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A STAGE-BASED POPULATION MODEL FOR LOGGERHEAD SEA TURTLES AND IMPLICATIONS FOR CONSERVATION[1]

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or

$$\underbrace{\begin{bmatrix} a_{11} & a_{12}\cdots a_{1s} \\ a_{21} & a_{22}\cdots a_{2s} \\ \cdot & \cdot\ \cdots\ \cdot \\ a_{s1} & a_{s2}\cdots a_{ss} \end{bmatrix}}_{A} \begin{bmatrix} n_1 \\ n_2 \\ \cdot \\ n_s \end{bmatrix}_t = \begin{bmatrix} n_1 \\ n_2 \\ \cdot \\ n_s \end{bmatrix}_{t+1}$$

where n_i gives the abundance of individuals in a particular life stage at time t.

TABLE 3. Stage-based life table for loggerhead sea turtles based on data in Frazer (1983*a*). These values assume a population declining at ≈3%/yr.

Stage number	Class	Size* (cm)	Approximate ages (yr)	Annual survivorship	Fecundity (no. eggs/yr)
1	eggs, hatchlings	<10	<1	0.6747	0
2	small juveniles	10.1–58.0	1–7	0.7857	0
3	large juveniles	58.1–80.0	8–15	0.6758	0
4	subadults	80.1–87.0	16–21	0.7425	0
5	novice breeders	>87.0	22	0.8091	127
6	1st-yr remigrants	>87.0	23	0.8091	4
7	mature breeders	>87.0	24–54	0.8091	80

* Straight carapace length.

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```
% Define projection matrix A
A=[ 0     0     0     0     127      4    80  ;
  .6747  .737   0     0     0        0    0   ;
     0   .0486 .661   0     0        0    0   ;
     0     0   .0147 .6907  0        0    0   ;
     0     0     0   .0518  0        0    0   ;
     0     0     0     0   .8091     0    0   ;
     0     0     0     0     0      .8091 .8089 ];
```

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     0     0     0   .0518  0        0    0   ;
     0     0     0     0   .8091     0    0   ;
     0     0     0     0     0      .8091 .8089 ];


% Compute eigenvalues and eigenvectors of A
[V,D]=eig(A)
% Returns matrix V, columns of which are eigenvectors
% Diagonal matrix D, entries of which are corresponding eigenvectors
```

```
>> loggerhead_stage_class_model

V =

  0.7768            0.7768           -0.5700            0.4710            0.0127 + 0.2951i   0.0127 - 0.2951i   0.2908
 -0.6219 - 0.0901i  -0.6219 + 0.0901i   0.8155           -0.8699            0.9345            0.9345            0.9430
  0.0384 + 0.0120i   0.0384 - 0.0120i  -0.1002            0.1461            0.0735 - 0.1838i   0.0735 + 0.1838i   0.1614
 -0.0007 - 0.0003i  -0.0007 + 0.0003i   0.0035           -0.0067           -0.0106 - 0.0078i  -0.0106 + 0.0078i   0.0093
  0.0000 + 0.0003i   0.0000 - 0.0003i   0.0007           -0.0009           -0.0008 - 0.0003i  -0.0008 + 0.0003i   0.0005
  0.0010 - 0.0010i   0.0010 + 0.0010i   0.0021           -0.0020           -0.0009 - 0.0001i  -0.0009 + 0.0001i   0.0004
 -0.0010 + 0.0008i  -0.0010 - 0.0008i  -0.0031            0.0038            0.0007 + 0.0033i   0.0007 - 0.0033i   0.0026


D =

  -0.0884 + 0.1196i        0                0                0                0                0                0
         0          -0.0884 - 0.1196i        0                0                0                0                0
         0                 0                0           0.2655                0                0                0
         0                 0                0                0           0.3717                0                0
         0                 0                0                0                0           0.7462 + 0.2131i        0
         0                 0                0                0                0                0           0.7462 - 0.2131i        0
         0                 0                0                0                0                0                0           0.9450
```

```
>> loggerhead_stage_class_model

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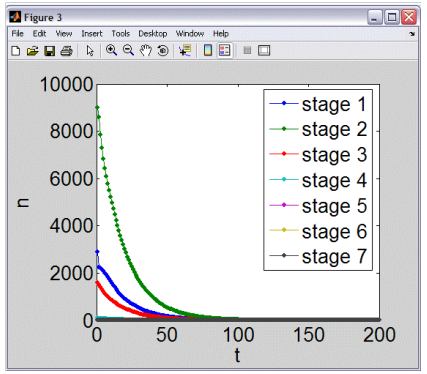
         0                 0                0           0.2655                0                0                0
         0                 0                0                0           0.3717                0                0
         0                 0                0                0                0           0.7462 + 0.2131i        0
         0                 0                0                0                0                0           0.7462 - 0.2131i        0
         0                 0                0                0                0                0                0           0.9450
```

λ_1

```
16
17  %-----------------------------------------------------------
18  %Simulate the model via iteration
19  %Initial population size in each class
20  n_zero=[2900;
21          9000;
22          1600;
23          100;
24          5;
25          4;
26          20];
27
28
29  Tmax=200;
30  n_vs_t=zeros(7,Tmax);
31
32  n_vs_t(:,1)=n_zero ;
33
34  for t=2:Tmax;
35     n_vs_t(:,t)=A*n_vs_t(:,t-1) ;
36  end
37
38  figure
39  set(gca,'FontSize',20)
40  plot(1:Tmax,n_vs_t','.-','MarkerSize',14)
41  xlabel('t','FontSize',20)
42  ylabel('n','FontSize',20)
43  legend('stage 1','stage 2','stage 3','stage 4','stage 5','stage 6','stage 7')
```



BAD NEWS!

Management plan: which entries do I increase?

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% Compute eigenvalues and eigenvectors of A
[V,D]=eig(A)
% Returns matrix V, columns of which are eigenvectors
```

$$\begin{bmatrix} P_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 \\ G_1 & P_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_2 & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_5 & P_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{bmatrix}$$

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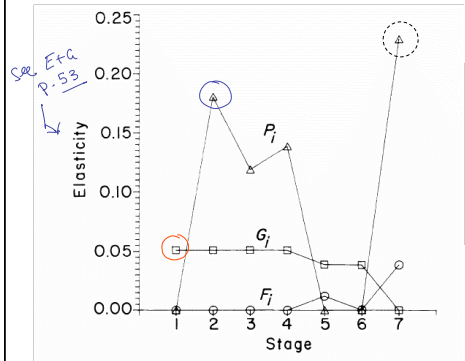

FIG. 3. The elasticity, or proportional sensitivity, of λ_m to changes in fecundity F_i (○), survival while remaining in the same stage P_i (△), and survival with growth G_i (□). Because the elasticities of these matrix elements sum to 1, they can be compared directly in terms of their contribution to the population growth rate r.

G_1: Transition egg → sm. juvenile

P_2: Juvenile survival

See E+A p. 53

$$\begin{bmatrix} P_1 & F_2 & F_3 & F_4 & F_5 & F_6 & F_7 \\ G_1 & P_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_2 & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_5 & P_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{bmatrix}$$

Predict: increasing P_2 has good chance of saving population.

TEST by increasing P_2 in MATLAB... vs increasing G_1.

CONCLUDE: Must preserve juveniles.

...ing the increase to 1 in this stage proportionately larger.)

More importantly, the simulation indicates that no matter how much effort was put into protecting eggs on the beach, this alone could not prevent the eventual extinction of the model population. Similarly, the turtles could not reverse their decline via increases in

Intrin

any stage to 1.0, the National Marine Fisheries Service has recently devised a technology, the Trawl Efficiency or Turtle Excluder Device (TED), that virtually eliminates turtle mortality due to incidental capture and drowning in shrimp and fish trawls (Seidel and McVea 1982, Anonymous 1983). Such incidental capture is believed to be the major source of mortality in juvenile

Happy ending:

TED required as of 1994
Sea turtle populations stable or increasing as of 1998 – rebound!

Not conclusive proof of model predictions, but highly suggestive.