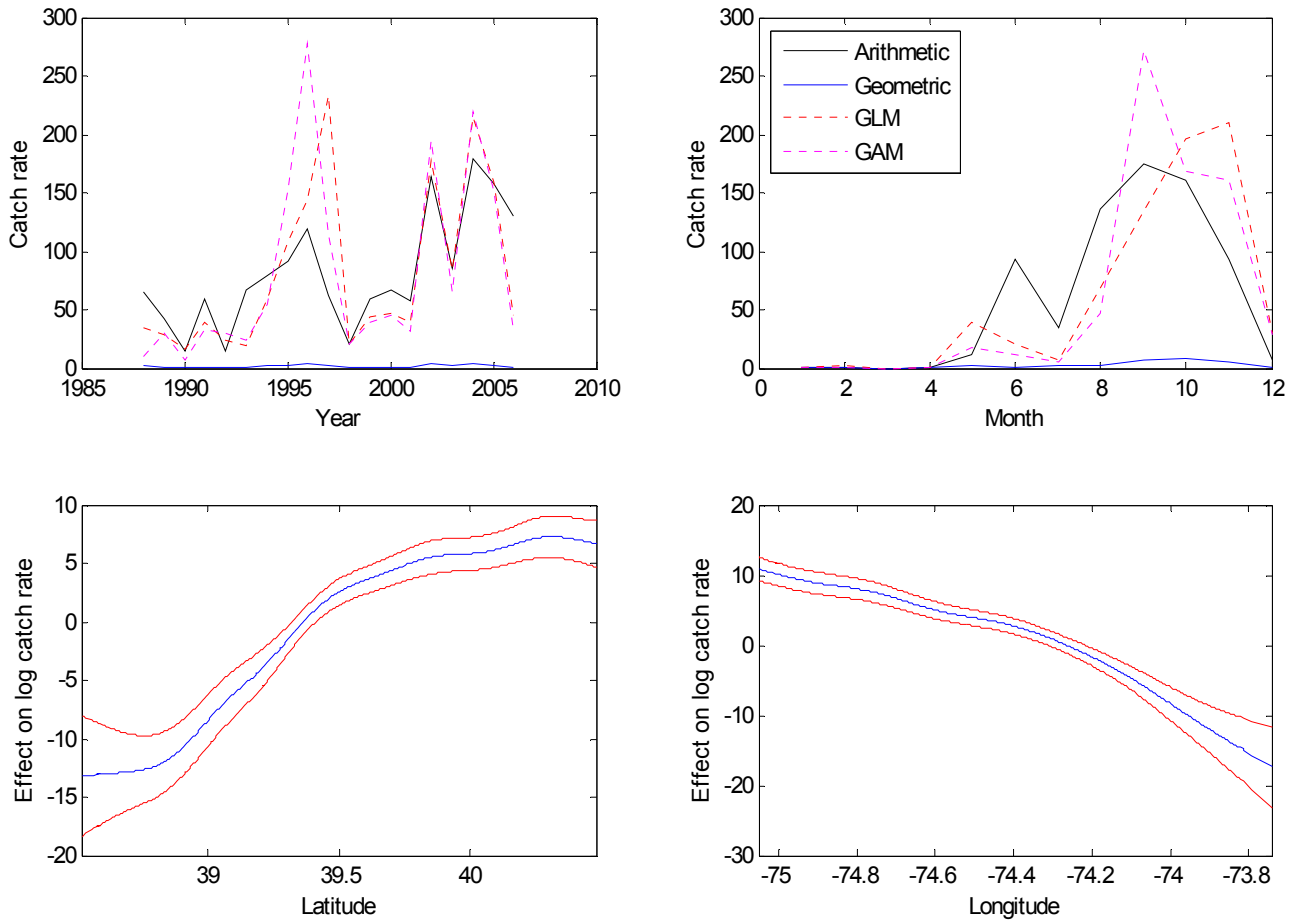


Figure A3. Pairwise plots of NMFS vs. NJ and MRFSS vs. NJ yearly catch rate indices, with black shading indicating the salient (high or low) indices that are most likely to have significant correlations (shown as dotted lines).  $R^2$  values of correlations calculated for the salient indices are shown on each plot.

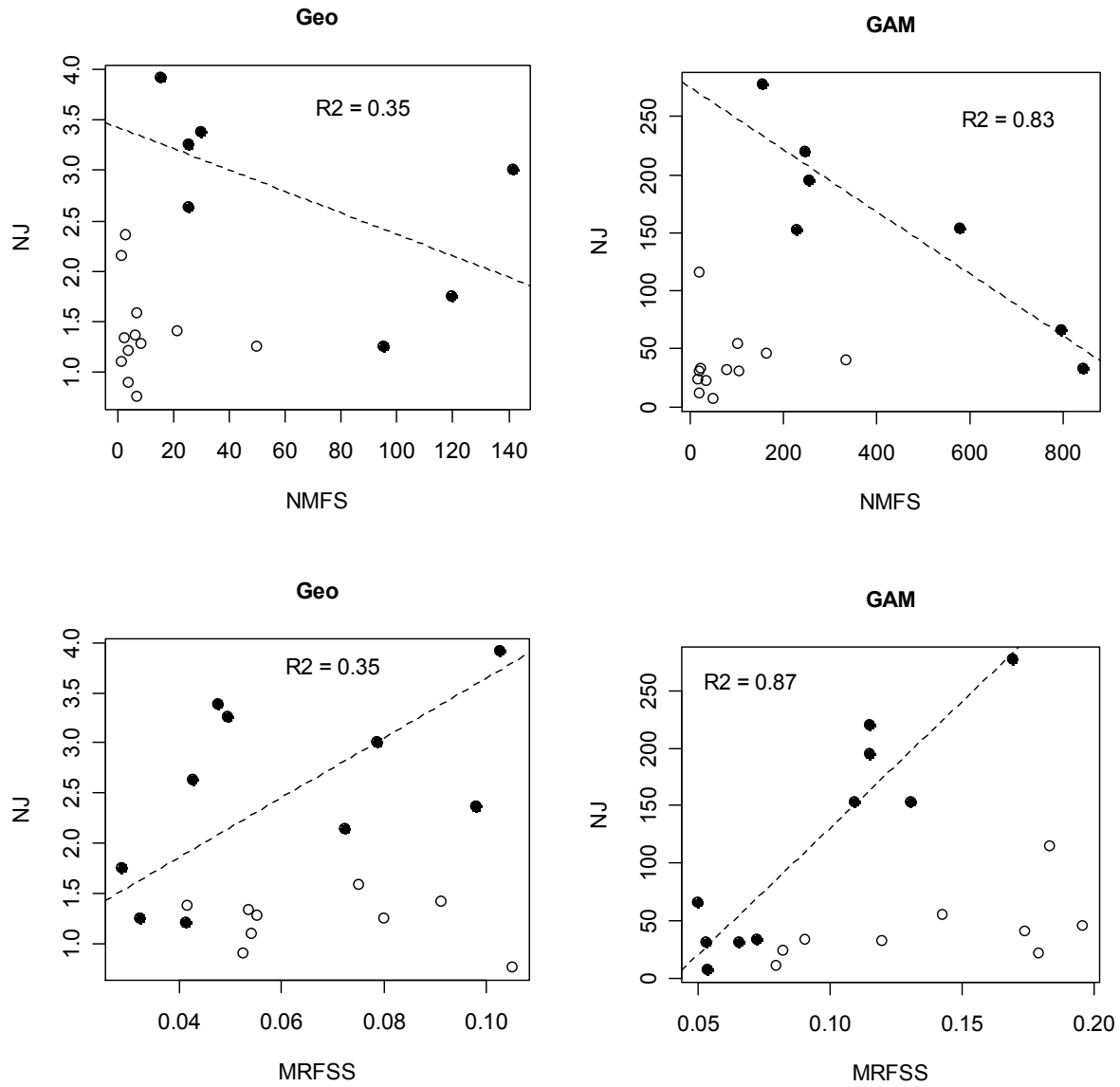


Figure A4: Lengths-at-age denoted by gear type for three states: Maryland, Virginia, and North Carolina, and growth functions fitted separately to lengths >600-650 mm and <600-650 mm. Lengths-at-age of a fourth state, Rhode Island, show a more continuous growth function with only one gear type having been used.

