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A simulation model used to evaluate assessment and management procedures for the Pacific swordfish fishery[1]

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A simulation model is currently being developped to help evaluate the performance of stock-assessment methods and potential management procedures in the 'data poor' context of the Pacific ocean swordfish fishery. This paper summarizes the main features of this model, as well as its underlying hypotheses, limitations and current user interface.

Historical background and model features

In early 1998, the fisheries research staff of the Honolulu Laboratory of the National Marine Fisheries Agency initiated a project aimed at providing advice on the stock status of the Pacific swordfish (*Xiphias gladius*) population and its supported fisheries. Several agencies in the Pacific are engaged in stock monitoring and data collection activities aimed at providing information on this species and its supported fisheries. However, there remains much uncertainty on the demographic traits of this species, the structure and movement patterns of the stock(s), the link between fishing effort and harvest rates, and the stock/fishery interactions.

Given the well recognized shortcomings of conventional stock-assessment methods in such contexts, there is a need to design alternative methods that make better use of existing data. This uncertainty also precludes fishery agencies from relying on conventional stock status indicators, so there is also a need to identify alternative reference points for management purposes (see review by Smith et al. 1993, Caddy and Mahoon 1995). To design assessment methods that can make optimal use of deficient data sets, and determine the reliability and cost-effectiveness of alternative indicators, one must compare the performance of conventional and new analytical tools using known benchmarks.

With this approach in mind, it was decided that a numerical simulation model should be designed to mimic key aspects of the population dynamics of swordfish fisheries, the effects of environmental factors and fleet dynamics, as well as the fishery monitoring and management processes. This model would then serve to conduct local and basin wide tests of the performance and suitability of assessment and management methods under the various hypothetical, but plausible scenarios related to the stock/fishery dynamics. The effects of measurement error, process error[1], deficiencies in sampling regimes and survey coverage could be tested for as well.

In principle, this exercise should help us develop more powerful analytical tools, increase the reliability of population forecasts, explore the consequences of hypotheses that are difficult to test empirically, and help formulate scientifically credible fishery management guidelines. Similar modelling approaches has been used by NMFS staff in previous swordfish investigations (Goodyear 1989), by fishery scientists from the Commonwealth Scientific and Industrial Research Organization (CSIRO) to provide better tuna fishery management advice (Campbell et al. 1998), and by stock-assessment review committees in Europe (ICES, 1993), and in North America (NRC, 1998).

Work on this model was initiated in April '98. From the start, it was assumed that model would eventually be used by fishery scientists in several agencies. Models designed to represent single systems or that use non-generic code, preclude porting the code to other compilers or operating systems without making changes to it, and in the process, possibly altering the results. Consequently, efforts were made to use a 'platform independent' syntax and user-interfaces to facilitate portability. The present version runs as a standard console application, that interfaces with the user though keyboard inputs, and simple displays of options and results. The simulation model is currently written in C++ language so that it can easily link with standard template libraries (STL, Breymann 1998), and sophisticated numerical libraries such as those of IMSL (IMSL 1989) and AUTODIFF (Fournier, 1992).

Efforts are made to structure the model according to the 'state-space' principles described by Schnute (1994). This involves specifying distinct vectors for population characteristics (or states), observations, controls, and time-independent parameter values. This framework is suited for the development of sequential fisheries models, can be used for simulation and estimation purposes, can accommodate Bayesian and frequentists contexts, can serve to delineate the limits of the data, and establish rational priorities for future data collection. The framework has been used to conduct exploratory analyses (Schnute and Richards 1995, Richards et al. 1997), and thus represents a logical framework to adopt given the objectives of this study.

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1. Variability in the population dynamics that cannot be accounted for by deterministic population models, but can be modeled as random processes (NRC 1998).

The model is not designed to 'estimate' stock or fishery parameters, but to provide time series of observations of certain aspects of the fishery given a set of hypothesized input parameter values for the various fishery components. Data can be generated with variable levels of resolution and error as could be obtained in reality. Sampling periodicity and intensity can be adjusted to determine cost:benefit ratios, and conduct sensitivity analyses, and so forth. Bias and noise can be added to the observations to determine the effects of data contamination and measurement errors.

The present version of the model accounts for growth, reproduction, natural mortality, exploitation, and observation error associated with catch sampling activities. The version can project trends in abundance, catch, recruitment, spawning biomass and so forth for a simple one stock and one gear fishery. The model initially generates matrices of expected proportions in length-at-age, and weight-at-length using the morphometric relations reported by Uchiyama et al. (in prep.). These proportions serve to update the length and weight distributions of the swordfish in given categories and periods. The model initially builds-up a virtual population through constant recruitment, growth and natural mortality. Once the population stabilizes, and the matrix of survivors-at-age is full, the actual simulation process begins and all dynamic components are implemented. The accounting procedure is similar to that of a forward cohort analysis (Fig. 1), with several vectors or matrices updated at each time step. These include the numbers alive and caught by sex/age, sex/length and sex weight category. The model thus incorporates key attributes of length-based and aged-structured models.

Most of the code in the model is actually used to handle all the overhead (Fig. 2). This includes interfacing with the user, doing the bookkeeping work, taking 'snapshots' of the state of the stock and fishery at certain points in time, computing reference points, and generating output.

When you run the model, you are presented with this interface (Fig. 3). You simply specify the options you want from the list, and let the model run. This list of options will increase with time, get more sophisticated to handle complex scenarios and data requirements.

Here you have the results for two different scenarios (Fig. 4). The user requested options 4 and 3 for catch size by year/month and age for both sexes combined. Then the user requested the same data, but with 50% under-reporting, and measurement error as a combination of mistakes during the catch recording and coding processes. You will note that the numbers include decimals, which is done intentionally to remind the user that these are expected values, so there is no truncation or rounding.

This version of the model displays only a portion of the output requested, but stores all the output in textfile which can easily be read by your favorite application. Here is a time series of standing stock biomass as predicted by the model under a certain combination of hypotheses (Fig. 5). The data generated were read in and charted with Excel.

Obviously, much work remains to be done before we can make projections that are representative of realistic and plausible events. Work is in progress to incorporate stock and fleet movements, multiple fishing gears, various types of species and fleet interactions, and process error. In future versions, a graphical libraries will likely be used to map out the output generated. I'm quite confident that we will end up with a fairly sophisticated model within the next year or so. However, I should admit I'm less confident about the models ability to provide the insight we hope to get out of it. The reason for my concern is data. With so little data on the biological aspects, behavior and movement of swordfish, it will be very difficult to parameterize the model in a realistic fashion. It is a well know fat that model failures are generally due to data failures, and I doubt this case will be the exception to the rule. So I would like to take this opportunity to highlight the need for data on swordfish, and the importance of implementing large scale investigations as soon as possible.

That about sums-up what I had to say. I've covered a lot of grounds without going into detail about the mathematical components of the model. For those of you who have interest in such details, I have made a copy of the document describing the model in detail as well as the computer code. Feel free to consult it, and I will do my best to clarify any question you might have on the document. Thank you.

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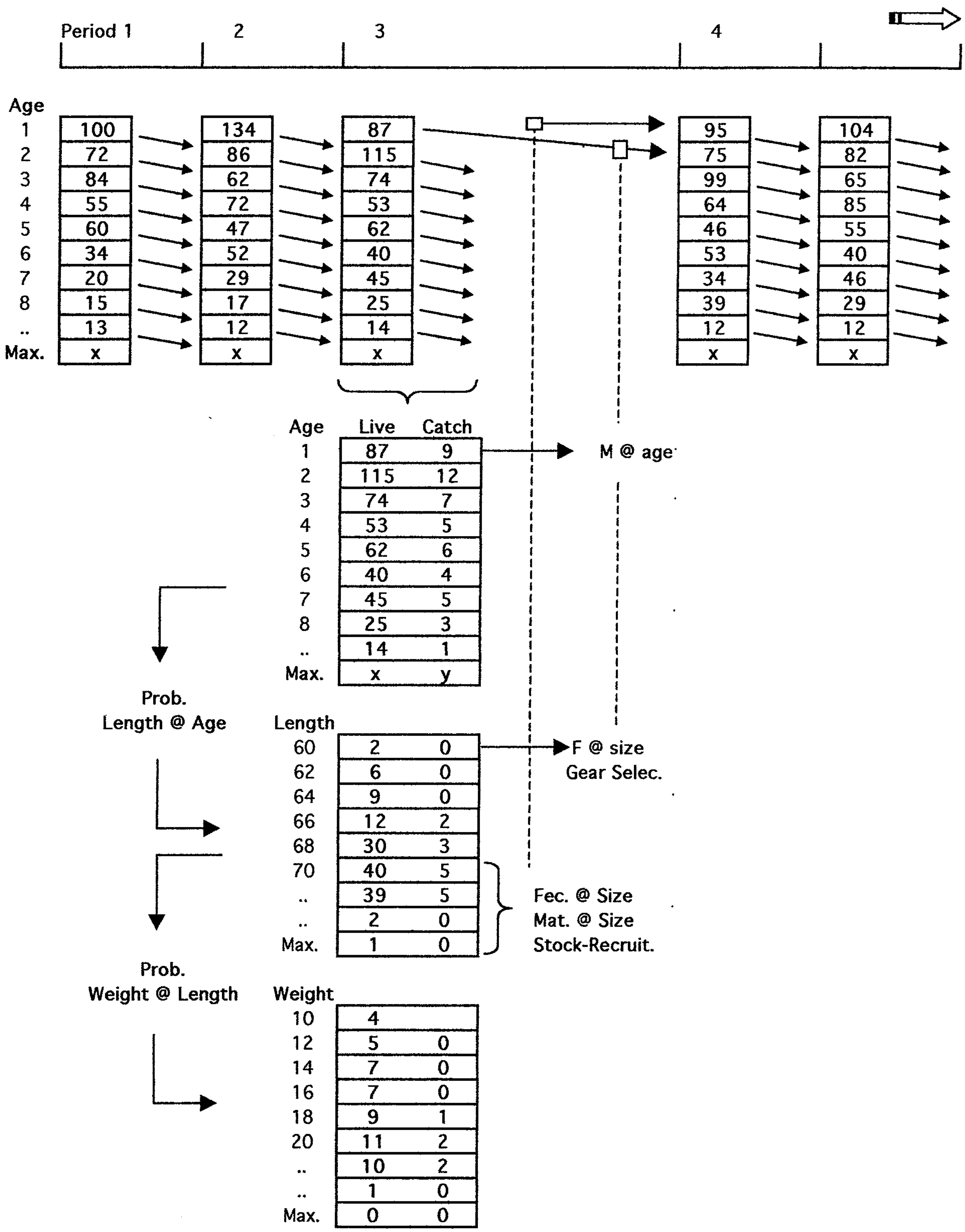
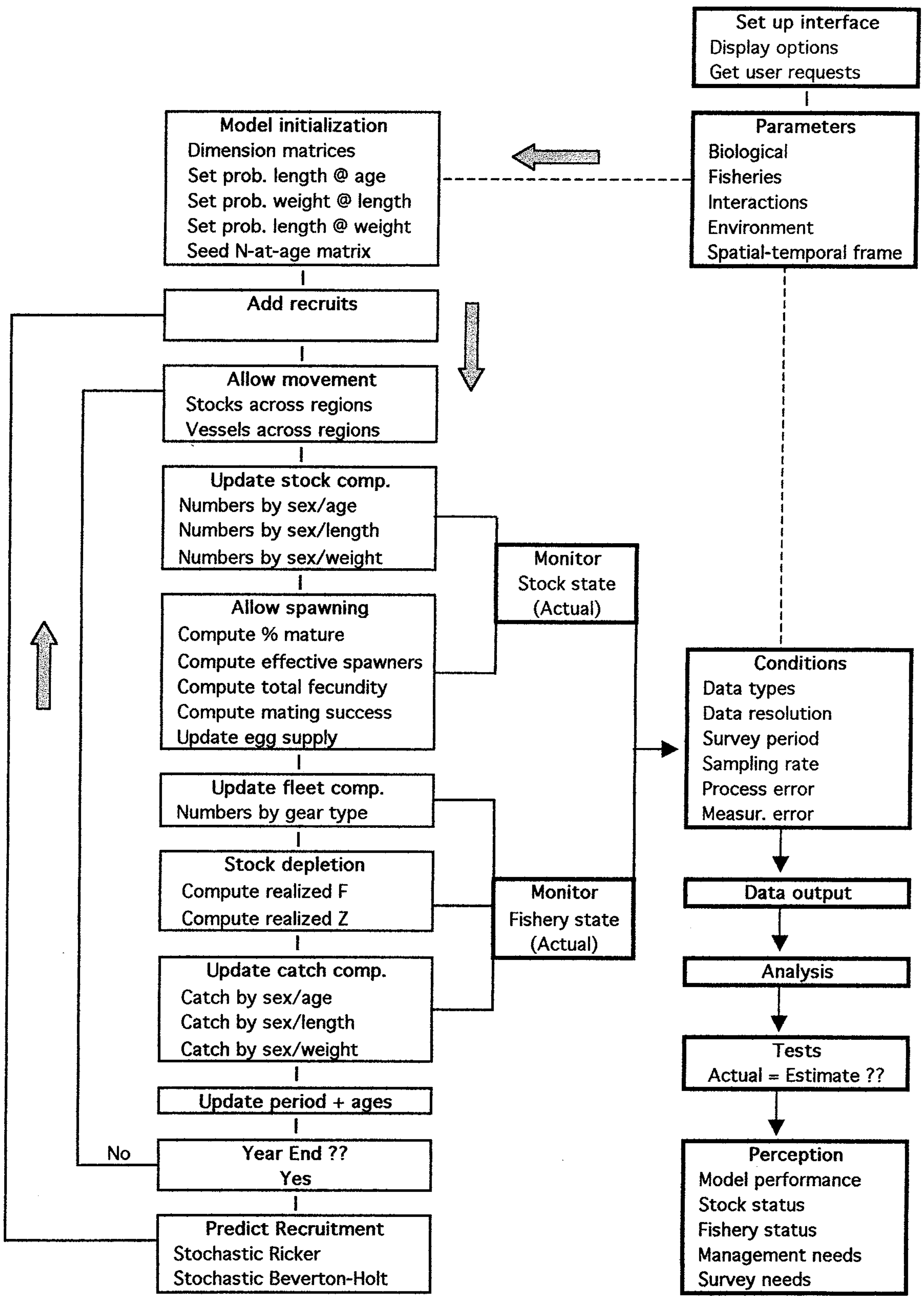
PELAGIC FISHERY SIMULATION MODEL STRUCTURE



PELAGIC FISHERY SIMULATION MODEL STRUCTURE



NOAA/NMFS PACIFIC OCEAN PELAGIC FISHERY SIMULATION PROGRAM [V 2.0]

THIS VERSION CAN GENERATE EXPECTED VALUES FOR

```
{1} Stock size by year/age                {2} Stock size by year/month/age
{3} Catch size by year/age                {4} Catch size by year/month/age
{5} Stock size by year/length             {6} Stock size by year/month/length
{7} Catch size by year/length             {8} Catch size by year/month/len
{9} Stock size by year/weight             {10} Stock size by year/month/wt
{11} Catch size by year/weight            {12} Catch size year/month/weight
{13} Mean age stock by year               {14} Mean age stock by year/month
{15} Mean age catch by year               {16} Mean age catch by year/month
{17} Mean length stock by year            {18} Mean length stock by year/month
{19} Mean length catch by year            {20} Mean length catch by year/month
{21} Mean weight stock by year            {22} Mean weight stock by year/month
{23} Mean weight catch by year            {24} Mean weight catch by year/month
{25} Stock biomass by year                {26} Stock biomass by year/month
{27} Spawning biomass by year             {28} Spawning biomass by year/month
{29} Catch biomass by year                {30} Catch biomass by year/month
{31} Recruitment by yea                   {32} Realized F-at-size by yr/month
```

AND PSEUDO-OBSERVATIONS FOR

```
{40} Catch size by year/age               {41} Catch size by year/month/age
{42} Catch size by year/length            {43} Catch size by year/month/length
{44} Catch size by year/weight            {45} Catch size by year/month/weight
{46} Mean age catch by year               {47} Mean age catch by year/month
{48} Mean length catch by year            {49} Mean length catch by year/month
{50} Mean weight catch by year            {51} Mean weight catch by year/month
{52} Stock biomass by year                {53} Stock biomass by year/month
{54} Spawning biomass by year             {55} Spawning biomass by year/month
{56} Recruitment by year                  {57} Effect. F-at-size by year/month
```

```
AVAILABLE FOR SEX CATEGORIES: {1} Males {2} Females {3} M+F combined

ENTER INTEGER 1-50 {Rtn} INTEGER 1-3 {Rtn} FOR OPTION, OR HIT 'q' TO EXIT
Some results will be displayed. All output sent to specified textfile
6
3
Options chosen: 6 3     Data output in => Option_6.txt

    Steady-state conditions for R = 2000/yr, F = 0.0,   M = 0.1
Eff. spawner density       = 16302.6
Egg production index       = 6.40036e+11    Pre-juv. surv. coeff. = 6.24965e-10
Ricker spaw. scale coeff. = 1.25805e-10    Ricker recr. scale coeff. = 0.648572
B-Holt spaw. scale coeff. = 4.45741e-11    B-Holt recr. scale coeff. = 0.697239

Simulation proceeding >>>>>>>
```

4
3
Simulation proceeding >>>>>>>

Catch in year 9, by month (T->B), age categories 1-9 (L->R)

_1	1.66	2.23	7.15	5.06	2.04	1.77	4.72	3.80	1.58
_2	1.82	2.31	7.26	5.08	2.04	1.76	4.67	3.76	1.56
_3	1.99	2.40	7.35	5.09	2.03	1.75	4.63	3.72	1.55
_4	2.16	2.48	7.44	5.10	2.02	1.73	4.59	3.69	1.53
_5	2.33	2.56	7.52	5.10	2.01	1.72	4.55	3.65	1.52
_6	2.50	2.63	7.60	5.10	2.00	1.71	4.51	3.62	1.50
_7	2.66	2.70	7.66	5.10	1.99	1.70	4.47	3.58	1.49
_8	2.83	2.77	7.73	5.10	1.98	1.68	4.43	3.55	1.47
_9	2.99	2.83	7.78	5.09	1.97	1.67	4.39	3.51	1.46
_10	3.15	2.89	7.83	5.09	1.96	1.65	4.35	3.48	1.44
_11	3.31	2.94	7.87	5.08	1.95	1.64	4.31	3.44	1.43
_12	3.46	2.99	7.90	5.06	1.94	1.63	4.27	3.41	1.41

Completed 100% of simulation
Run completed: Ready for re-run : Hit 'q' <Enter> to Quit, other letter to continue
....

ENTER INTEGER 1-50 {Rtn} INTEGER 1-3 {Rtn} FOR OPTIONS, OR HIT 'q' TO EXIT
Some results will be displayed. All output sent to specified textfile
41
3
SPECIFY: % CATCH UNDER-REPORTING (0-100) AND CATCH RECORDING ERROR (0/1)
Ex: Report = 80% Actual, No recording err => Type 20 {Rtn} 0 {Rtn}
50
1
SPECIFY: WEIGHT-LENGTH CONVERSION ERROR (0/1) AND AGEING ERROR (0/1)
0
0
Options chosen: 41 3 50 1 0 0 Data output in => Option_41.txt

Catch in year 9, by month (T->B), age categopries 1-9 (L->R)

_1	0.54	0.73	2.34	1.66	0.67	0.58	1.54	1.24	0.52
_2	0.46	0.59	1.84	1.28	0.52	0.45	1.18	0.95	0.40
_3	1.47	1.77	5.44	3.76	1.50	1.29	3.43	2.75	1.14
_4	0.45	0.51	1.54	1.06	0.42	0.36	0.95	0.76	0.32
_5	0.19	0.21	0.62	0.42	0.17	0.14	0.37	0.30	0.13
_6	1.89	2.00	5.77	3.88	1.52	1.30	3.43	2.75	1.14
_7	6.04	6.12	17.39	11.58	4.52	3.85	10.14	8.12	3.37
_8	0.28	0.27	0.76	0.50	0.20	0.17	0.44	0.35	0.14
_9	3.46	3.27	8.99	5.89	2.28	1.93	5.07	4.06	1.68
_10	0.63	0.57	1.55	1.01	0.39	0.33	0.86	0.69	0.29
_11	5.19	4.61	12.33	7.95	3.05	2.57	6.75	5.39	2.24
_12	0.34	0.29	0.77	0.50	0.19	0.16	0.42	0.33	0.14

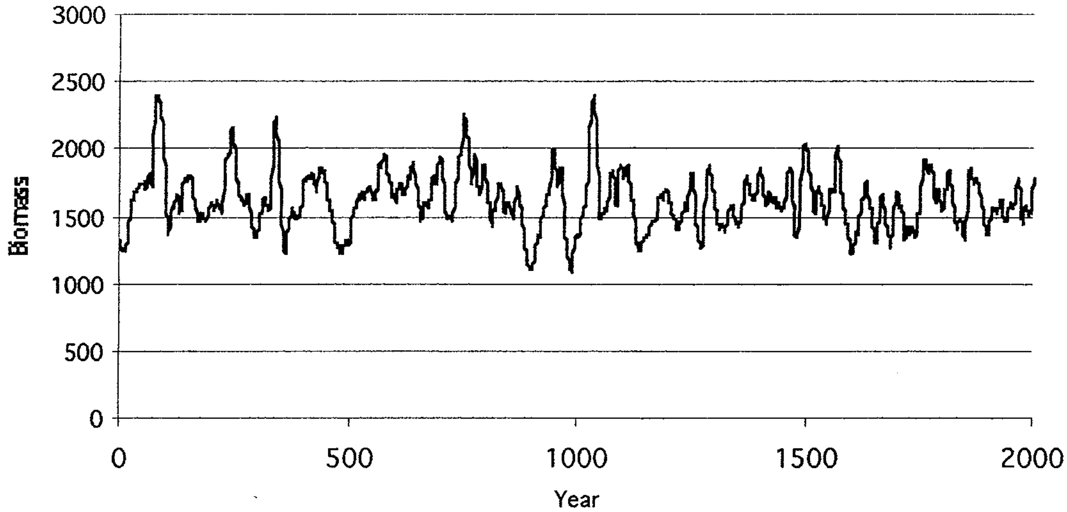


Figure 5. Simulated trends in standing stock biomass over 2000 years, given M=0.1, F=0.25, and stochastic (lognormal) variation in recruitment predicted with a Ricker type function.