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Reduction in Shrimp Bycatch: Effort/Stock Responses Based on the Elasticity of Demand

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Abstract

Given the assumptions underlying this bioeconomic model, management mesures that eliminate bycatch result in a decline in stock size caused by an increase in fishing effort in the directed fishery when demand is relatively elastic. With relatively inelastic demand, the stock recovers as fishing effort declines at the expense of jobs in the directed fishery and a loss of capital investment in fishing craft. Regulations that attempt to reduce or eliminate bycatch in the shrimp fishery must also include measures that correct the common property externality in the affected finfish fisheries to prevent future stock collapses and to increase net benefits to society.

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Introduction

Increasing unit prices for shrimp have resulted in increased fishing effort for this common property resource. Various studies have indicated that one consequence of increased shrimp harvesting effort is the taking of a significant level of finfish bycatch. Blomo and Nichols (1974) found that four pounds of finfish were landed for every pound of shrimp. A study conducted by Chittendon and McEachran (1976) found a ten to one ratio of finfish to shrimp. Bryan's (1980) finfish to shrimp ratio was three to one. In 1985, Pellegrin, et. al. found finfish to shrimp ratios that ranged from 2:1 to 21.1:1. Although a portion of the bycatch is marketed and contributes to the income of shrimp fishermen (crew) or to the profits of the shrimp fishing firm (owner), the bycatch is generally not in a form that has market value to the fishermen. This portion of the bycatch is discarded by the shrimp fishermen and is not available for recruitment later into the commercial or recreational finfish fishery (Pellegrin, et. al., 1985).

The effect of this bycatch on finfish stocks has been addressed by Nichols, et. al. (1987)[1]. The estimated bycatch of red snapper, king mackerel, and Spanish mackerel was found to be comparable to or exceed the average recreational catch. In a subsequent analysis based on these results, Powers, et. al. (1987) concluded that the elimination of red snapper from the shrimp bycatch would result in a ninety percent increase in this fish stock available to recreational and commercial finfish fishermen.

These studies do not explicitly address the effect that the resulting increased availability of finfish has on the level of fishing effort applied by fishermen to the resource. That is, given that the level of finfish fishing effort remains unchanged, an increase in the level of finfish landings will occur as a result of the increase in stock size. However, finfish fishing effort levels are unlikely to remain unchanged given the substantial increases in stock availability found in the Powers, et. al. (1987) study. Although the economic data necessary to determine the effect on fishing effort levels due to the elimination of bycatch has never been collected by the NMFS in the southeastern region, a computer simulation using a simple bioeconomic model indicates that the resulting stock size, fishing effort level, and harvest level is dependent on the own price elasticity of demand for finfish.

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1 These estimates are being revised, but are not yet available for all species.

Bioeconomic Model

Assuming that the fish stock is represented by a logistic growth function:

$$F(X) = rX(1-X/K) \tag{1}$$

where X is biomass or stock size,
K is the environmental carrying capacity,
r is the intrinsic growth rate,

that satisfies the requirements that

$$F(X) > 0, F''(X) < 0, \text{ and } F(0) = F(K) = 0 \text{ for } 0 \leq X \leq K,$$

(Clark, 1985) and harvest occurs in a directed fishery and as incidental take in an alternative fishery.

$$Q = h_1 + h_2 = aEX + bEX \tag{2}$$

where Q is total harvest of the fish stock,
h_1 is the harvest level in the directed fishery,
h_2 is the incidental harvest level in the alternative fishery,
a is the catchability coefficient for the directed fishery,
b is the catchability coefficient for the alternative fishery, and
E is the level of fishing effort; assumed to be identical in both fisheries.

The change in biomass or stock size over time is equal to growth minus the total harvest level:

$$\overset{o}{X} = F(X) - Q; \tag{3}$$

Substituting equation (1) and (2) into (3) and solving for sustainable stock size (X) when the change in biomass over time is zero results in:

$$X = K(1-(a+b)E/r) \tag{4}$$

Solving equation (2) for X and substituting into equation (3) when biomass does not change with respect to time and solving for directed harvest (h_1) results in:

$$h_1 = K(a+b)E[1 - (a+b)E/r] - bEX \tag{5}$$

Both stock size (X) and directed harvest (h_1) are functions of the system parameters (K,a,b,r) and fishing effort (E). This explicitly assumes that fishing effort is fixed at some known level. However, fishing effort levels are actually determined endogenously through the actions of profit maximizing firms. Total profits for the industry are represented in an open access fishery by

$$\pi = Ph_1 - cE = 0 \tag{6}$$

where π represents profits,

P is exvessel price; a constant for competitive firms, and

c is the unit price of fishing effort that includes the fisherman's opportunity cost.

Substituting equations (4) and (5) into (6) and solving for fishing effort (E):

$$E = r(a - c/pK)/(a^2 + ab) \tag{7}$$

Fishing effort (E) is a function of the system parameters representing the intrinsic growth rate (r), the catchability coefficients (a,b), the environmental carrying capacity (K), the unit effort cost (c), and the exvessel price of fish (P).

Computer Simulation

The system of equations (4), (5), and (7) is a simple bioeconomic model that describes an open access fishery characterized by a directed harvest and a bycatch in an alternative fishery. Ideally, economic and biological data would be used to estimate the model parameters. However, since vessel operating costs are not available for use in construction of an unit cost of effort parameter (c), arbitrary values are assigned to r, c, and P in a computer simulation to generate values of h_1, X, and E for different directed and incidental (a,b) harvest levels. Figure 1 shows the harvest, biomass, effort, and price results in the standard four quadrant graph that illustrates the interaction of a backward bending open access supply curve (SOA), a sustained yield effort curve (SY(E)), and a population equilibrium curve (PE). To complete the model for purposes of this discussion, relatively elastic (D) and inelastic (D') demand curves are imposed on the open access supply curves in quadrant 1 of Figure 1.

Discussion

Initially, the directed fishery is in equilibrium in quadrant 1 of Figure 1 where both demand curves (D and D') equal open access supply (SOA) at price (P) and harvest level (h). The sustained yield curve [SY(E)] in quadrant 4 indicates that this level of harvest is maintained by fishing effort level (E) and a biomass of (X) from the population equilibrium curve (PE) in quadrant 3.

Another open access supply curve (SOA') is derived assuming that the bycatch in the alternative fishery reduces the directed harvest by one half (b = a) at some point in the future. Eliminating the bycatch in the alternative fishery causes the supply curve to shift outward reflecting the increased abundance of fish in the directed fishery. Simultaneously, the sustained yield effort curve S(YE) shifts outward to SY(E'). The population equilibrium curve (PE) remains unchanged since neither the intrinsic growth rate (r) or the environmental carrying capacity (K) have been affected by the change in bycatch (b).

With a relatively elastic demand for the fish product represented by (D), the increase in supply from SOA to SOA' causes the change in price (P) to be trivial and harvest increases from (h) to (h'). However, because exvessel price has remained relatively unchanged while the costs of fishing have decreased due to the increased abundance of fish, long run fishing effort levels increase to (E') where the short run increase in profits is dissipated among the new entrants and the marginal vessel is earning a zero return. The increase in fishing effort to (E') causes stock size to decline from (X) to (X') as can be seen on the population equilibrium curve (PE) in quadrant 3. As a result, harvest levels are not as great as they would have been had fishing effort levels remained unchanged and stock size is smaller than its previous level when bycatch in the alternative fishery existed.

An entirely different scenario unfolds when a relatively inelastic demand curve (D') is assumed for the fishery product. The increase in supply from SOA to SOA' causes a decline in exvessel price from (P) to (P') in Figure 1. Harvest levels increase to h" (approximately doubling) and fishing effort collapses to E". As a result of the reduced fishing pressure, stock size increases to (X") on the population equilibrium curve.

The decline in price more than offsets the reduced costs of harvesting caused by the increase in stock abundance from eliminating bycatch in the alternative fishery. The resulting losses cause firms to exit the fishery until fishing effort reaches (E") where returns to labor and capital are again equal to zero. The reduced fishing effort allows stock size to grow and results in increased harvest levels.

Conclusions

When demand is relatively elastic, eliminating the bycatch in the alternative fishery results in a decline in biomass or stock size from the increase in fishing effort in the directed fishery; the entry of fishermen and fishing craft. With relatively inelastic demand, the stock recovers as fishing effort declines, but this is accomplished by eliminating jobs in the directed fishery and the loss of a significant level of capital investment in fishing craft. The cost to society in this scenario depends on the degree of labor mobility and capital malleability in the directed fishery relative to the increases in consumer surplus.

Since the data does not exist to quantify the parameters of this bioeconomic model, which scenario best represents the outcome of eliminating bycatch in the shrimp fishery is difficult to determine. However, since many finfish stocks are under or are being considered for regulated reductions in landings in the southeastern region[2], intuition suggests that these fish stocks have been exploited beyond maximum sustained yield on the open access supply curve. Also, the applied research (W. Emerson, 1988) generally indicates relatively elastic demand for fish products ranging from (-1.49) to (-12.78). Assuming these conditions exist, any reductions in alternative fishery bycatch would lead to increased fishing effort and a further reduction in the finfish fishery's equilibrium stock size.

Neither scenario represents an economic improvement for the fishery since excess capacity and overcapitalization would still exist in the directed fishery. Eventually, increases in demand would further exacerbate the overfishing problem in the directed fishery in either case. Regulations that attempt to reduce or eliminate bycatch in the Gulf of Mexico shrimp fishery must, therefore, also include measures that correct the common property externality in the affected finfish fisheries to prevent future stock collapses and to increase net benefits to society.

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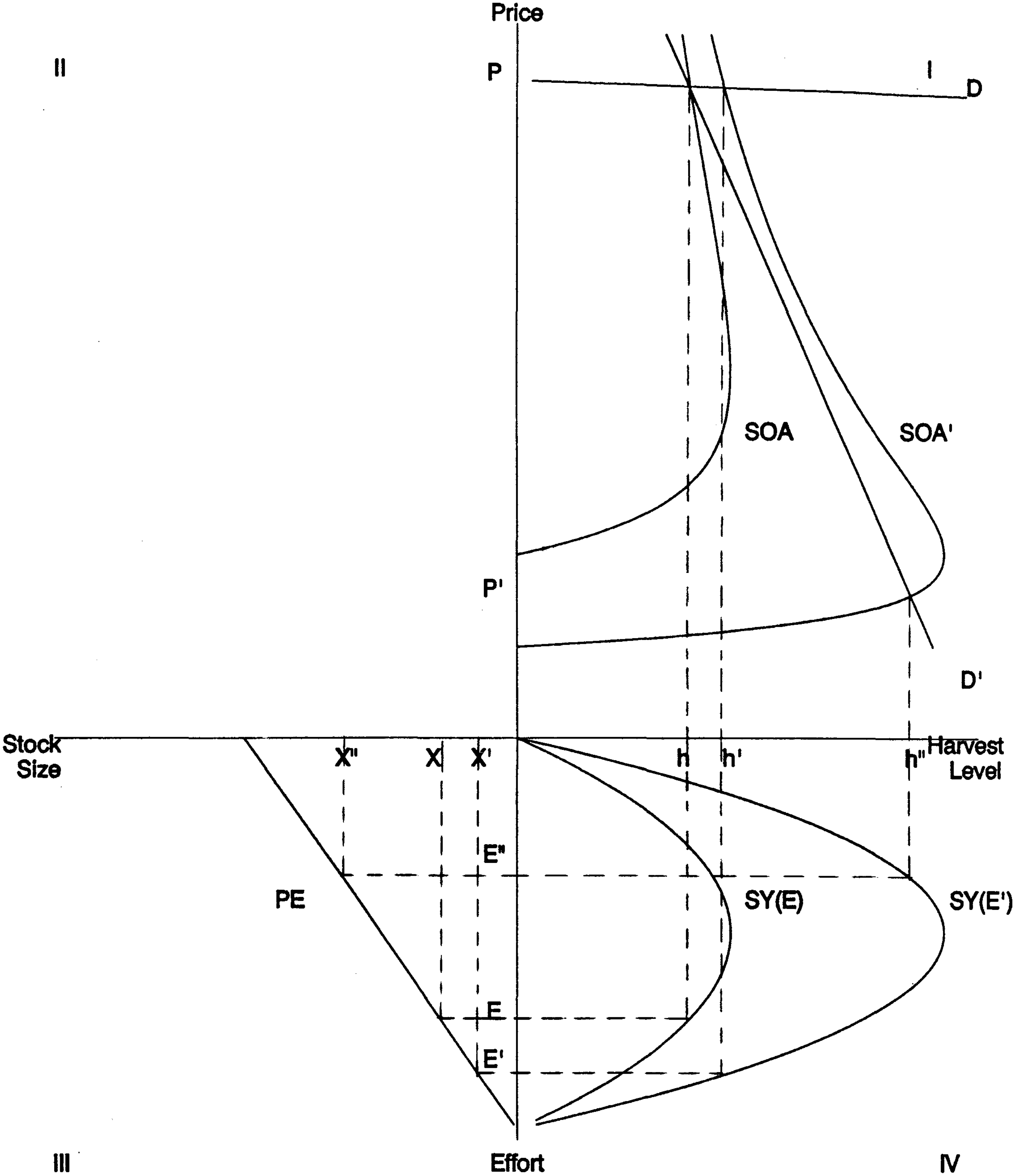
2 Total acceptable catch (TAC) and acceptable biological catch (ABC) regulation impacts are not covered in this simple model since they unnecessarily complicate the analysis without significantly affecting the results.

FIGURE 1
Finfish Fishery



Acknowledgements

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References

Blomo, V.J. and J.P. Nichols (1974). Utilization of finfishes caught incidental to shrimp trawling in the western Gulf of Mexico, Part I: Evaluation of Markets, Sea Grant Publ. TAMU-SG-74-212, Texas A&M Univ., Coll. Stn.

Bryan, C.E. (1980). Organisms Captured by the Commercial Shrimp Fleet on the Texas Brown Shrimp (Penaeus aztecus Ives) Grounds, Masters Thesis, Corpus Christi State Univ., Corpus Christi, Tex., 44p.

Chittenden, M.E., Jr. and J.D. NcEachran (1976). Composition, Ecology, and Dynamics of Demersal Fish Communities on the Northwestern Gulf of Mexico Continental Shelf, with a Similar Synopsis for the Entire Gulf. Sea Grant Publ. TAMU-SG-76-208, Tex. A&M Univ., Coll. Stn., 104p.

Emerson, W. (1988). A Spacial Allocation Model for the New England Fisheries. Ph.D. Dissertation, Department of Natural Resource Economics, University of Rhode Island, Kingston, RI.

Nichols, S., A. Shah, G. Pellegrin, Jr., and K. Mullin (1987). Estimates of Annual Shrimp Fleet Bycatch for Thirteen Finfish Species in the Offshore Waters of the Gulf of Mexico. Draft Report, NOAA, NMFS, SEFC, Mississippi Laboratory, Pascagoula, MS.

Pellegrin, G.J., Jr., S.B. Drummond, and R.S. Ford, Jr. (1985). The Incidental Catch of Fish by the Northern Gulf of Mexico Shrimp Fleet. Draft Report, NOAA, NMFS, SEFC, Mississippi Laboratories, Pascagoula, MS.

Powers, J.E., C.P. Goodyear, and G.P. Scott (1987). The Potential Effect of Shrimp Fleet Bycatch on Fisheries Production of Selected Fish Stocks in the Gulf of Mexico. Draft Report, NOAA, NMFS, SEFC, Miami Laboratory, Miami, FL.

APPENDIX

COMPUTER PROGRAMS

```
filename grafout 'a:bycth.sgf';
options ps=55  ls=132;
data sye1;

c = 1.75;                    *UNIT COST OF EFFORT;
e = 50000;                   *TOTAL EFFORT LEVEL;
k1 = 3000;                   *ENVIRONMENTAL CARRYING CAPACITY;
r1 = 0.25;                   *INTRINSIC GROWTH RATE;
                             *   0 r1 1;
x = 1900;                    *FIRST STOCK CONSTANT SUPPLY LEVEL;
v= 423;                      *SECOND STOCK CONSTANT SUPPLY LEVEL;
a = r1/e;                    *CATCHABILITY COEFFICIENT;
                             *    - Set to ensure that (a+b)e/r = 1;
b1 =  0*a;                   *        bycatch fishery;
a1 = a-b1;                   *        directed fishery;


pa = c/(k1*a1);              *PRICE INTERCEPT;
                             *      - Price at which effort equals zero;
pmax = 10000;                *MAXIMUM VALUE FOR PRICE;
pmid = .5*pmax;
pmin = .1*pmax;
do p1 = pa to pmin by 1, pmin to pmid by 100, pmid to pmax by 1000;
       e1 = r1*(a1 - c/(p1*k1))/(a1**2 + a1*b1);*OPEN ACCESS EFFORT LEVEL;
                             * - TOTAL COST = TOTAL REVENUE;
       x1 = (k1*(1 - (a1+b1)*e1/r1));*POPULATION EQUILIBRIUM CURVE;
       h1 = (k1*(a1+b1)*e1)*(1 - ((a1+b1)*e1)/r1) - b1*e1*x1;*SUSTAINABLE;
                             * YIELD EFFORT CURVE;
  hd1 = 200 - 0.15*p1;       *INELASTIC DEMAND CURVE;
  output;
end;
run;
*proc print;
*run;
data sye2;
  set sye1;

   if hd1  < 0 or hd1   > 900 then hd1 = .;*SCALES GRAPH FOR THE IN-
ELASTIC DEMAND CURVE;
   if hs1  <0 or hs1  > 205 then hs1 = .;*SCALES GRAPH FOR THE SUPPLY
CURVE;
   e1=-e1;
   x1=-x1/25;                *SCALES BIOMASS;
   if p1  > 900 and h1  <100 then p1 = .;
   p1=p1*100;                *SCALES PRICE;
run;
```

```
*-------------------------------------------------------------------;

data sye1a;
c = 1.75;                *UNIT COST OF EFFORT;
e = 50000;               *TOTAL EFFORT LEVEL;
k2 = 3000;               *ENVIRONMENTAL CARRYING CAPACITY;
r2 = 0.25;               *INTRINSIC GROWTH RATE;
                         *   0 <r1  <1;
y = 425;                 *STOCK CONSTANT SUPPLY LEVEL;
z = r2/e;                *CATCHABILITY COEFFICIENT;
                         *  - Set to ensure that (a+b)e/r = 1;
b2 = 0.50*z;             *      bycatch fishery;
a2 =  z-b2;              *      directed fishery;

pb = c/(k2*a2);          *PRICE INTERCEPT;
                         *  - Price at which effort equals zero;
pmax = 10000;            *MAXIMUM VALUE FOR PRICE;
pmid = .5*pmax;
pmin = .1*pmax;
do     p2 = pb to pmin by 1, pmin to pmid by 100, pmid to pmax by 1000;
       e2 = r2*(a2 - c/(p2*k2))/(a2**2 + a2*b2);*OPEN ACCESS EFFORT LEVEL;
                         * - TOTAL COST = TOTAL REVENUE;
       x2 = (k2*(1 - (a2+b2)*e2/r2));*POPULATION EQUILIBRIUM CURVE;
       h2 = (k2*(a2+b2)*e2)*(1 - ((a2+b2)*e2)/r2)-b2*e2*x2;  *SUSTAINABLE;
                         *YIELD  EFFORT  CURVE;
       hd2 = 2400 - 9.2764*p2;*SCALES GRAPH FOR THE ELASTIC DEMAND
CURVE;
       hd2 = 8400 - 10.0*p2;*SCALES GRAPH FOR THE ELASTIC DEMAND
CURVE;
       output;
end;
run;
data sye2a;
  set sye1a;
       e2=-e2;
            if e2  0 then e2 = .;
   x2=-x2/25;            *SCALES BIOMASS;
       if hd2  0 or hd2  200 then hd2 = .;*DEMAND CURVES;
       if hs2  0 or hs2  300 then hs2 = .;*SCALES THE SUPPLY CURVE;
       if p2  900 and h2  75 then p2 = .;
       if h2  0 then h2 = .;
       p2=p2*100;        *SCALES PRICE;
run;
*proc print;
*run;
```

```
*--------------------------------------------------------------------;

data sye3;
 merge sye2 sye2a;
run;
data bych;
length function $ 8 text $ 11 position $ 1;
function='label';x=180;y=0;style='swiss';
xsys='2';ysys='2';position='6';text='Harvest';output;
function='label';x=190;y=-3300;style='swiss';
xsys='2';ysys='2';position='6';text='Level';output;
function='label';x=-200;y=0;
xsys='2';ysys='2';position='4';text='Stock';output;
function='label';x=-200;y=-3300;
xsys='2';ysys='2';position='4';text='Size';output;
function='label';x=0;y=90000;
xsys='2';ysys='2';position='2';text='Price';output;
function='label';x=0;y=-50000;
xsys='2';ysys='2';position='8';text='Effort';output;
function='label';x=190;y=-50000;
xsys='2';ysys='2';position='8';text='IV';output;
function='label';x=-200;y=-50000;
xsys='2';ysys='2';position='8';text='III';output;
function='label';x=-200;y=90000;
xsys='2';ysys='2';position='8';text='II';output;
function='label';x=180;y=90000;
xsys='2';ysys='2';position='8';text='I';output;
function='label';x=100;y=-20000;
xsys='2';ysys='2';position='6';text='SY(E)';output;
function='label';x=190;y=-20000;
xsys='2';ysys='2';position='6';text="SY(E')";output;
function='label';x=-100;y=-20000;
xsys='2';ysys='2';position='5';text='PE';output;
function='label';x=200;y=8400;
xsys='2';ysys='2';position='5';text="D'";output;
function='label';x=200;y=84000;
xsys='2';ysys='2';position='5';text='D';output;
function='label';x=100;y=40000;
xsys='2';ysys='2';position='6';text='SOA';output;
function='label';x=180;y=40000;
xsys='2';ysys='2';position='5';text="SOA'";output;
function='label';x=-10;y=18000;
xsys='2';ysys='2';position='B';text="P'";output;
function='label';x=-10;y=84000;
xsys='2';ysys='2';position='B';text='P';output;
function='label';x=70;y=0;
```

```
xsys = '2';ysys = '2';position = 'F';text = 'h';output;
function = 'label';x = 90;y = 0;
xsys = '2';ysys = '2';position = 'F';text = "h'";output;
function = 'label';x = 170;y = 0;
xsys = '2';ysys = '2';position = 'F';text = 'h"';output;
function = 'label';x = -20;y = 0;
xsys = '2';ysys = '2';position = 'F';text = "X'";output;
function = 'label';x = -40;y = 0;
xsys = '2';ysys = '2';position = 'F';text = 'X';output;
function = 'label';x = -80;y = 0;
xsys = '2';ysys = '2';position = 'F';text = 'X"';output;
function = 'label';x = -10;y = -16000;
xsys = '2';ysys = '2';position = 'B';text = 'E"';output;
function = 'label';x = -10;y = -36000;
xsys = '2';ysys = '2';position = 'B';text = 'E';output;
function = 'label';x = -10;y = -42000;
xsys = '2';ysys = '2';position = 'B';text = "E'";output;
run;
*proc print;
*run;
*goptions dev = lq800;
*goptions dev = egal;
*goptions dev = vga16;
 goptions dev = hpljs2 gaccess = 'sasgastda:lazer2.prt' gsfmode = replace;
symbol1 v = point i = join l = 1 w = 2;
symbol2 v = point i = join l = 20 w = 2;
proc gplot annotate = bych data = sye3;
  title1 f = swiss h = 1 'FIGURE 1';
  title2 f = swiss h = 1 'Finfish Fishery';
  plot p1*h1 = 1 e1*h1 = 1 e1*x1 = 1
     p2*h2 = 1 e2*h2 = 1 e2*x2 = 1
     p1*hd1 = 1 p2*hd2 = 1
     /overlay
     vref = 0 href = 0
     noaxes;
run;
```