Supplementary Material

Table S1. Data sources for biomass estimates used in SPiCT models or application of the direct method. Biomass estimates for species not listed here came from the NEFSC fall bottom trawl survey. "Both" refers to species for which both the NEFSC spring and fall bottom trawl surveys were used.

Species	EPU	Data Source
Acadian Redfish	SS	Both
American Plaice	GOM	Both
Atlantic Herring	MAB	Both
Atlantic Herring	SS	Both
Atlantic Herring	GB	Both
Atlantic Surf Clam	MAB	NEFSC clam survey
Atlantic Surf Clam	GB	NEFSC clam survey
Barndoor Skate	SS	Both
Blue Crab	MAB	VIMS/Maryland DNR Chesapeake Bay winter dredge survey
Clearnose Skate	MAB	Both
Haddock	GB	Both
Ocean Quahog	MAB	NEFSC clam survey
Ocean Quahog	GB	NEFSC clam survey
Pollock	SS	Both
Red Hake	GOM	Both
Sea Scallop	MAB	NESFC scallop dredge survey
Sea Scallop	GB	NESFC scallop dredge survey
Silver Hake	GB	NEFSC spring
Spiny Dogfish	MAB	NEFSC spring
Spiny Dogfish	GOM	Both
Striped Bass	MAB	ASMFC stock assessment
Weakfish	MAB	Both
White Hake	SS	Both
White Hake	GB	Both

Table S2. Natural mortality values used for estimating production. Values were derived from recent stock assessments or calculated using Jensen's (1996) estimate of the second Beverton and Holt invariant applied to published von Bertalanffy growth parameters. Some species had specific values for each Ecological production unit (in parentheses)

Species	M	Species	M	Species	M
Acadian redfish	0.05	Fourspot flounder	0.25	Sea scallop (MAB)	0.2
Alewife	0.5	Goosefish	0.3	Silver hake	0.4
American lobster	0.25	Haddock (GOM)	0.2	Smooth dogfish	0.22
American plaice	0.225	Haddock (GB)	0.2	Spiny dogfish	0.092
Atlantic cod (GOM)	0.2	Jonah crab	0.7	Spot	1.09
Atlantic cod (GB)	0.2	Little skate	0.29	Spotted hake	0.3
Atlantic croaker	0.3	Longfin squid	3.6	Striped anchovy	1.5
Atlantic herring	0.2	Northern searobin	0.45	Striped bass	0.3
Atlantic mackerel	0.2	Northern shortfin squid	5	Summer flounder	0.25
Atlantic rock crab	0.7	Northern shrimp	0.6	Thorny skate	0.18
Atlantic surfclam	0.15	Ocean quahog	0.02	Weakfish	0.43
Barndoor skate	0.21	Ocean quahog (SS)	0.03	White hake	0.2
Bay anchovy	1.41	Pollock	0.2	Winter flounder (MAB)	0.3
Black sea bass	0.4	Red hake	0.29	Winter flounder (GB)	0.3
Blackbelly rosefish	0.17	Rosette skate	0.2	Winter flounder (GOM)	0.3
Blue crab	0.9	Round herring	1.4	Winter skate	0.11
Bluefish	0.2	Sculpins	0.86	Witch flounder	0.15
Butterfish	1.22	Scup	0.2	Yellowtail flounder (GB)	0.4
Clearnose skate	0.26	Sea raven	0.19	Yellowtail flounder (GOM)	0.2
Cownose ray	0.2	Sea scallop (GB)	0.16	Yellowtail flounder (MAB)	0.4

Text S1. The following section describes the simulation model structure and functions, followed by tables listing symbol definitions and values used for this study. Simulations were performed with R in Rstudio. All simulations began with the same starting population abundance determined by multiplying the unfished equilibrium recruitment number by the equilibrium population structure vector (***l***).

$$N_{t,y=1} = R_0 * \boldsymbol{l}$$

The equilibrium population structure vector comprised proportions, beginning with 1 and declining to 0 following the function for instantaneous natural mortality (*M)*.

$$\boldsymbol{l_t} = l_{t-1}e^{M(t,y=1)}$$

The natural mortality function began high and declined exponentially toward an asymptote equal to adult natural mortality with a normally distributed random term representing the quality of growth and mortality in a year (Q) and an additional normally distributed random term scaled with age (φ_M).

$$M_{t,y} = \left(M_{juv}e^{-st} + M_{adu}\right)Q_y + \varphi_{M^t}$$
$$\varphi_{M^{(t)}} = \mathrm{N}(0, dM_{t,Q_y=1})$$
$$Q_y \sim \mathrm{N}(1, {\sigma_Q}^2)$$

Combining the equation for instantaneous natural mortality with the equation for instantaneous fishing mortality enabled the calculation of yearly abundance (*N*) for each cohort.

$$N_{t+1,y+1} = N_{t,y}e^{-(F_{t,y}+M_{t,y})}$$

The equation for instantaneous fishing mortality followed a logistic form with a recursive total fishing pressure term (ε_F) and an additional random term for each age class, each year (φ_{F_1}).

$$F_{t,y} = \left(a_1 + \frac{a_2 - a_1}{1 + ce^{-by}}\right)\varepsilon_{F^{(y)}} + \varphi_{F_1}$$
$$\varepsilon_{F^{(y)}} = \varepsilon_{F^{(y-1)}} + \varphi_{{F_2}^{(y)}}$$
$$\varepsilon_{F^{(y=0)}} = 1$$
$$\varphi_{F_1} \sim \mathrm{N}(0, {\sigma_{F_1}}^2)$$
$$\varphi_{F_2} \sim \mathrm{N}(0, {\sigma_{F_2}}^2)$$

To model recruitment, we calculated a maturity ogive vector $\boldsymbol{m}$. For simplicity, we used static maturity at age throughout each simulation.

$$\boldsymbol{m}_{(t)} = \frac{1}{1 + e^{\frac{t_{mat} - t}{m_{slope}}}}$$

Combining maturity and abundance at age enabled a Beverton-Holt style stock-recruit model (Goodyear 1993) with random lognormal variation.

$$R_{(y)} = \frac{S_0 E_y}{1 + E_y \beta} e^{\varepsilon_{R^{(y)}} - 0.5{\sigma_R}^2}$$
$$E_y = \sum \boldsymbol{m} * N_y$$
$$S_0 = \frac{g}{\phi}$$
$$\phi = \boldsymbol{m} \cdot \boldsymbol{l}$$
$$\beta = \frac{g - 1}{R_0 * \phi}$$
$$\varepsilon_R \sim \mathrm{N}(0, {\sigma_R}^2)$$

Weight at age followed the von Bertalanffy growth equation for body weight with the same quality coefficient for natural mortality that was explained previously, making growth and survival interdependent.

$$W_{t,y} = W_\infty(1 - e^{-Q_y kt})^3$$

The weight at each age for the first year was randomly determined using $Q = 1$ and inputted into the first row of matrix $\boldsymbol{W}$.

$$\boldsymbol{W}_{t,y=0} \sim \mathrm{N}(W_{Q=1}, h_{y=0}W_{Q=1})$$

The weight at age for each recruitment class was randomly determined using the previous year's quality of growth, assuming it would influence recruitment through parental condition or some other mechanism.

$$\boldsymbol{W}_{t=0,y} \sim \mathrm{N}(W_{Q_{y-1},t=0}, hW_{Q_{y-1},t=0})$$

The weight at age for each cohort increased recursively following the von Bertalanffy growth equation with another random term in addition to the randomly determined year quality.

$$\boldsymbol{W}_{t,y} = W_{t,y} + W_{t-1,y-1} - W_{t,Q=1} + \varphi_{W^{(t)}}$$

$$\varphi_{W^{(t)}} \sim \mathrm{N}(0, h(W_t - W_{t-1})$$

An index of biomass (***B***) was determined by simply multiplying weight at age by abundance at age.

$$B = \boldsymbol{W}_{\boldsymbol{t,y}} N_{t,y}$$

A survey index ($\boldsymbol{I_{obs}}$) was simulated assuming lognormal sampling error and application of a catchability coefficient.

$$\boldsymbol{I}_{\boldsymbol{obs}_{\boldsymbol{y}}} = q \sum_{t=0}^{tmax} (\boldsymbol{B}_{t,y})\, e^{\,\varepsilon_I - 0.5{\sigma_I}^2}$$

$$\varepsilon_{I^{(y)}} \sim \mathrm{N}(0, {\sigma_I}^2)$$

Finally, annual catch at age (***C***) was calculated with Baranov's catch equation.

$$\boldsymbol{C}_{t,y} = N_{t,y} \frac{F}{F+M} (1 - e^{-(F_{t,y} + M_{t,y})})$$

SPiCT models were then fit to the survey and catch indices and converted to production using the SP conversion and direct methods for comparison to real production calculated using the increment-summation method. SPiCT models that accurately predicted biomass (normalized root mean square deviation < 0.2) were selected for full analysis because the goal of this study was to evaluate our new production estimation methods, not to validate the effectiveness of the SPiCT model.

Table S3. Description of the variables used in the simulation equations

Symbol	Description
N	Abundance
t	Age
y	Year
R_0	Unfished equilibrium recruitment
$\boldsymbol{l}$	Equilibrium population age structure
M	Instantaneous natural mortality
M_{juv}	Additional early-juvenile mortality
M_{adu}	Adult natural mortality
Q	Year quality
s	Mortality curve parameter (shape)
d	Variance coefficient for M
F	Instantaneous fishing mortality
a_1	Lower asymptote for F
a_2	Upper asymptote for F
c	Curve Horizontal shift parameter
b	Curve shape parameter for F
$\boldsymbol{m}$	Maturity vector (proportions)
t_{mat}	Age at 50% maturity
m_{slope}	Slope of maturity function
R	Recruitment
S_0	Unfished spawning biomass
E	Spawners
g	Goodyear (1993) stock-recruit parameter
R_0	Unfished equilibrium recruitment
W	Mean cohort weight
W_∞	Asymptotic weight
k	Growth curve parameter
$\boldsymbol{w}$	Matrix of cohort weights at age
h	Variance coefficient
$\boldsymbol{B}$	Matrix of biomass
$\boldsymbol{I}_{obs}$	Vector of observed relative biomass
q	Catchability coefficient
t_{max}	Maximum age
$\boldsymbol{C}$	Catch matrix

Table S4. Parameter values utilized for the four simulated scenarios; Large and small species with low and moderate stochasticity.

Species: Variability: **Symbol**	**Large** **low,moderate**	**Small** **low,moderate**
${\sigma_Q}^2$	0.01,0.05	0.01,0.05
${\sigma_{F_1}}^2$	0.01,0.1	0.01,0.1
${\sigma_{F_2}}^2$	0.01,0.05	0.01,0.05
${\sigma_R}^2$	0.01,0.8	0.01,0.8
${\sigma_I}^2$	0.05,0.2	0.05,0.2
W_∞	15	1
k	0.3	1
M_{juv}	0.3	1.0
M_{adu}	0.25	0.325
d	0.01,0.1	0.01
s	0.8	1.1
a_1	0.05	0.05
a_2	0.2	0.2
c	Inflection point of growth curve	
b	0.8	0.8
R_0	10^7	10^7
g	5	5
t_{mat}	Inflection point of growth curve	
t_{max}	25	7
m_{slope}	0.7	0.7
h	0.05	0.05
h_o	0.01	0.01
q	0.2	0.2

References:

Goodyear CP (1993) Spawning stock biomass per recruit in fisheries management: foundation and current use. Publ Spec Can Sci Halieut Aquat 120:67–81