DISCUSSION PAPER

ALTERNATIVE STRATEGIES FOR MANAGING LONG ISLAND'S HARD CLAM RESOURCE

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Abstract

Dramatic declines in harvests strengthen the assumption that Long Island's hard clam fishery may be heading for collapse. A family of prey-predator models has been developed to test and evaluate alternative strategies to reverse the decline in hard clam harvests and/or stabilize the clam population. Harvesting is simulated as a fixed percent of standing stock and the behavior of baymen in response to price and supply of clams is not included in the models.

Five types of policies are evaluated: closed season, maximum size limit, hatchery seeding, bounty on predators, and nursery sanctuaries (closed areas). Effectiveness is judged for both the short term (ten years) and the long term (eleven to twenty years after a policy was instituted). While seeding options produce modest short term improvement in annual value (8.0 to 10.8 percent), only the two bounty policies produce significant improvement in both the short term (17.0 and 72.6 percent) and the long term (20.4 and 66.4 percent).

The results of this model reflect the influence of specific management policies on the biological system alone. A later version, incorporating the behavior of the baymen, will introduce key social and economic factors.

The Problem

Concern about Long Island's hard clam fishery, for several years the province of fisheries experts and baymen, has gone public. A recent article in

NEWSDAY, one of Long Island's leading newspapers, sums up the problem succinctly:

> In the past five years, the clam catch has plummeted 46 per cent, and, although experts say they do not know precisely why, there are plenty of theories--including predators, poaching, overfishing and a changed environment. [1]

The sharp decline in clam harvest recalls the collapse of populations of one species of fish after another in New York's marine waters over the past hundred years [2], and has implications at both the local and national levels. Long Island's hard clam fishery is of both local and national importance. It employs over 7000 licensed commercial fishermen, who add more than $100 million annually to Long Island's economy [3], as well as providing food for many non-commercial (recreational) harvesters. Until recently, half the littlenecks, cherrystones and chowders sold across the county originated in Long Island's Great South Bay.

A variety of solutions for reversing the decline of Long Island's hard clams has been suggested, including size limits, sanctuaries, hatchery seeding, and a bounty on predators. Neither scientists nor policy-makers agree on what action, if any, to take. Theories abound, but the effectiveness of specific strategies for managing the hard clam resource is unknown.

Purpose

One group which is particularly interested in this problem is the New York Sea Grant Institute, which has been supporting a multi-disciplinary research program on the hard clam fishery of Great South Bay. In response to the needs of that organization, a series of models has been developed to test and evaluate alternative strategies to reverse the decline in hard clam harvests and/or stabilize the clam population. Five types of policies were evaluated: closed season, maximum size limit, hatchery seeding, bounty on predators, and nursery sanctuaries (closed areas).

Model Structure

The model looks at a small (1000 m^2) area, assumed to be in the midst of Great South Bay. It consists of three sectors--a clam sector, a predator sector, and a harvesting sector. The clam sector is represented by a five-level aging chain (larvae, juvenile clams, littlenecks, cherrystones and chowders), while the predators are patterned after one specific species, the whelk, which is representative of low-metabolism, slow-growing, long-lived clam predators. The predator population is divided into juvenile and adult stages. Clams and predators are assumed to be homogeneously dispersed within the model area. Harvesting is simulated as a fixed percentage of the standing crop of hard clams. The behavior of baymen in response to price and supply of clams is not included in this model.

The Clam Sector. The clam population is divided into five age groups--larval clams, juveniles, littlenecks, cherrystones and chowders. Larvae begin life as fertilized eggs. They float in the water column until they are about two weeks old, when their shells become large enough to pull them to the floor of the bay. Juvenile clams are sexually immature, but otherwise resemble adult clams. At about three years they reach sexual maturity, and, coincidentally, minimum legal harvestable size. The adult stages are divided into littlenecks (3 year olds), cherrystones (4 to 7 years), and chowders (8 to 25 years). Figure 1 shows juveniles, littlenecks, cherrystones and chowders represented as levels. Larval clams (LC1) were modelled as an auxiliary in order to reduce computation costs.

An earlier version of this model contains a full description of the structure and behavior of the clam sector [4]. The constant clam fertility has

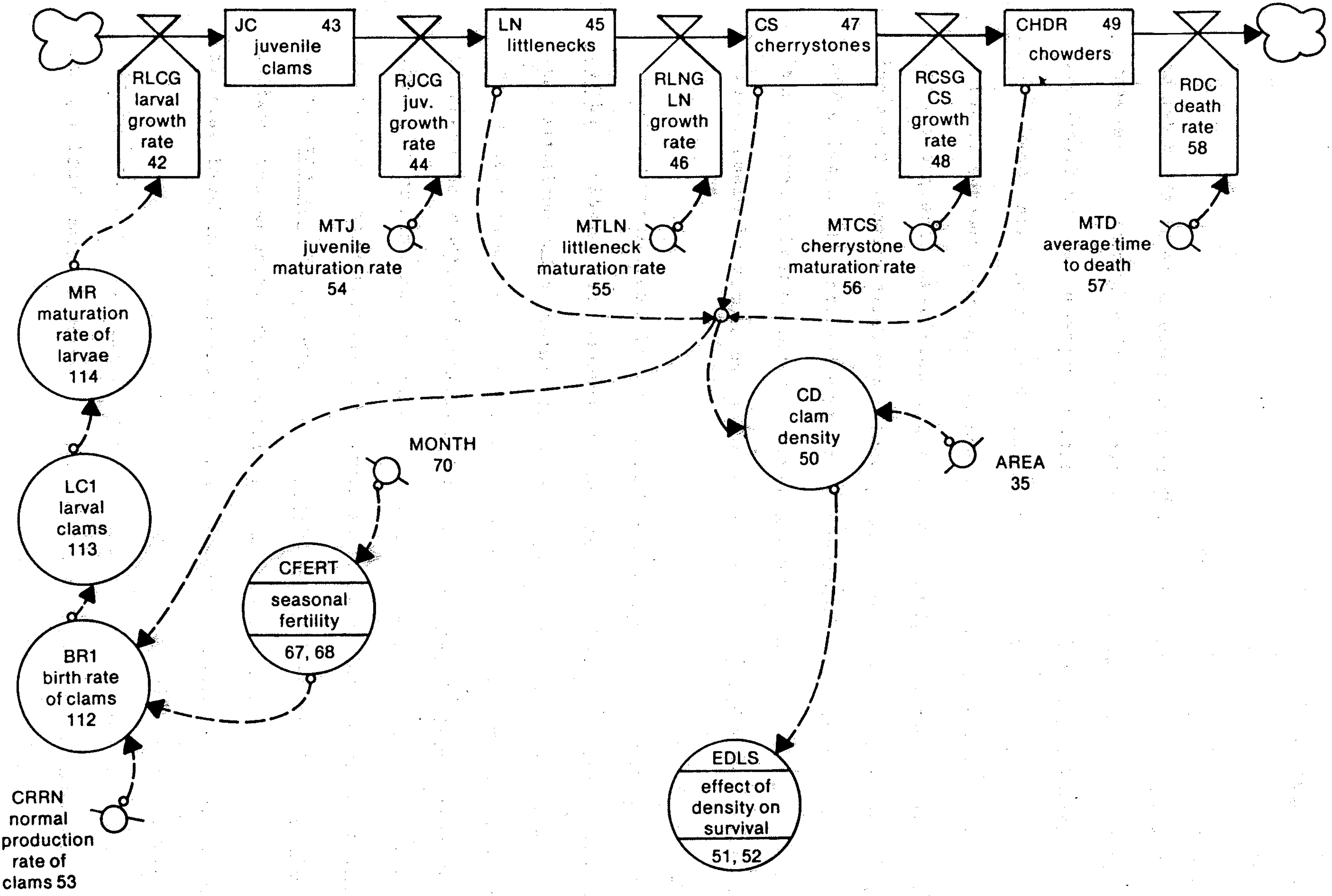


Figure 1. **CLAM SECTOR**

been replaced with seasonal fertility, based on what is known about the hard clam in Long Island's Great South Bay. The relationship between fertility and time of year is shown in Figure 2. Data are based on discussions with Robert Malouf and Monica Bricelj, Marine Sciences Research Center, SUNY/Stony Brook [5].

The Predator Sector. The main difference between this model and the work reported earlier [6] is the division of the predator population into two age groups, or levels--juvenile clam predators (JCP), which range in age from birth to twelve months and eat only juvenile clams, and large clam predators (LGCP), which are sexually mature, twelve to 36 months of age, and eat both littlenecks and cherrystones (but not chowders, which are considered to have outgrown natural predation).

The growth of the predator population is governed, in large part, by the size of the clam population. Four factors affect the size of the predator population (see Figure 3): the juvenile predator's death rate (JPDR), the juvenile predator's maturation rate (RPM), fecundity (FECUND), and the adult predator's lifetime (PLTM). The influence of clams on the predator population is shown in Figure 4. The larger the population of juvenile clams (JC), the greater the density of juvenile clams (DJC). This greater density reduces the predator's "search time", and results in the location of more food per day (JCETN), and thus a higher nutritional level for the predator. The higher the nutritional level has two consequences. First, it reduces the death rate of the juvenile predator (STARV), and second, the better-fed predators mature more quickly (JCPGRF). The converse is also true. A sparse juvenile clam population will result in a higher juvenile predator death rate and a slower maturation time.

The abundance of large clams affects the large predators in a similar

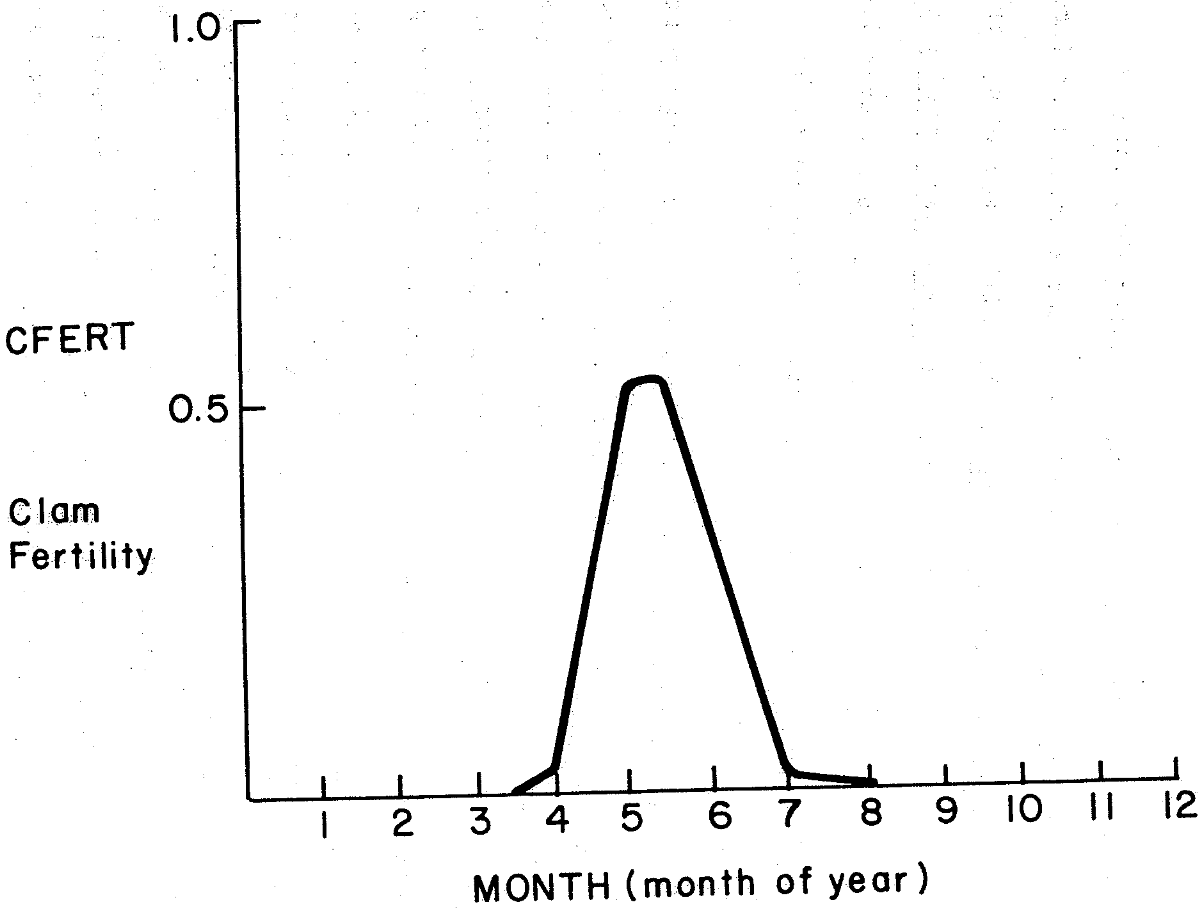


Figure 2. Seasonal Clam Fertility Table

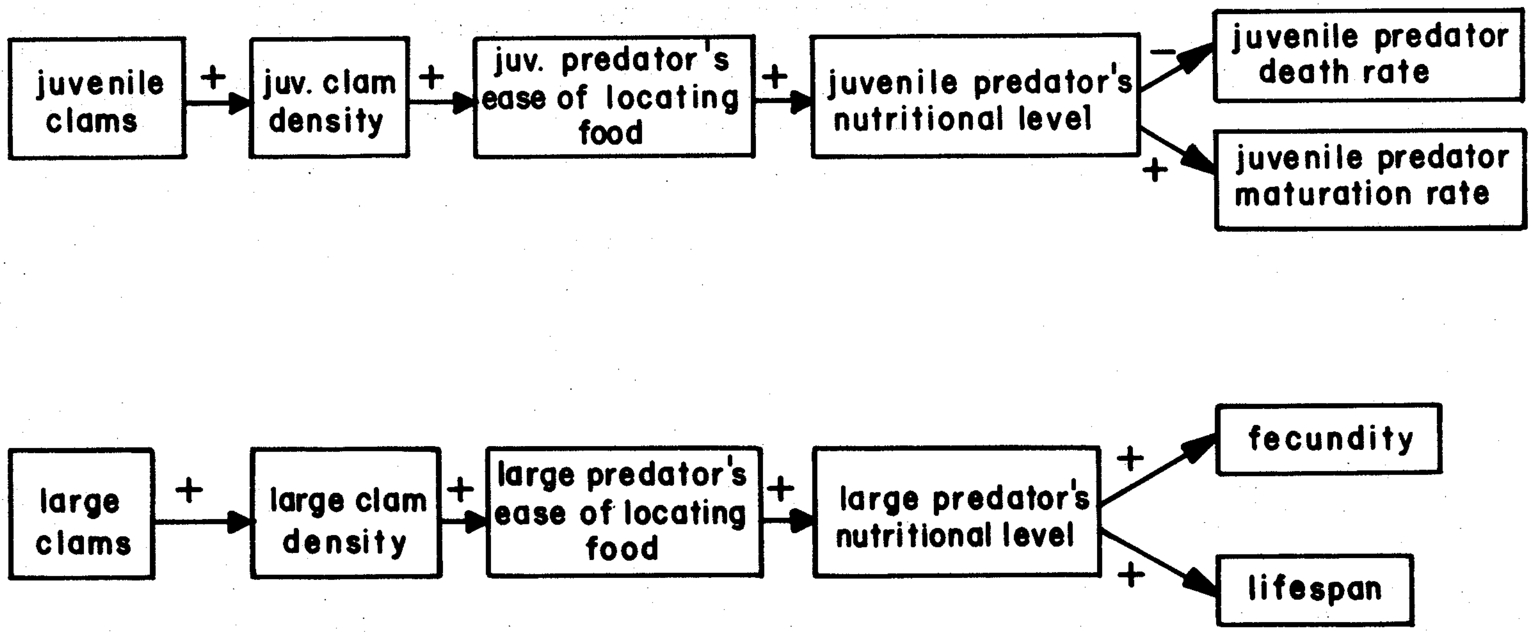
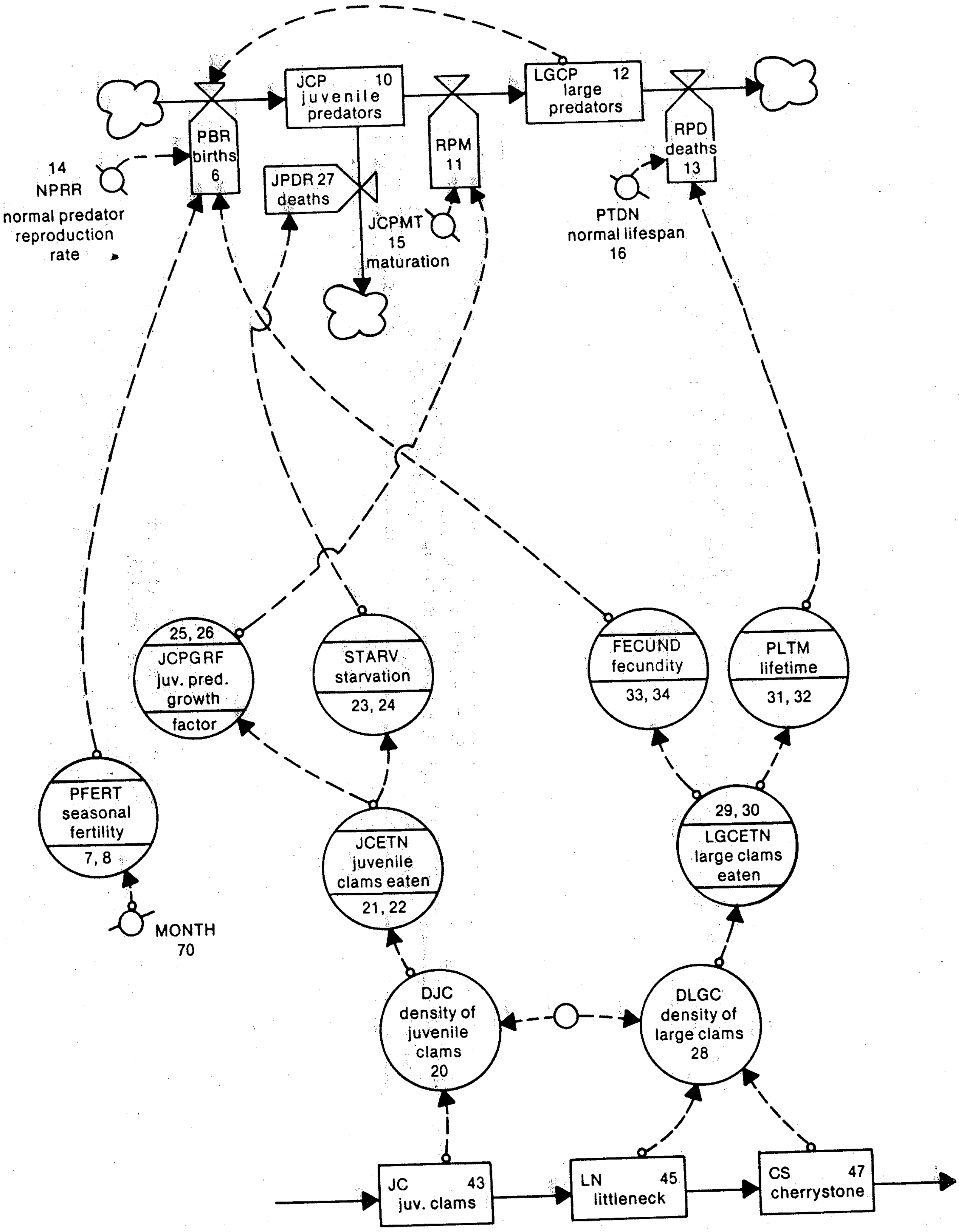


Figure 3: Factors Affecting the Size of the Predator Population

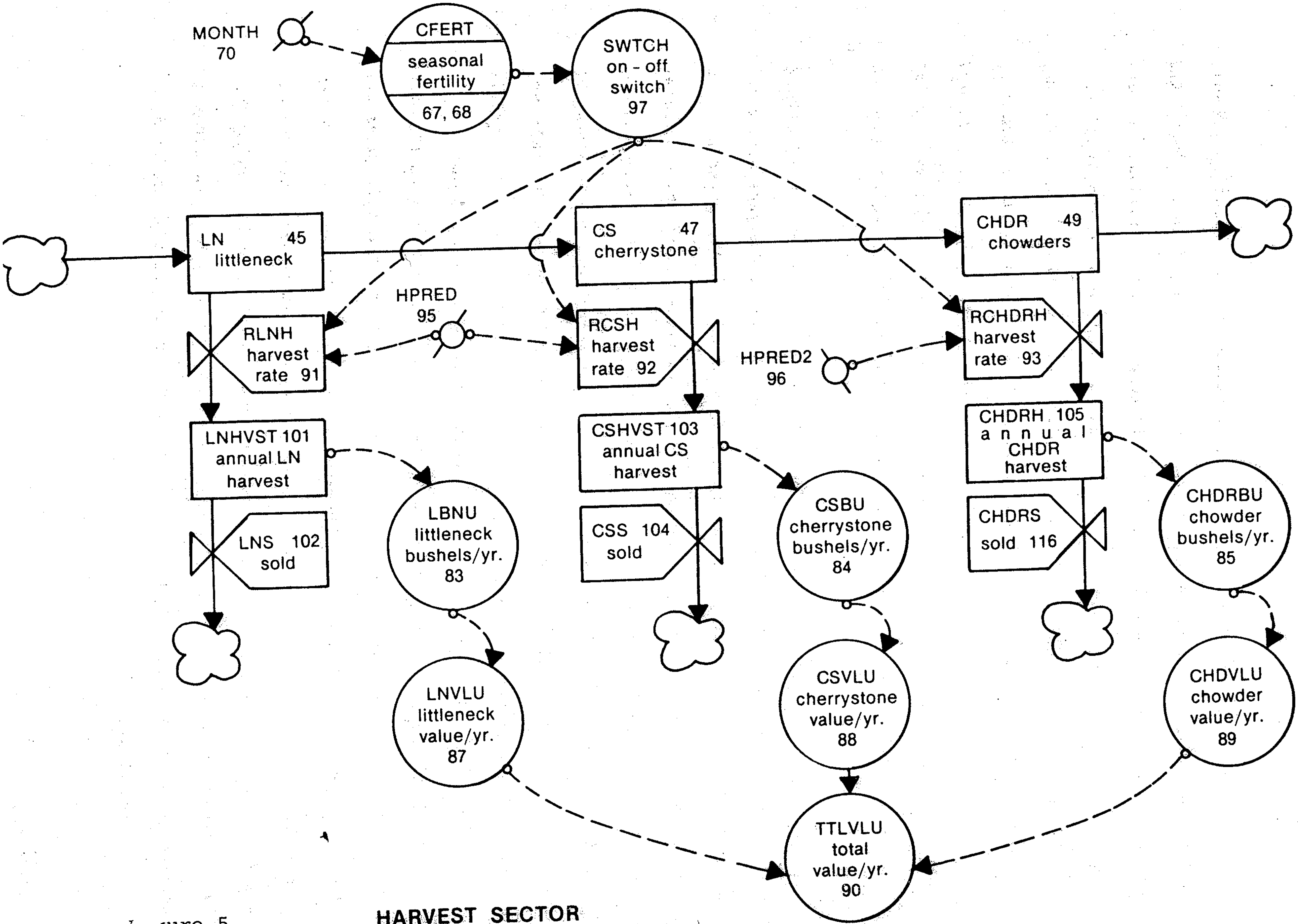
Figure 4. **PREDATOR SECTOR**



fashion. The more large clams (LN and CS), the greater their density (DLGC), and the greater the large clam predator's ease of locating food (LGCETN). The easier it is to locate food, the higher the large predator's nutritional level. The higher the nutritional level of the adult predators, the higher their fecundity (FECUND), and the longer they will live (PLTM). Data on the consumption of clams by predators were derived from research currently underway by Mary Gibbons at the Marine Sciences Research Center, State University of New York at Stony Brook [7]. Other relationships between clams and predators are based on consultations with Dr. Robert Malouf, Shellfish Biologist, also at Stony Brook [8].

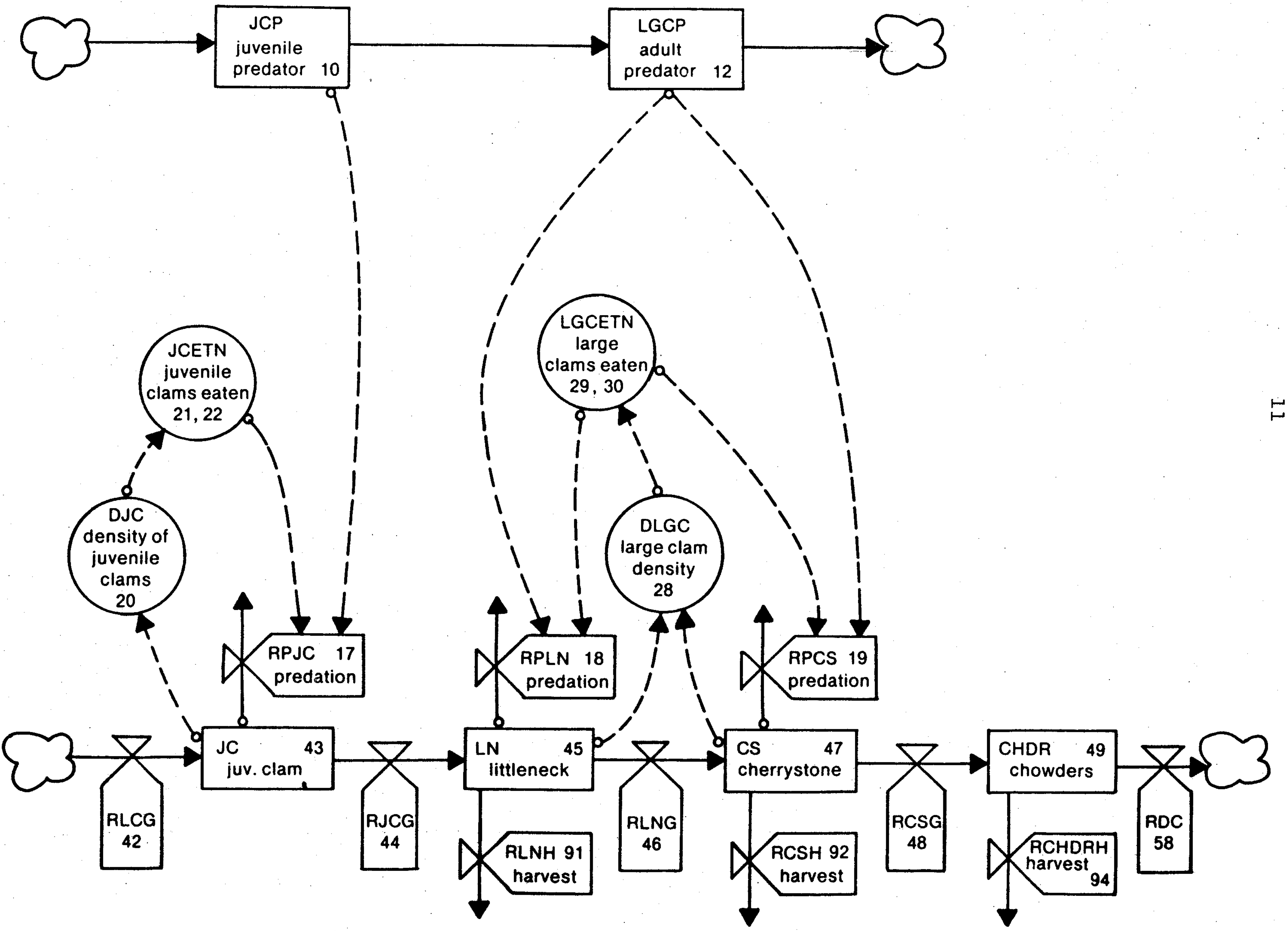
The Harvesting Sector. Figure 5 shows that only littlenecks, cherrystones and chowders are subject to harvesting, since younger clams are generally below minimum legal size. Harvesting is simulated as 6 percent of the standing crop per month, or about 80 percent per year, a high figure supported by biological surveys of the clam population of Great South Bay [9]. This simplified representation of harvesting permits a clearer understanding of the impact of alternative management policies on the basic prey-predator system. It ignores, however, the potentially powerful influence of the baymen. A new set of models is therefore being developed which incorporate the behavior of the baymen.

Effect of Predators and Fishing on Clams. The effect of both predation and fishing on the clam population is displayed in Figure 6. Juvenile predators reduce the juvenile clam population through the rate of predation on juvenile clams (RPJC), which is a function of the effect of clam density (DJC) on the number of juvenile clams eaten (JCETN), and the number of juvenile predators. Littlenecks and cherrystones are similarly reduced by the large clam predator through the rate of predation on littlenecks (RPLN) and the rate of predation on cherrystones (RPCS).



ure 5. **HARVEST SECTOR**

Figure 6. **EFFECT OF PREDATORS . D FISHING ON CLAMS**



Policy Alternatives

In all cases the policies are inserted into a prey-predator system in equilibrium. While such an equilibrium is clearly unnatural, it permits the understanding of the impact of various policies under controlled conditions. This approach is particularly useful at this stage of the model-building process, allowing the researcher to gain better insight into the underlying behavior of predator and prey to external manipulation [10].

Closed Season. One approach used to manage fisheries is the closed season. This concept is simulated by cutting off all harvesting during the clam's spawning season. The confluence of biology and regulation suggests that this might be a useful strategy. Biologically, clams reach sexual maturity about their third year. However, regulations written many years ago set a 1-inch minimum legal size for hard clams, which most reach at about three years of age. Thus many littlenecks, or three year olds, may never have an opportunity to spawn before being caught. A closed season would permit littlenecks at least one spawning season.

Maximum Size Limit. Jon Conrad, a resource economist at Cornell University, has suggested that imposing a maximum size limit might increase net economic return from the clam fishery: "These cohorts are more valuable in Great South Bay as spawning stock than in the market." [11]. His reasoning is based on the chowders's low market value ($11/bu vs. $22-23/bu for cherrystones and $63-65/bu for littlenecks) combined with their high fecundity. This policy tests the impact of curtailing all harvesting of chowders.

Seeding. Stocking lakes and rivers with hatchery raised fish is another common management practice. Baymen strongly favor expanding existing programs which add small clams, called "seed", from hatcheries to augment the wild clam stock, a practice known as "seeding." Seeding is simulated as the annual addition of an amount of hatchery-raised seed equal to a normal year's natural spawning from the bay--a level far beyond the hatcheries's realistic output.

Since an earlier version of this model [12] indicated that seeding alone has little or no effect on increasing stocks of hard clams, several modified seeding strategies are examined. (1) Time of seeding. There is some biological evidence that the time that seed is added to wild stocks affects their survival. Two approaches were therefore tested for comparison, seeding in the fall (after the predators have spawned), and seeding in the spring (permitting a full season's growth). (2) Growing seed on racks. Michael Castagna, Virginia Institute of Marine Sciences, has found that the survival of seed introduced from hatcheries can be raised from near zero to over 90 percent by protecting the young seed from predators [13]. One way of protecting the seed is to grow them on racks above the bay bottom, out of reach of most predators.

Bounty on Predators. The idea of instituting a bounty comes from management policies applied to other species. A classic System Dynamics exercise, for example, looks at the impact of a bounty on mountain lions on the deer population of the Kaibab Plateau. The high bounty assumes that baymen will harvest predators with the same intensity as clams. The low bounty assumes that baymen will merely treat predators as an incidental catch, no longer throwing them back into the bay.

Sanctuary. Conventional wisdom and sampling studies [14] support the idea that the density of clams is far greater in portions of the bay closed to harvesting for many years because of pollution than in "open", or generally harvested, areas. The closed areas also contain a much larger proportion of older, more fertile, clams. This policy tests the effectiveness of setting aside portions of the bay as natural breeding sanctuaries, an idea analogous to the medieval "three field system" of agriculture. Figure 7 shows how the

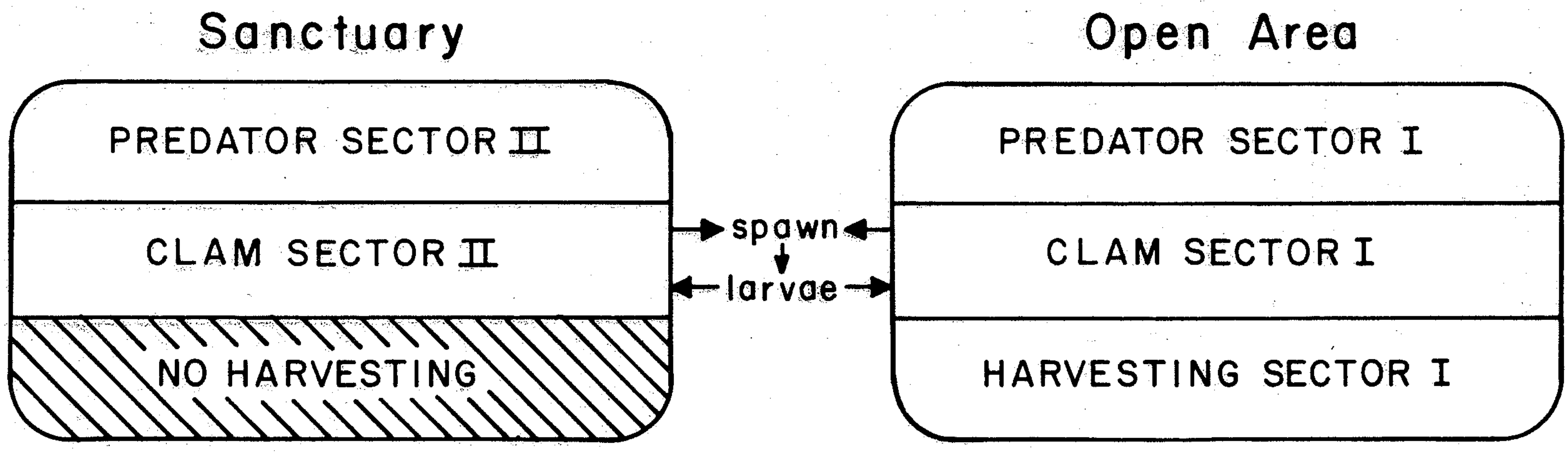


Figure 7. Modelling the Sanctuary Policy

sanctuary policy was modelled. The original model (open area) was duplicated to represent a second 1000 m^2 area adjacent to the original open area. The expanded sanctuary model assumes that clams spawned from the two sectors will mix and the resulting larvae will be evenly divided among the open and closed areas.

<u>Results</u> Policy effectiveness was judged in terms of both short term (arbitrarily set as the first ten years after policy implementation) and long term (ten to twenty years following the sustained use of a given policy) effects on the annual value of clam harvests. Results are given in Table 1. In the short term exceptional improvement was shown only with a high bounty on predators (72.6 percent increase in total value). Two of the policies (maximum size limit and the sanctuary), were ineffective in increasing market value. Five alternatives produced modest increases (8.0 to 17.0 percent). Instituting a closed season led to a loss of over one-fourth in total value in both the short term and the long term. Only the two bounty policies produced significant increases in the value of clam harvests in the long term (20.4 percent for the low bounty and 66.4 percent for the higher bounty.)

Table 1. CHANGES IN TOTAL ANNUAL VALUE OF CLAM HARVESTS FOR ALTERNATIVE MANAGEMENT STRATEGIES

Management Option	Years 1-10 Percent Change Over Base Year*	Years 11-20 Percent Change Over Base Year
1. Closed Season	-26.0	-28.3
2. Maximum Legal Size	- 1.7	- 0.3
3. Seeding		
-spring seeding	10.4	1.6
-fall seeding	8.0	- 0.1
-spring seeding on racks	10.6	1.9
-fall seeding on racks	10.8	2.6
4. Bounty		
-low bounty	17.0	20.4
-high bounty	72.6	66.4
5. Sanctuary	2.4	1.8

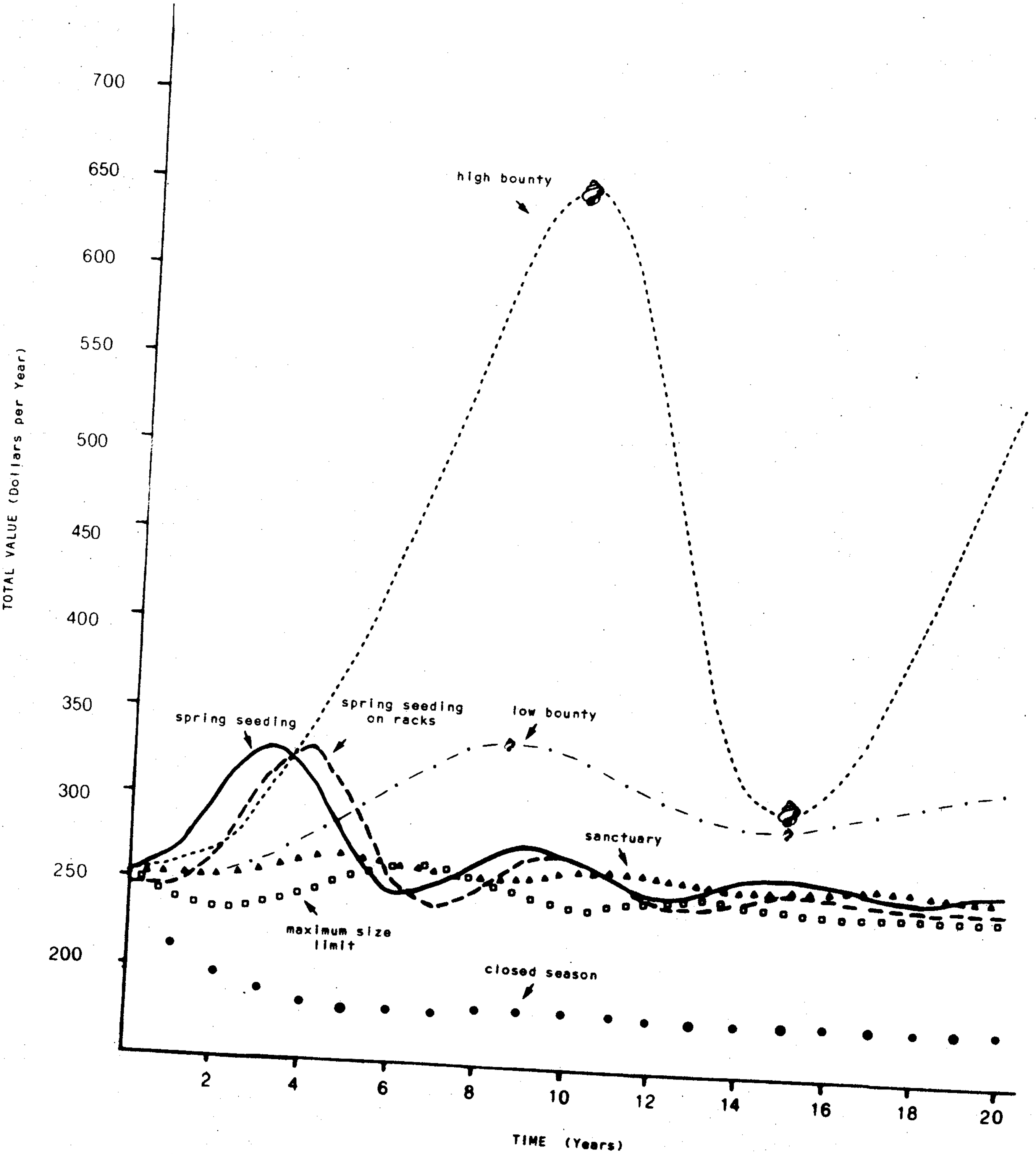
*Base Year = Year 0

Figure 8 indicates a the behavior of several of the management policies over the 20-year period. While data in Table 1 indicate that the high bounty lead to the highest average increase in total value, the graph shows that the high bounty also introduces considerable instability into the system. On the other hand, the sanctuary option, which has but a modest effect on total value, causes little disturbance to the system.

Future Directions

Work is currently underway to introduce the social and economic behavior of the baymen into the model [15]. The new version replaces the current harvesting method--80 percent of the standing crop per year--with a set of complex relationships between clam abundance, price, fishing effort and number of baymen. In addition, since both biologists and baymen recognize that high-metabolism, short-lived predators such as green crabs or mud crabs are responsible for much of the mortality of juvenile clams, they, too, will be added in the next version.

Figure 8. Annual Value of Harvest for Selected Policies



Finally, the difference between the information in Table 1, which indicates that a high bounty will clearly increase annual revenues over the first and second ten years following its introduction, and Figure 8, which shows that the same policy creates significant instability in annual income, suggests that evaluating the effectiveness of alternative policies is, in itself, a complex problem. Clearly there is a need to continue the analysis of system dynamics output beyond the interpretation of model behavior. Therefore, major attention will be given to the question of evaluating the "effectiveness" of alternative management policies for hard clams, a problem neglected in System Dynamics, but of crucial importance to shellfish managers.

References

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2. McHugh, J. L. 1972. "Marine Fisheries of New York State," in Fishery Bulletin, V. 70, No. 3, 585-610.
3. Nassau-Suffolk Regional Planning Board. 1974. Guidelines for the Management of Long Island's Hard Clam Resources.
4. Steinberg, Marian N. 1980. "A Preliminary System Dynamics Model of the Effectiveness of Shellfish Hatcheries on Increasing Harvestable Yields." Proceedings of the 1980 IEEE Conference.
5. Malouf, Robert (Shellfish Biologist) and Monica Bricelj (Doctoral Candidate), Marine Sciences Research Center, SUNY/Stony Brook. Personal communication.
6. Steinberg, op. cit.
7. Gibbons, Mary. Doctoral Candidate, Marine Sciences Research Center, SUNY/Stony Brook. Personal communication.
8. Malouf, op. cit.
9. WAPORA, Inc. Estuarine Impact Assessment (Shellfish Resources) for the Nassau-Suffolk Streamflow Augmentation Alternatives.
10. A technical report describing the effect of these policies on the basic prey-predator system is currently being drafted.
11. Conrad, John M. 1981. "Management of a Multiple Cohort Fishery: The Hard Clam in Great South Bay." Unpublished manuscript. Department of Agricultural Economics, Cornell University.
12. Steinberg, op. cit.
13. Castagna, Michael, Virginia Institute of Marine Sciences. Personal communication.
14. WAPORA, op. cit.
15. Steinberg, Marian N. Memorandum, "Expanded Harvesting Sector." May 18, 1981.

APPENDIX. Equation List, Base Model

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@XQT,D STAT*DYNAMO.DYNAMO


P-  1 RUN-          MINI-DYNAMO  * VERSION 1.0


* BASE RUN -- CONTINUOUS HARVESTING
* CLAM*MODELS.HVST
* COPYRIGHT APRIL 6, 1981
* MARIAN N. STEINBERG, GSPA, SUNY/ALBANY
* MONTHLY CALCULATION, SEASONAL FERTILITY
R PBR.KL=LGCP.K*NPRR*FECUND*PFERT.K
A PFERT.K=TABLE(PFT,MONTH.K,0,12,.5)
T PFT=0/0/0/0/0/0/0/.12/.22/.25/.28/.29/.29/.30/.29/.28
X 7.27/.25/.23/.11/ /0/0/ /
L JCP.K=JCP.J+(DT)(PBR.JK-RPM.JK-JPDR.JK)
R RPM.KL=(JCP.K/JCPMT)*JCPGRF
L LGCP.K=LGCP.J+(DT)(RPM.JK-RPD.JK)
R RPD.KL=LGCP.K/(PTDN*PLTM.K)
C NPRR=3
C JCPMT=36
C PTDN=240
R RPJC.KL=JCETN.K*JCP.K
R RPLN.KL=(LN/(LN+CS))*LGCP.K*LGCETN.K
  RPCS.KL=LGCP.K*(CS/(LN+CS))*LGCETN.K
  DJC.K=JC.K/AREA
A JCETN.K=TABHL(JCETNT,DJC.K,0,28,4)
T JCETNT=0/.25/.65/1.5/2.5/3.1/3.4/3.5          ←
A STARV=TABHL(DRMT,JCETN.K,0,4,.5)
T DRMT=1/.53/.3/.19/.1/.05/.02/.02/.0
A JCPGRF.K=TABHL(JCPGRT,JCETN.K,0,4,.5)
T JCPGRT=0/0/.1/.25/.45/.65/.85/.95/1
R JPDR.KL=JCP.K*STARV.K
A DLGC.K=(CS.K+LN.K)/AREA
A LGCETN.K=TABHL(LGCATT,DLGC.K,0,20,5)
T LGCATT=0/.6/1.8/3.2/3.5
A PLTM.K=TABHL(PLTMT,LGCETN.K,0,4,.5)
T PLTMT=0/0/.6/.76/.89/.93/.98/.99/1
A FECUND.K=TABLE(PERMT,LGCETN.K,0,4,.5)
T PERMT=0/0/.1/.23/.55/.76/.98/.99/1
C AREA=1000
N JCP=JCPI
C JCPI=122.56
N LGCP=LGCPI
C LGCPI=192.85
NOTE CLAM*MODELS.3-2-81
NOTE CLAM SECTOR MONTHLY, SEASONAL SPAWNING
R RLCG.KL=MR.K
L JC.K=JC.J+(DT)(RLCG.JK+SEED.JK-RJCG.JK-RPJC.JK)
  RJCG.KL=JC.K/MTJC
  LN.K=LN.J+(DT)(RJCG.JK-PL[illegible]H.JK-RLNG.JK-RPLN.JK)
R PLNG.KL=LN.K/MTLN
L CS.K=CS.J+(DT)([illegible].JK-[illegible].JK-[illegible].JK-[illegible].JK)
  [illegible]
  [illegible]
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```
A CD.K=(LN.K+(1.5*CS.K+2*CHDR.K))/AREA
A EGLS.K=TABHL(SURV,CD.K,0,200,50)
T SURV=1/.9/.6/.15/0
C CHR.=1
C MTJ=36
C MTLN=12
C MTCS=48
C MTD=216

P=  2 RUN-        BASE RUN -- CONTINUOUS HARVESTING

R RDC.KL=CHDR.K/MTD
N JC=JCI
C JCI=18434
N LN=LNI
C LNI=3274.5
N CS=CSI
C CSI=2499.6
N CHDR=CHDRI
C CHDRI=799.99
A CFERT.K=TABLE(FT,MONTH.K,0,12,.5)
T FT=0/0/0/0/0/0/0/0/.35/.26/.52/.524/.35/.18/.03
X /.03/ /././ /./ / / /[illegible]
A MONTH.K=TIME.K-STIME.K
A STIME.K=SAMPLE(TIME.K,INTVL,NITIAL)
C NITIAL=0
C INTVL=12
NOTE   ***   ***   ***    BEGIN SEEDING POLICY    ***    ***    ***
R SEED.KL=SEEDS.K/1
A SEEDS.K=PULSE(QUANT/DT,T1,INT)
C QUANT=10000
C T1=8000
C INT=12
NOTE   ***   ***   ***      END SEEDING           ***    ***    ***
NOTE
NOTE   ***   ***   ***    BEGIN FISHING    ***    ***    ***
A LNBU.K=LNHVST.K/500
A CSBU.K=CSHVST.K/275
A CHDRBU.K=CHDRH.K/175
A MXCBU.K=LNBU.K+CSBU.K+CHDRBU.K
A LNVLU.K=LNBU.K*36
A CSVLU.K=CSBU.K*11
A CHDVLU.K=CHDRBU.K*5
A TTLVLU.K=LNVLU.K+CSVLU.K+CHDVLU.K
R RLNH.KL=LN.K*HPRED*SWTCH
R RCSH.KL=CS.K*HPRED*SWTCH
R RCHDRH.KL=CHDR.K*HPRED2*SWTCH*MAYSIZ
C MAYSIZ=1     1 PERMITS HARVESTING OF CHDR, 0 DOESN'T
C HPRED=.[illegible]
C HPRED2=.[illegible]
A SWTCH.K=CLIP([illegible])
NOTE [illegible] IF [illegible]
C [illegible]
  Y[illegible]=[illegible]
```

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L LNHVST.K=LNHVST.J+(DT)(RLNH.JK-LNS.JK)
R      .KL=LNHVST.K/12
L CSHVST.K=CSHVST.J+(DT)(RCSH.JK-CSS.JK)
R CSS.KL=CSHVST.K/12
L CHDRH.K=CHDRH.J+(DT)(RCHDRH.JK-CHDRS.JK)
N LNHVST=LNHI
C LNHI=2295
N CSHVST=CSHI
C CSHI=1766.6
N CHDRH=CHDHI
C CHDHI=576.24
A BR1=(LN.K+(2*CS.K)+(2*CHDR.K))*CPRN*EDLS.K*CFERT.K
A LC1.K=BR1.K*.5
A MR.K=LC1.K*2


*- 3 RUN-          BASE RUN -- CONTINUOUS HARVESTING


R CHDRS.KL=CHDRH.K/12
PRINT LNBU,LNHVST,CSBU,CSHVST,CHDRBU,CHDRH,MXDBU,LNVLU,CSVLU,CHDVLU,
X TTLVLU
PRINT JCP,LGCP,LN,LC1,JC,CS,CHDR
PLOT LNBU=1,CSBU=2,CHDRBU=3(0,10)/MXDBU=T(0,20)
PLOT JCP=*,LGCP=+(0,800)/LN=1(0,5000)/CS=2(0,4000)/JC=J(1000,
X      00)/CHDR=3(0,8000)
PLOT LNVLU=1(0,250)/CSVLU=2(0,200)/CHDVLU=3(0,25)/TTLVLU=*(0,400)
SPEC DT=.25/PRTPER=12/PLTPER=3/LENGTH=12
RUN BASE RUN
    COMPILED -
```