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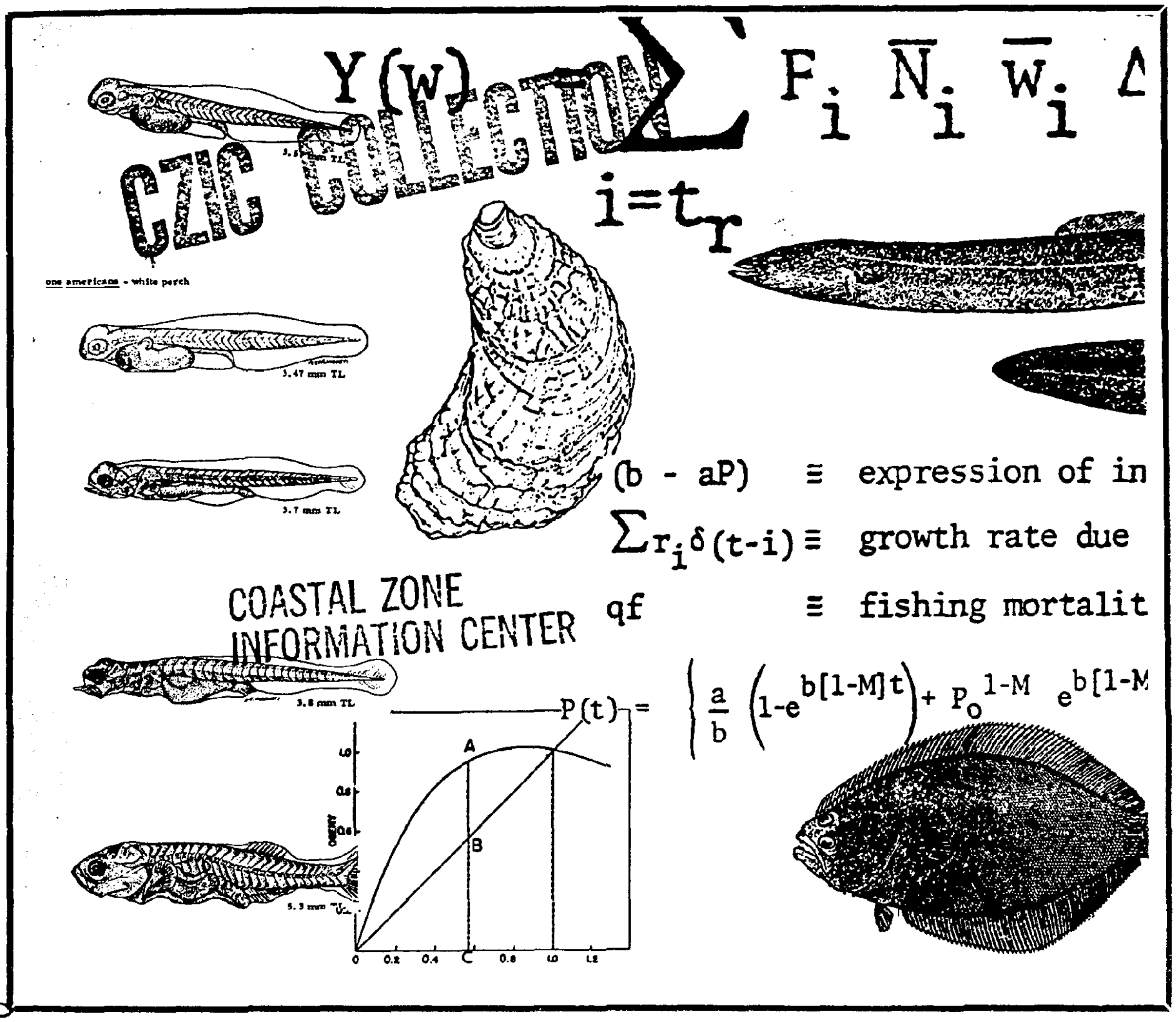
A Review and Evaluation of Fisheries Stock Management Models



Maryland. Dept. of Natural Resources

A REVIEW AND EVALUATION OF FISHERIES STOCK MANAGEMENT MODELS

Part I - Text

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I. INTRODUCTION

The major objective of this study is to assess the suitability of existing fisheries production and population models for use in the management of Maryland's tidewater fisheries. Volume I of this report contains Phase I of the project, consisting primarily of 1) a literature review of quantitative fisheries yield and management models and 2) life history data of selected Maryland species. Volume II contains bibliographies of literature used in the Phase I activities. This interim report presents the results of work performed by the Martin Marietta Environmental Center (EC) for the Coastal Resources Division (CRD) of the Maryland Tidewater Administration, under contract C12-80-430.

Quantitative models serve several important functions in the management of living resources. By serving as a means of organizing, causally connecting, and relating various kinds of population, exploitation and economic data, they provide the basis for conceptualizing problems in management policy. Because data-input and model structures are goal oriented, models also reveal information deficiencies and inadequacies.

The application of numerical schemes for catch prediction in a fishery was initiated by Baranov; it was he who first proposed the concept of surplus production, stating that "... a fishery, by thinning out a fish population, itself creates the production by which it is maintained" (Baranov, 1927).*

The concept of surplus production and its use can be illustrated by a diagram, such as shown in Figure I-1 (from Ricker, 1978). This curve relates magnitude of the parent stock (as measured alternatively in numbers, weight, egg production, etc.) to numbers of individuals recruited into the adult or exploited population. A population can be viewed as being at an equilibrium level that is consistent with the carrying capacity of its environment. If the population size deviates from this level, the population acts to restore itself to its equilibrium by increased or decreased survival and growth. If harvesting of an unexploited stock causes the population to decline to level C in Figure I-1, the population responds with an increase of magnitude AB.

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* from Ricker (1978)

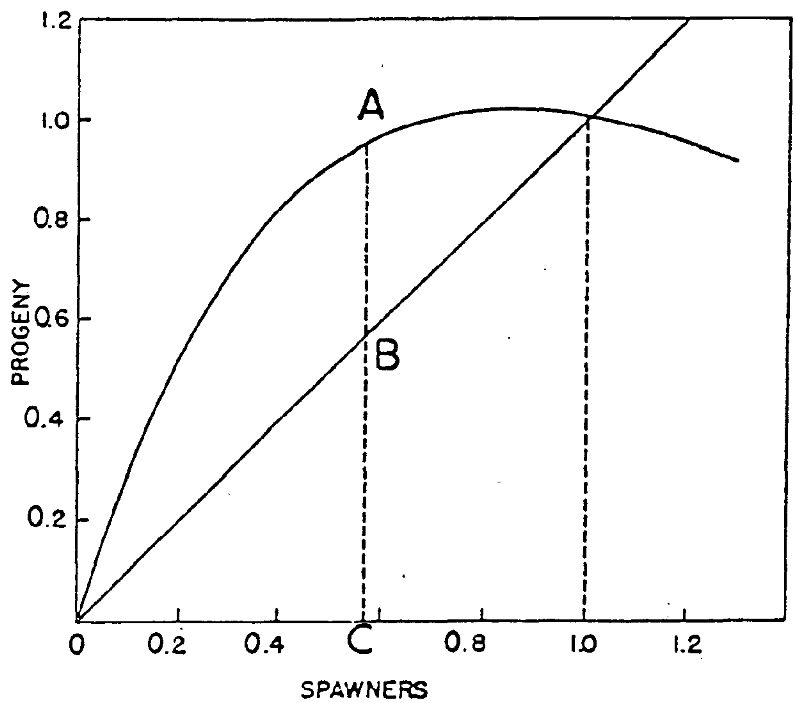

Figure I-1. A Ricker-type stock recruitment curve, illustrating the concept of surplus production; the distance A-B represents the amount of progeny which can be harvested at population size C without decreasing the population size further (from Ricker, 1978).

As long as a harvest generated by recruitment of magnitude AB is taken each year, the population remains around a constant, equilibrium level C. Of course, growth of the recruits in a single age group or cohort will influence the magnitude of biomass harvest from that cohort, depending on the age at harvest. Figure I-2 shows the influence of natural mortality and growth upon cohort biomass. The relationship depicted in Figures I-1 and I-2 form the basis of many mathematical fisheries models.

The population level at which surplus biomass production is maximized will generate the Maximum Sustainable Yield (MSY), a term frequently used in fisheries literature. Many fisheries management programs have focused on attaining MSY. More recently, the alternative concept of Optimum Sustainable Yield (OSY) has been promoted in fisheries management (Larkin, 1977). In this approach, the major management goal is not only the maximization of biomass yield but, alternatively, the maximization of economic return, or "benefit" to the ecosystem, or optimum recreational activity, for example. Much of the current literature, particularly in bioeconomics, deals with optimization of fisheries yields from different perspectives.

The concepts presented here, described in a somewhat simplistic manner, form the basis for most mathematical formulations of exploited populations presented in the fisheries literature. Generally, these formulations relate the reproductive potential of a population and growth of members of that population to mortalities caused by man as well as by natural phenomena. They can thus be used to examine consequences of various levels of exploitation and of other environmental perturbations caused by man to resource stocks. The major limitation in model applications, however, is that certain simplifying assumptions about population dynamics must generally be made, and the validity of model output will be heavily dependent upon whether various assumptions employed are reasonable in a variable real world. Thus, a comparison of model characteristics to life history characteristics of the species considered provides a first step in assessing model applicability.

Also, data requirements of models vary widely, depending on their level of complexity. The most simplified models, which tend to be those based on the greatest number of assumptions, usually require the least data. Models which attempt to account for most factors influencing fisheries populations require the greatest amounts of data. Thus, assessment of model suitability

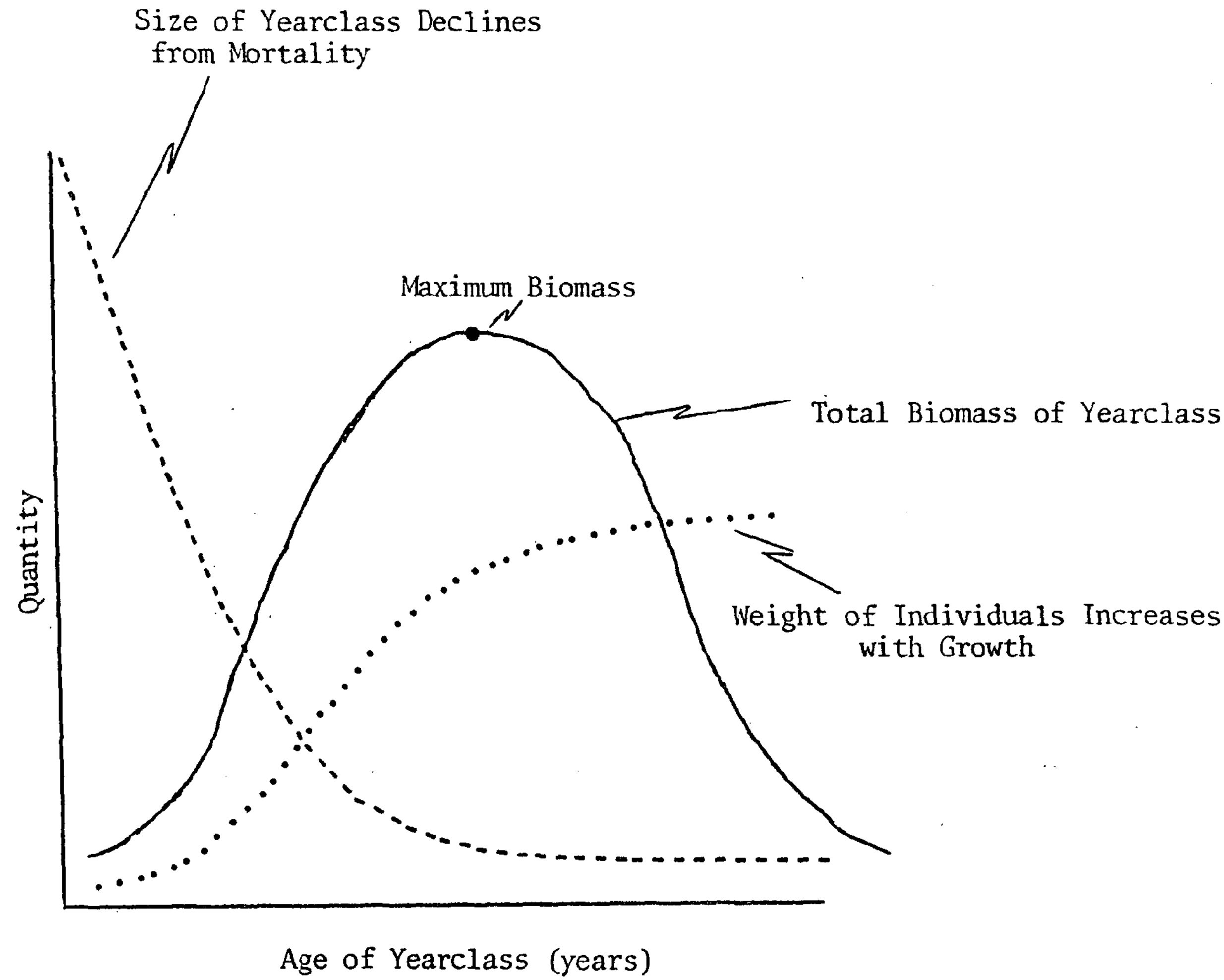

Figure I-2. Change in size and total weight of a year class of fish as a function of age, showing the concept of maximum biomass yield from such a year class (modified from Rounsefell, 1975).

involves a review of data availability, data quality, and means of acquiring and estimating properties of the necessary data.

The organization of this project is based on the relationship noted above. The Phase I work reported here consists of: 1) an extensive review of literature on current and classical fisheries models and their application; 2) documentation of life history characteristics of selected, exploited Maryland species; 3) an evaluation of suitability of existing models that use assumptions and mathematical structures consistent with the life histories of particular Maryland species; and 4) a review of literature dealing with input* models to production models or means of deriving parameters for such models. Phase II activities will center on 1) a review of fisheries data currently available in Maryland; 2) an assessment of data needs for the application of management models; 3) the development of recommendations concerning data acquisition and processing procedures; and 4) the detailed assessment of the applicability of potentially suitable production or population models to selected Maryland species.

Since the study is ongoing, the results of Phase I presented here may be modified or appended during the course of Phase II investigations. Any such modifications will appear in the final project report.

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* An input model is generally considered a mathematical formulation which represents processes (e.g., growth or recruitment) other than changes in numbers of individuals in the population.

II. REVIEW OF FISHERIES MODEL LITERATURE

A. Objective

To evaluate the suitability of yield and management models for use with Maryland species, we first had to identify potentially useful models and document their mathematical structure. The first step in this task was to locate literature on mathematical models which have been used in the management of fisheries or which, because of their tractable and useful mathematical structure, might have management applicability.

B. Selection Criteria and Search Procedures

Initial selection of potentially relevant articles was based on the titles of papers and reports. Key words used in both computerized library retrieval searches and in the direct review of readily available journals and books were:

- fish management (1)
- fish yield (2)
- fish population (3)
- model of stock recruitment (4)
- model of fish management (5)
- model of fish population (7)
- mathematical model of (4) to (7)

The library retrieval services employed in the literature review are listed in Table II-1. A total of 249 abstracts was obtained as a result of this search. From examination of the titles, we culled many articles that appeared irrelevant to the study and did not appear in bibliographies of other selected articles.

Issues of all applicable in-house journals and books were directly reviewed, based on the key words noted above. Journals and books covered in this review are listed in Table II-2.

Table II-1. Results of library retrieval searches employed in the review of fisheries model literature

Retrieval Service	Sources Covered	Inclusive Dates	Number of Abstracts Obtained
DIALOG Biosis Previews	Biological Abstracts and Bioresearch Index: 2,265,000 citations	1969 - present	103
DIALOG Enviroline	Periodicals, government publications, industry reports, proceedings of meetings: 75,000 citations	1971 - present	52
DIALOG Oceanic Abstracts	Journals, books, technical reports, conference proceedings, governmental and trade publications: 110,500 citations	1964 - present	35
NTIS	Government-sponsored research, development, and engineering reports: 725,000 citations	1964 - present	59

Table II-2. Martin Marietta-owned journals and books used in the review of fisheries model literature

Journals

(P = Present)

Bulletin of Mathematical Biology (1973-P; Volumes 35-41)
Chesapeake Science (Complete; Volumes 1-18)
Coastal Zone Management Journal (1975-P; Volumes 2-5)
Deep Sea Research (1973-P; Volumes 20-26)
Ecology (1972-P; Volumes 53-60)
Ecological Modelling (Complete; Volumes 1-7)
Estuaries (Complete; Volumes 1-2)
Estuarine and Coastal Marine Science (1974-P; Volumes 2-8)
Fish Bulletin (1974-P; Volumes 72-77)
Journal of Experimental and Marine Biology (1978-P; Volumes 32-39)
Journal of Fish Biology (1974-P; Volumes 6-14)
Journal of Fisheries Research Board, Canada (1973-P; Volumes 30-36)
Journal of Marine Biological Association, U.K. (1973-P; Volumes 53-59)
Journal of Marine Research (1974-P; Volumes 32-36)
Marine Biology (1974-P; Volumes 24-52)
Oecologia (1975-P; Volumes 18-34)
Proceedings of National Shellfisheries Association (1973-1977;
Volumes 63-67)
Transaction of American Fisheries Society (1971-P; Volumes 100-108)

Books

Books

Cushing, D.H. 1975. Marine Ecology and Fisheries. London: Cambridge University Press. 278 pp.

Gulland, J.A. (ed.). 1977. Fish Population Dynamics. New York: John Wiley and Sons. 372 pp.

Harden-Jones, F.R. (ed.). 1974. Sea Fisheries Research. New York: John Wiley and Sons. 510 pp.

Knauss, J. (ed.). 1979. Climate and Fisheries. Center for Ocean Management Studies. Kingston, Rhode Island. 135 pp.

Ricker, W.E. (ed.). 1971. Methods for Assessment of Fish Production in Fresh Waters. Oxford: Blackwell Scientific Publications. 348 pp.

Ricker, W.E. 1978. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Bd. Canada 191. 382 pp.

Smith, R.F. (ed.). 1966. A Symposium on Estuarine Fisheries. Am. Fish. Soc. Spec. Publ. 3. 154 pp.

Van Winkle, W. (ed.). Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Administration, and Electric Power Research Institute.

Considerable overlap with the titles acquired in the library retrieval process was noted. Bibliographies of all articles obtained in-house were also searched.

An attempt was made to acquire copies of all the possibly relevant articles. Acquisition was restricted to those articles published since 1960, with the exception of some which are considered "classics" based on their frequency of citation (e.g., Schaefer, 1954, 1957; Beverton and Holt, 1957; and Graham, 1935). Two hundred and twenty-three were ordered through interlibrary loan. Since considerable time lags occurred between distribution, 28 of the articles ordered had not been received by the end of Phase I. These articles will be reviewed and added to the annotated bibliography (Appendix A) upon receipt.

III. CHARACTERIZATION OF STOCK MANAGEMENT MODELS

A. Model Reviews

Of the 397 relevant manuscripts, journal articles, and reports selected by the criteria discussed in the previous section, all but 14 of the 123 articles were reviewed. The review of incoming articles was discontinued on October 5 to maintain the project and report schedule. The remaining articles will be reviewed and presented in a supplement to the appended bibliography in the final report at the end of the second phase of this project.

The 383 available articles concerning the determination, management, or optimization of fishery yields were evaluated, and "potentially useful" models were retained for further examination. Results of this review were documented in Appendix A, which contains comments generally describing each model's applicability to the management of Maryland fishery yield, and abstracts of the individual articles. Of the 383 articles reviewed, 83 contained information pertaining to models "potentially useful" for the management of Maryland fish and shellfish populations.

Criteria used to determine the potential usefulness of individual models were somewhat subjective, but the primary ones included:

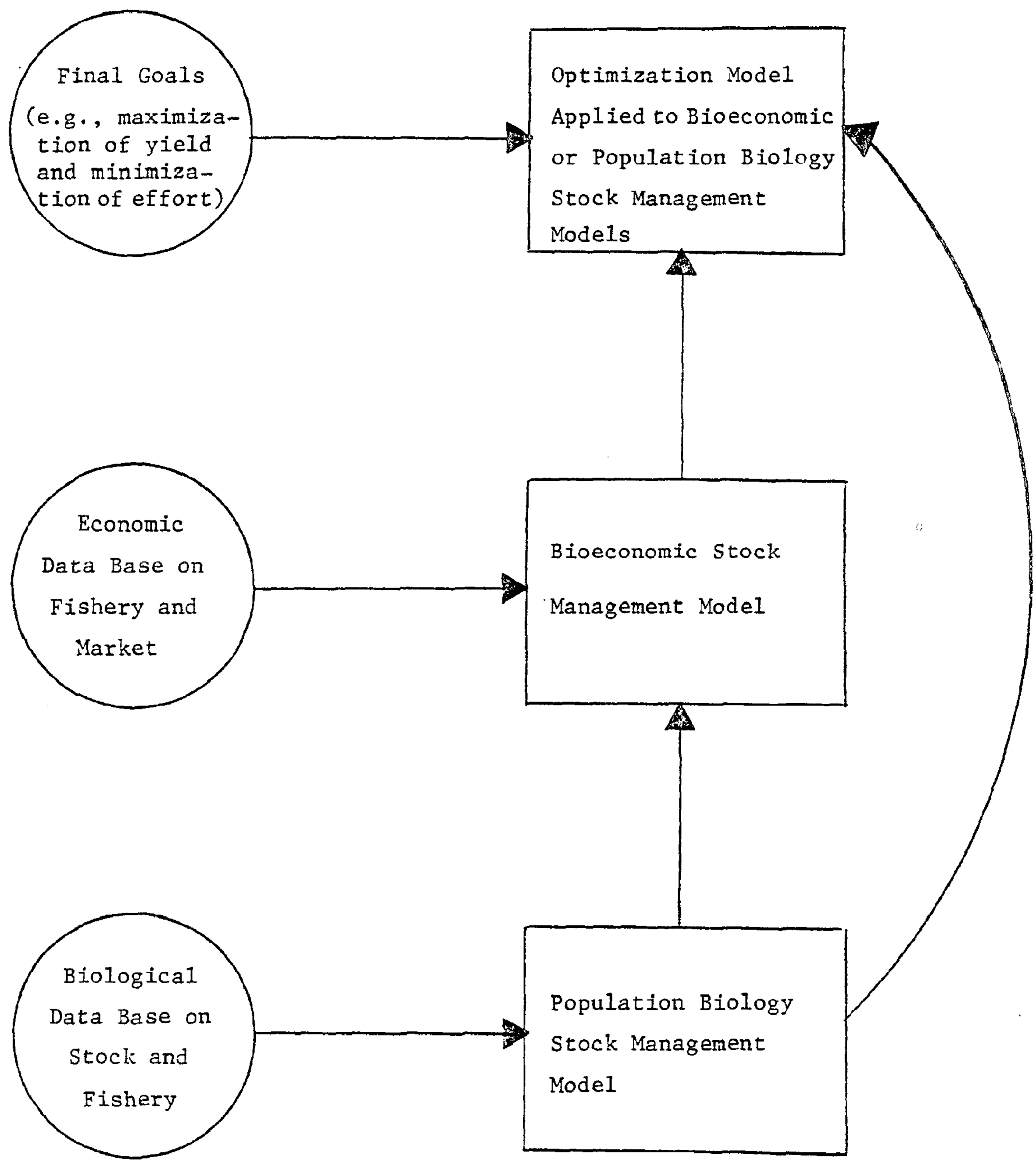
- the direct applicability of the model structure to a Maryland fishery
- the general applicability of the model structure
- the complexity of the data base necessary for the construction of the model
- the rationality of the biological and economic assumptions on which the model structure was based
- the potential applicability of the model structure to estuarine and/or coastal environments.

B. Major Categorization of Stock Management Models

All stock management models for the management of a resource can be partitioned into three hierarchical groups (Figure III-1):

- optimization models as applied to functioning stock management models (that is, models which integrate population biology and economics of a fishery such that management activities could be developed to optimize a certain aspect of that fishery, such as economic return)

Figure III-1. Hierarchical organization and basic data requirements of stock management model types



- bioeconomic models for stock management (i.e., those models which deal with the economic costs and returns of fisheries)
- population biology models for stock management (i.e., those models dealing only with the biological aspects of fish populations).

Because both optimization and bioeconomic stock management models depend on the existence of a population level biological model, biological models were chosen as the most basic form of fishery yield formulations (Figure III-1), and further effort was concentrated on the analysis of this type of stock management model. Biological stock management models take many forms (e.g., stock population, population dynamics), the complexity of which depends on the objectives of the modeler and the availability of data; thus, population models can be relatively simplistic (e.g., involving only statistical relationships between yield and environmental variables (Welcomme, 1976; Adams and Olver, 1977) or very complex, encompassing numerous aspects of a population (Parrish, 1975; Sissenwine, 1977) or several interacting populations (Andersen and Ursin, 1977).

Although economic functions are the primary output of bioeconomic models, these models, as shown in Figure III-1, require a biological population model or submodel of the species being managed as a base on which to determine economic relationships (Plourde, 1970; Southey, 1972; Clark, 1973; Anderson, 1975; Clark et al., 1973; Dow et al., 1975; Silvert, 1977; Grant and Griffin, 1979). As a result, this class of models is considered to be secondary in the development of stock management plans for Maryland fisheries: their construction should be approached in most cases only after a model of the population dynamics of the various fisheries has been formulated or determined irrelevant to the success of the fishery. An example of the latter situation would be a shellfishery in which the cost of harvesting restricts fishing effort when stocks are at low density, and reproductive capacity at that density is sufficiently high for stock maintenance.

Optimization procedures represent the highest order of complexity in this hierarchy (Figure III-1) because their use, which depends on the goals and objectives of the manager, requires a functional stock management model on either the bioeconomic or biological population level. These models determine a set of parameters that produce a maximal or minimal result for the control functions (e.g., yield, effort, catch/effort) (Clark et al., 1973; Palm, 1975;

Saila and Hess, 1975; Hilborn, 1976: Huang et al., 1976; Peterman, 1977; Agnew, 1979), and represent a tertiary step in the management scheme, i.e., they cannot be considered for Maryland stocks until functional biological stock management models are constructed.

Because bioeconomic models and optimization procedures are considered secondary goals for developing management plans of Maryland stocks, management models were further evaluated in Phase I. This model type represents a basic, first-level formulation of the stock and its dynamics and is necessary to any management plan. Bioeconomic and optimization procedures may be investgated at a later date after population formulations are completed.

C. Categorization of Biological Stock Management Models

Biological stock management models of resource populations can be minimally classified into five different groups, depending primarily on existing data describing the fishery and its dynamics and the assumptions of the various model structures. The five biological model types in order of increasing complexity are:

- statistical models
- surplus production models
- yield-per-recruit models
- population simulation models
- interacting multispecies simulation models.

1. Statistical Stock Management Models

Statistical stock management models include all model formulations in which yield or production is statistically related to some variable. There are basically two types of statistical yield models which could be useful in the modeling of Maryland fisheries:

- autoregressive stock management models
- single and multiple regressive stock management models.

The objective of the autoregressive yield model is to predict the next year's yield (not necessarily the maximum sustainable yield [MSY] or optimal sustainable yield [OSY]) from a set of previous yield data. This method, adapted from linear and non-linear forecasting (Montgomery and Johnson, 1976), has been utilized with particular success in areas where environmental variability is low (Dyer and Gillooly, 1979). The model's predictive power is based on the primary assumption that the correlative statistical relationship between yield and previous yield(s) remains unchanged in time. The nature of the data required, estimates of the size of the data set, and examples of autoregressive yield models are presented in Table III-I.

Regressive stock management models are generally expressed as a statistical relationship (generally a linear or non-linear single or multiple regression) between yield or stock size and an environmental variable(s) (e.g., water temperature, water transport). The main objective of these models is to estimate the potential annual yield expected from a fishery (i.e., not MSY OR OSY), and the only major assumption is a constant correlative relationship between yield and the environmental parameter(s) measured. The parameter may be represented as the value of the variable coincident with the yield measurement (Sutcliffe et al., 1977) or lagged by some time quantity, usually the length of time between spawning and recruitment (Flowers and Saila, 1972).

A major use of these density-independent stock management models has been to characterize potential yield of lakes (e.g., Matuszek, 1978) using the concentrations of total dissolved solids and lake depth. Ryder et al. (1974) developed a morpho-edaphic index as a predictor of fisheries yield of lakes based on these relationships. The adaptation of the lake morpho-edaphic index to rivers by Welcomme (1976) may be usable in some altered form for estuarine situations. The nature of data required, estimates of the size of the data set necessary to implement this model type, and examples of its use are given in Table III-1.

2. Surplus Production Models

Surplus production models represent a class of fishery yield models which are not heavily data dependent. The major objective of this model

Table III-1. Data requirements and examples of biological stock management models

Model Type	Data Requirements	Time Span of Data	Examples
Statistical Stock Management Models			
a) Autoregressive	Yield	5 to 10 years	Orach-Meza and Saila (1978) Dyer and Gillooly (1979)
b) Single and multiple regressive	Yield and environmental data (e.g., water temperature or freshwater discharge)	5 to 10 years	Talbot (1954) Flowers and Saila (1972) Clady (1975) Welcomme (1976) Adams and Olver (1977) Patriarche (1977) Sutcliffe et al.(1977) Matuszek (1978)
Surplus Production Models			
a) Basic model without recruitment lag	Yield and effort	Span must include complete range of effort data and yield data for the same period; the longer the time span, the more likely assumptions are to be invalidated	Graham (1935) Schaefer (1954, 1957, 1968) Pella and Tomlinson (1969) Fox (1970) Jensen (1972) Schnute (1977) Fletcher (1978) May et al. (1979)
b) Basic model including recruitment delay	Yield, effort, estimate of recruitment rate, and time lag between spawning and recruitment	Span must include complete range of effort data and yield data for the same period; the longer the time span, the more likely assumptions are to be invalidated	Walter (1973, 1976, 1978) Marchesseault et al. (1976)

Table III-1. Continued.

Model Type	Data Requirements	Time Span of Data	Examples
Yield-Per-Recruit Models			
a) Beverton-Holt	Age of recruitment into exploitable phase (t_r)	Time span should be $\geq$ life span of fish species considered	Beverton (1953)
	Number of individuals at time of initialization (t_o)		Beverton and Holt (1957)
	Maximum age of fish (t_λ)		Walters (1969)
	Estimate of instantaneous fishing mortality rate (F)		Sissenwine and Tibbetts (1977)
	Estimate of natural mortality rate (M)		
	Maximal length or weight of fish (L_∞ or W_∞)		
	Time fish spend in exploited phase (t_λ - t_r)		
	Growth constant from von Bertalanffy analysis (K)		
b) Ricker	Number of recruits to each cohort	Time span should be $\geq$ fishable life span of fish species considered	Ricker (1958, 1973)
	Estimate of instantaneous fishing mortality rate (F) of each cohort		Paulik and Bayliff (1967)
	Growth and natural mortality rates of each cohort		Schaaf and Huntsman (1972)
	Biomass of each cohort		Balsinger (1974)
			Lett et al. (1975)
			Loucks and Sutcliffe (1978)

Table III-1. Continued.

Model Type	Data Requirements	Time Span of Data	Examples
Simulation Models			
a) Dynamics of a single population	Data requirements depend on model structure, assumptions, and objectives; many different types of data required.	1 to 10 years for all parameters	Leslie (1945,1959) Lefkovitch (1965) Pope (1972) Balsinger (1974) Béland (1974) Hackney and Minns (1974) Kitchell et al. (1974) Caddy (1975) Rudd (1975) DeAngelis (1976) Englert et al. (1976) Lewis (1976) Ulltang (1976) Winters (1976, 1978) DeAngelis et al. (1977) Eberhardt and Siniff (1977) Horst (1977) Sissenwine (1977) Johnson (1978) Orth (1979)
b) Multi-population dynamics	Data requirements depend on model structure, assumptions, and objectives; many different types of data required.	1 to 10 years for all parameters	Swartzman and Van Dyne (1972) Regier and Henderson (1973) Parrish (1975) Andersen and Ursin (1977)

type is the determination of maximum sustainable yield. This type of yield model, developed initially by Graham (1935) and expanded into a more applicable form by Schaefer (1954, 1957), requires only annual catch and effort data (although estimates of catchability must be calculated or measured independently). Because its data requirements are limited (Table III-I), it is generally the most frequently encountered form of standardized yield model found in the scientific literature.

The most generalized form of this model may be expressed as follows: the change in catchable fish biomass per unit biomass (e.g., so many harvestable pounds per 100 pounds of stock) with respect to time is a function of population growth reduced by natural and fishing mortality. This can be mathematically expressed as:

$$\frac{1}{P}\frac{dP}{dt} = b - aP^{M-1} - qf \tag{1}$$

where

- P ≡ biomass of catchable fish in the fishery
- a and b ≡ regression coefficients related to population growth and mortality, respectively, derived using effort and yield data
- M ≡ a parameter based on catch data and related to the carrying capacity of the environment
- f ≡ fishing effort
- q ≡ catchability.

The solution of equation (1), which represents stock size at a given time, t, is:

$$P(t) = \left\{\frac{a}{b}\left(1-e^{b[1-M]t}\right) + P_o^{1-M}\ e^{b[1-M]t}\right\}^{\frac{1}{1-M}} \tag{2}$$

These mathematical formulations represent the generalized stock production model of Pella and Tomlinson (1969). The other major surplus production models, namely the Schaefer and Fox models, are simply special cases of these formulations with $M = 2$ and $M \to 1$, respectively.

Surplus production models generally ignore age, size, and sex-population parameters and essentially treat a population as a single unit. This approach requires several simplifying assumptions so that MSY levels can be determined from only catch and effort data. These assumptions are:

- The growth pattern of the stock is asymptotic.
- There is no time lag between spawning and recruitment; thus, the rate of population increase reacts instantaneously to changes in population size.
- The fishery is characterized by a stable age structure.
- Absence of fishing mortality would result in a fishery at a steady-state carrying capacity.
- The fishery is a definable unit stock.
- There is a functional relationship between yield and stock size (i.e., linear as in Schaefer [1954], exponential as in Pella and Tomlinson [1969], or logarithmic as in Fox [1970].
- Natural mortality is independent of age and time.
- Population recruitment is constant.
- The stock is at equilibrium level (Graham, 1935, only)
- The annual variability of economic, environmental, and interspecific factors are reflected in the annual catch data.
- The distribution of stock and exploitation effort is homogeneous.
- The rate of natural increase at a given population biomass is independent of the population's age composition.

Several modifications of the basic Schaefer surplus production model have altered the basic equation to include the time lag that generally exists between the time of spawning and the time of recruitment (Walter, 1973, 1976, and 1978). This new form allows the use of a surplus production model for fisheries in a state of disequilibrium. Mathematically, the equation includes the same terms as eq. (1) above, except that population growth attributable to recruitment is explicity accounted for. This model is represented as:

$$\frac{d \ln P}{dt} = b - aP + \sum_{i=-\infty}^{\infty} r_i \delta (t-i) - qf \qquad (3)$$

where

$(b - aP)$ $\equiv$ expression of individual growth and natural mortality rate

$\sum r_i \delta(t-i)$ $\equiv$ growth rate due to recruitment

qf $\equiv$ fishing mortality.

Submodels are generally unnecessary for the application of surplus production models. However, submodels for the normalization of fishing effort are often required for fisheries where technological advances have significantly altered relative catch per unit effort (i.e., relative catchability) over time, such as in the case of the menhaden fishery (Schaaf and Huntsman, 1972).

Table III-I presents the basic data requirements of all the types of surplus production models, along with estimates of the size of the data set and examples. In most equilibrium applications, surplus production models can be utilized interchangably (i.e., Graham, Schaefer, Pella-Tomlinson, and Fox models), depending on which yield-stock size relationship provides the "best fit" with the curve for stock or catch versus effort.

3. Yield-Per-Recruit Models

There are two well-known yield-per-recruit models in use in fisheries research and management. The first and less complex is the Beverton and Holt (1957) model, which incorporates a specific growth function, partitions mortality losses into natural and fishing mortalities, and includes an explicit accounting of the time lag between spawning and recruitment.

Mathematically, the Beverton-Holt approach defines

$$Y = F \int_{t=t_r}^{t=t_\gamma} R w_t e^{-Z(t-t_r)} \, dt \qquad (4)$$

where

Y $\equiv$ weight of yield (usually annual)

F $\equiv$ instantaneous rate of fishing

$R \equiv$ yearly number of recruits which enter fishery at age t_r

$Z \equiv$ instantaneous total mortality rate (= F + instantaneous natural mortality rate)

$t \equiv$ age in years

$t_r \equiv$ age of recruitment to fishery

$t_\gamma \equiv$ maximum age attainable

$w_t \equiv W_\infty(1-e^{-K[t-t_o]})^3$ (the von Bertalanffy growth equation)

where

$W_\infty \equiv$ asymptotic weight of a fish

$K \equiv$ Brody growth coefficient (Brody, 1927, 1945)

$t_o \equiv$ hypothetical age when fish would have zero length according to Brody - von Bertalanffy growth relationship.

The primary difficulty associated with the application of the Beverton-Holt yield-per-recruit model centers around its assumption of the applicability of the von Bertalanffy growth submodel and the constancy of natural and fishing mortality after recruitment. The additional assumptions of a stable age distribution and unit stock status of the fishery and of constant growth, mortality, and/or recruitment parameters as implicit reflections of economic and environmental variability also limit the applicability of the model.

The Beverton-Holt model is generally not used in management situations due to the constraints of its model structure and the relatively large amount of data necessary to implement its use (Table III-1). Examples of its practical use are also given in the table.

The second approach to yield-per-recruit modeling is generally attributed to Ricker (1958, 1978). This model allows for age-specific population functions and also allows population parameters to vary throughout the year, usually as a function of fishing season. For example, in a case where a species is fished only during one season of the year, the fishing mortality rate is zero during the remainder of the year. The Ricker model is generally applied under steady-state or equilibrium conditions. Although this ideal condition never really occurs in nature, equilibrium conditions may be approximated on a long-term average.

Under equilibrium conditions, the annual yield from all yearclasses will be the same as the yield of a single cohort over its entire life span and, according to the Ricker formulation, can be calculated as

$$Y(w) = \int_{t_r}^{t_\gamma} F(t)\,N(t)\,w(t)\,dt \tag{5}$$

where

$Y(w)$ $\equiv$ annual yield in weight

$F(t)$ $\equiv$ instantaneous fishing mortality coefficient at time t

$N(t)$ $\equiv$ number of individuals at time t

$w(t)$ $\equiv$ mean weight of an individual at time t

t_r $\equiv$ age of recruitment

t_γ $\equiv$ maximum age.

Since the functions F(t), N(t), and w(t) are not generally smooth, well-defined functions, Ricker has approximated the above equation by

$$Y(w) = \sum_{i=t_r}^{t_\gamma} F_i\,\overline{N}_i\,\overline{w}_i\,\Delta t_i \tag{6}$$

where, for each time interval t_i, the parameters are constant, and $\overline{N}_i$ and $\overline{w}_i$ are the mean number and mean weight for the time interval t_i. This modeling procedure generally uses submodels of growth (e.g. von Bertalanffy growth equation),natural and fishing mortality, and recruitment submodels that are age or size specific.

The approximation by Ricker effectively removes the major assumptions of the Beverton-Holt model, and holds the parameters of growth, natural and fishing mortality, and recruitment constant only over short, user-defined intervals. That is, the year can be divided into arbitrary time intervals within which certain parameters can be considered constant. This approach still assumes a unit stock with a stable age distribution and does not account for partial recruitment.

The Ricker yield-per-recruit model is generally not used in management situations because the data required for its implementation (Table III-1) are not available. With a data collection program for these types of data, this could prove to be a useful management tool for populations which display stable age distributions and unit stocks. Examples of its use in the management of fisheries (e.g., Balsinger, 1974; Lett et al., 1975 are given in Table III-1.

4. Simulation Stock Management Models

Computer simulation models have been increasingly used in fisheries research and management programs over the past decade. In the context presented here, the simulation model attempts to represent fishery yield or population dynamics as a set of functionally related equations, such as

$$\frac{dP}{dt} = f\,(P,G,R,F,M_N,M_F,T,I,Y,\Psi_1,\Psi_2) \qquad (7)$$

where

$dP/dt \equiv$ change through time of the population level in either weight or numbers

$P \equiv$ population level in biomass or numbers

$G \equiv$ individual or population growth

$R \equiv$ recruitment

$F \equiv$ fecundity

$M_N \equiv$ natural mortality

$M_F \equiv$ fishing mortality

$T \equiv$ migratory behavior

$Y \equiv$ annual catch

$\Psi_1 \equiv$ state history of the fishery (the historical data record of the fishery, such as yield or effort)

Ψ_2 $\equiv$ state history of the stock (the historical data record of stock dynamics, such as historical population levels or reproductive levels).

The simulation stock management model has a very flexible structure in that its assumptions and mathematical descriptions are controlled by the modeler. Various modifying factors on population growth, natural mortality, and recruitment, such as habitat destruction, environmental pollution, and unusual meteorological events, can be incorporated into the model structure. The drawback to this type of yield modeling is the heavy data dependency of these models. In most cases, large data collection efforts would have to be initiated to formulate simulation models of Maryland fisheries.

Single population models represent the least complex of the simulation models used in predicting yield and/or population dynamics. Model structures have been formulated that summarize population dynamics in terms of mass flow (Sissenwine, 1977; Orth, 1979), spatial dynamics (Caddy, 1975), network theory (Lewis, 1976), bioenergetics (Kitchell et al., Béland, 1974). These simulation models often rely heavily on submodels for the determination of growth, mortality, and recruitment rates. Examples of single population simulation model structures which may be potentially applicable to Maryland fisheries are given in Table III-1. In addition, new model structures could be formulated based on the collection of pertinent data on Maryland fisheries.

The most complex simulation models for yield determinations are multi-species or ecosystem level simulation models. Few examples (Table III-1) of this type of model structure are available (e.g., Andersen and Ursin, 1977), primarily due to the very large data sets necessary to implement the models. For example, the Andersen and Ursin (1977) ecosystem model of the North Sea requires over 800 sets of inputs and parameters to estimate the yield of 12 fisheries. While large-scale simulation models are not generally used in management, single population simulation models represent the most used and often most useful model structure for the determination of fishery dynamics and yields.

D. Data Dependence of Stock Management Model Types

Although not specifically stated in the characterization of stock management model categories, data requirements and availability are an important constraint on the choice of model structures for Maryland fisheries. While data availability does not necessarily restrict model usage as long as the data are realistically obtainable at some future time, time and economic constraints may complicate the collection of additional data.

Table III-2 shows the applicability of stock management model types based on data availability, regardless of model assumptions and species biology. This framework shows the pyramid-like compounding of usable model structures with increases in data. A large data base (i.e., #5) allows the use of all model structures, constrained only by individual model assumptions and the population characteristics of the individual fisheries.

Table III-2. Applicable stock management model types as determined by data availability

Data Availability	MODEL TYPES				
	Statistical		Surplus Production	Yield-Per-Recruit	Simulation
	Autoregressive	Density - Independent			
1) Yield data only	→				
2) Yield and environmental data	→	→			
3) Yield, effort, and environmental data*	→	→	→		
4) Specific population parameters, yield, effort, and environmental data*	→	→	→	→	
5) All major population parameters, yield, effort, and environmental data	→	→	→	→	→

* Environmental data not necessary for construction of some of the indicated models.

IV. INPUT SUBMODELS AND PARAMETER ESTIMATION

A. Selection Criteria and Search Procedures

The initial selection of articles potentially relevant to input submodels for yield models was based primarily on the title of the paper or report. The key words used in this initial screening process of current journals, reports, and books were:

- parameter estimation
- submodel
- growth
- mortality
- fishing effort
- recruitment
- migration
- fecundity
- age structure
- tagging studies
- stock assessment.

The in-house journals and books reviewed were presented in Table II-2. In addition, we conducted bibliographic searches of the literature cited in these papers and those selected as possibly relevant to yield modeling, using the same key words.

Two hundred and three articles concerning input submodels, data acquisition, and life history parameters were obtained through this search (including those obtained through interlibrary loan). Fifty-seven articles were determined, through inspection of abstracts, to directly concern various input submodels or the estimation of parameters for specific yield models. The remaining 167 articles and reports concerned life history information on Maryland fish and shellfish species and methods for the collection of life history and population information.

B. Categorization of Input Development

All procedures for developing inputs to yield models can be placed in three major categories:

- parameter determination for specific yield models. e.g., methods for determining parameters a and b in eq. (1)
- functional submodels
- data acquisition methods

Functional submodels can be further partitioned according to the mechanism modeled into:

- age structure submodels (determination of age from length)
- allometric submodels (determination of biomass from length or width)
- catchability submodels (normalization of biomass from length or width)
- effort submodels (normalization of effort through time)
- fecundity submodels (egg production from size distribution data)
- growth submodels (change of growth rate with age)
- mortality submodels (change of mortality rate with age)
- recruitment submodels (change of recruitment rate with age structure and time)
- yearclass strength submodels (yearclass size from environmental variables or stock size)

1. Parameter Determination for Specific Yield Models

Parameter estimation procedures were reviewed using biological realism and ease of application as criteria for potential utility to Maryland management plans for fisheries. All of the parameter estimation articles reviewed concerned the application of surplus production models and the estimation of parameters a, b, and M in eq. (1), as discussed earlier. Comments concerning the usefulness of the procedures and abstracts of the individual articles appear in Appendix B.

2. Functional Submodels

Fifty-seven articles were reviewed concerning submodels which could be used as inputs for yield models. The most important submodels for input to standard yield models (surplus production and yield-per-recruit models) are those for growth, mortality, recruitment, and effort. In addition, submodels for age structure, fecundity, and yearclass strength could provide important inputs for the construction of simulation yield models. Comments concerning the utility of functional submodels and abstracts of the individual articles evaluated appear in Appendix B. Relative data requirements of the functional submodel types are given in Table IV-1.

3. Data Acquisition Methods

The collection of data acquisition procedures is documented in Appendix C, subdivided according to type of information. This bibliography is directly applicable to Phase II of this project, where the present data collection procedures will be reviewed and improvements and/or the addition of new data acquisition techniques will be suggested. The categories of data acquisition presently encompassed by the review include:

- stock assessment
- tagging studies
- determination of growth rates
- determination of mortality rates
- migration studies
- recruitment analyses
- population age structure determinations.

Table IV-1. Relative data requirements of functional submodels and their potential utility as input to stock management models

Submodel Type	Applicable Yield Models	Effort Required for Data Acquisition	Applicability to Maryland Fisheries	Examples
Age Structure	Simulation, yield-per-recruit	Limited[1]	Generally not useful (age-length keys are biased); information can be collected directly	Kimura, 1977 Kumar and Adams, 1978 McNew and Summerfelt, 1978 Westrheim and Ricker, 1978
Allometric	Simulation	Limited	Information easily collected; useful, particularly with shellfish	Dame, 1972 Pienaar and Thomson, 1969
Catchability	Surplus production	Limited;[2] intensive (depending on specific procedure)	Potentially useful, particularly for surplus production model applications	Paloheimo, 1961 Rafail, 1977
Effort				
Commercial	Surplus production yield-per-recruit, simulation	Limited	Useful for Maryland fisheries, particularly where technological advances have been prevalent	Nicholson, 1971 Schaaf and Huntsman, 1972
Recreational	Surplus production yield-per-recruit, simulation	Intensive	Useful for future recreational surveys in Maryland	Malvestuto et al., 1978, 1979 Robson, 1961

1,2 See last page of table.

Table IV-1. Continued.

Submodel Type	Applicable Yield Models	Effort Required for Data Acquisition	Applicability to Maryland Fisheries	Examples
Fecundity	Simulation	Intensive	May prove useful for the construction of simulation yield models	Brousseau, 1978a,b Tsai and Gibson, 1971
Growth	Yield-per-recruit simulation	Limited to intensive	Necessary for the construction of these yield models	Allen, 1966 Bayley, 1977 Brousseau, 1978, 1979 Chadwick et al., 1978 Cloern and Nichols, 1978 Dame, 1975 DeAngelis and Contant, 1979 Gallucci and Quinn, 1979 Kitchell et al., 1977 Knight, 1969 Pratt and Campbell, 1956 Richards, 1959 Taylor, 1962 Ursin, 1967 Yamaguchi, 1975
Mortality				
Fishing	Yield-per-recruit, simulation	Intensive	Necessary to construct these yield models	Brown et al., 1979 Francis, 1974 Van Winkle et al., 1978 Young, 1975

1,2 See last page of table.

Table IV-1. Continued.

Submodel Type	Applicable Yield Models	Effort Required for Data Acquisition	Applicability to Maryland Fisheries	Examples
Mortality (Cont.)				
Natural	Yield-per-recruit, simulation	Intensive	Necessary to construct these yield models	Brousseau, 1978 Butler and McDonald, 1979 Marten, 1978 Paloheimo, 1961 Polgar, 1978 Robson and Chapman, 1961 Ursin, 1967 Van Sickle, 1977 Ware, 1975
Recruitment	Yield-per-recruit simulation	Intensive	Necessary to construct simulation models	Allen, 1968 Beverton and Holt, 1957 Christensen et al., 1978 Ricker, 1954
Yearclasses Strength	Simulation	Intensive	Procedure is potentially applicable, but existing submodels are not applicable	Stevens, 1977 Walter and Hoagman, 1975

1 Data set required for implementation is small, well defined, and easily obtainable.
2 Data set required for implementation is large, poorly defined, and/or difficult to acquire.
3 In a combined structure which includes yield-per-recruit and stock recruitment models.

V. LIFE HISTORY CHARACTERIZATION OF EXPLOITED MARYLAND SPECIES

A. Objective

This portion of the study was designed to obtain information on certain life history characteristics of selected exploited finfish and shellfish species. Life history characteristics of interest were those frequently incorporated into various mathematical fisheries models.

B. Selection of Species

Table V-1 lists all finfish and shellfish species which were reported taken in commercial landings in Maryland tidewaters between 1971 and 1975. Many of these species are not sought-after and are taken only incidentally during harvests of more desirable species. Others are taken in very small quantities and have little importance in either commercial or recreational fisheries in Maryland.

Before proceeding further, we decided that only a limited number of species from Table V-1 should be considered for the project. Accordingly, species for consideration were selected in consultation with personnel of Maryland's Tidewater Fisheries Division and Coastal Resources Division and are listed in Table V-2. Some of the criteria considered in the selection process were: commercial and sport importance, residence characteristics, longevity, and current abundance.

Pertinent life history characteristics chosen for inclusion in Table V-2 are presented as column headings. Highest priority was placed on obtaining life history information for Maryland stocks of the selected species. If such data could not be located, data from other Atlantic coast stocks were included. Sources of life history information are listed in Appendix D. To augment the in-house search for life history data, a draft copy of Table V-2 was distributed to the staff of the Tidewater Fisheries Division and other fisheries research workers in Maryland and Virginia. Numerous additions to the table were obtained from these sources. Additional information is being collected and this table will be regularly updated as the study progresses.

Table V-1. Finfish and shellfish species reported in commercial fisheries statistics for Maryland, 1971-1975 (NOAA, 1971-1975)

Species	Atlantic Ocean	Chesapeake Bay and Tributaries
Finfish		
Alewife	x	x
Bluefish	x	x
Butterfish	x	x
Carp		x
Catfish	x	x
Cod	x	
Crappie		x
Croaker	x	x
Drum	x	x
Eels		x
Blackback flounder	x	x
Fluke	x	x
Other flounders	x	x
Gizzard shad		x
Red hake	x	
Sea herring	x	x
Hickory shad	x	x
Hogchoker		x
King whiting	x	
Mackerel	x	
Menhaden	x	x
Mullet	x	x
Scup	x	
Sea bass	x	x
Sea trout	x	x
Shad	x	x
Gray shark	x	
Other sharks	x	
Spanish mackerel	x	x
Spot	x	x
Striped bass	x	x
Sturgeon	x	x
Suckers		x
Sunfish		x
Tautog	x	
White perch	x	x
Whiting	x	
Yellow Perch	x	x
Shellfish		
Blue crab	x	x
Lobster	x	
Hard clam	x	x
Soft-shell clam		x
Surf clam	x	x
Conch	x	x
Oyster	x	x
Squid	x	x
Terrapin		x
Snapper		x
Horseshoe crab	x	
Total Finfish Species	31	30
Total Shellfish Species	8	9

Table V-2. Life history data on selected Maryland species; reference numbers correspond to sources listed in Appendix D; migration refers to movements of exploitable age groups; blank columns indicate that data have not yet been obtained or do not exist.

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Alewife *Alosa pseudoharengus*	No strong relationship between adult stock size and production of juveniles in Virginia rivers [82]	Mean of 100,000 [57] 50,000 - 100,000 [27] 48,000 - 360,000 mean of 229,000 [20]	$\geq$ 6 yr [94]	3 - 4 [27,52]	Commercial: pound nets, gill nets, haul seines, fyke nets, hoop nets [49]	Anadromous; juveniles move seaward from spawning grounds in summer; adults migrate to freshwater spawning areas in spring [27,48]	In Maryland, in selected tributaries of 0-3 ppt salinity [58,59]	In Long Pond, Maine: Age / Length I 5.3 in. II 8.7 in. III 10.8 in. IV 11.9 in. V 12.4 in. [33] Data available from Choptank and Susquehanna river systems [75]	Mostly age group IV and V in Long Pond, Maine [33] In North Carolina, age range: males = 3 to 7, females = 3 to 8 [71]	In Long Pond, Maine, annual expected mortality: age V to VI = 78.6%, age VI to VII = 74.7%; post-spawning mortality between 1954 - 1959 averaged 41%, age groups combined [33] Freshwater adult annual mortality in R.I. = 38% after spawning [27] In Bride Lake, Conn., adult annual mortalities: 1966 - 57.4%, 1967 - 48.6% Tagged fish overall = 57.4% mortality [20] In North Carolina 1978, adult annual mortality rate = 44% [71]	Length by age data: juveniles in R.I. [27,48], ages I-IV in Long Pond, Maine [33], ages 0-IV in Ches. Bay [59], juveniles in North Carolina [71] Monthly growth rates, 1971: James River = 8.5 mm, Pamunkey River = 9.7 mm, Mattaponi River = 10.7 mm, Rappahannock River = 7.7 mm, Potomac River = 12 mm [38]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in MD.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
American Eel *Anguilla rostrata*		413,000-2,561,000 [53]	5 - 18 [53]	5 - 18 [53]	Commercial; eel pots, pound nets [49,58]	Catadromous; leave coastal rivers and estuaries in fall for spawning grounds; juveniles enter estuaries and streams in spring [53]	Atlantic Ocean (in Sargasso Sea) [58,59]				Length by age data, juveniles and adults in Ches. Bay [59]
American Shad *Alosa sapidissima*	Density-dependent [79]	250,000 [65] 262,000 [52] 58,500 - 659,000 [52]		2 - 4 [52]	Commercial: gill nets, pound nets Recreational [38,49]	Anadromous; move oceanward in fall, enter coastal waters and the Ches. Bay in spring [23,44,58]	In Maryland, selected tributaries of 0 - 1 ppt salinity [58,59]	Data available from Choptank and Susquehanna river systems [75]	In North Carolina, age range: male = 3-7, female = 4-7 [71]	In North Carolina, 1978, total annual mortality = 36% [71]	Monthly growth rates, 1978 James River = 12.3 mm, Pamunkey River = 9.7 mm, Mattaponi River = 9.0 mm, Rappahannock River = 14.0 mm, Potomac River = 12.7 mm [38]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Blueback Herring <u>Alosa aestivalis</u>	No strong relationship between adult stock size and production of juveniles in Virginia rivers [82]	Mean of 100,000 [57] 45,800 - 349,700 [70]		4 [52]	Commercial: pound nets, gill nets, haul seines, fyke nets, hoop nets [38]; recreational: dip nets [71]	Anadromous; juveniles migrates to ocean in fall, adults return to spawn in spring [52]	In Maryland, in selected tributaries of 0 - 2 ppt salinity [58]	In North Carolina, 1978: 30% were males from 140-293 mm, 30% females from 140-310 mm, 40% juveniles from 58-110 mm [71] Data available from Choptank and Susquehanna river systems [75]	In Connecticut River, both sexes present in age classes III - VII [70] Same range in North Carolina (III-VII) [71]	In North Carolina, 1978, 41% adult annual mortality rate [71]	Monthly growth rates, 1971: James River = 7.5 mm, Pamunkey River = 6.3 mm, Mattaponi River = 5.7 mm, Rappahannock River = 7.0 mm, Potomac River = 9.0 mm [38] Length by age data, juveniles in North Carolina [71]
Bluefish <u>Pomatomus saltatrix</u>	Circulation of continental shelf waters determines magnitude of year class size [4]	112,000-195,000 [54]		2 [59]	Commercial: pound nets; recreational [54]	Migrate along coast (south in fall, north in spring), move inshore into Ches. Bay in May through August, and again in September and October [28,54,58]	Two spawning periods coastal waters in spring in the Gulf Stream, summer over the Continental Shelf [4,28,58]	24-30 in. TL [18] > 12 in. TL In recreational fishery [95]			Two populations defined by the size of fish when the first annual ring forms in May: fish spawned in spring south of Cape Hatteras that reach about 260 mm by end of first winter, fish spawned in summer in the Middle Atlantic

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Bluefish <u>Pomatomus saltatrix</u> (cont.)											Might reach about 120 mm by end of first winter [28]
Carp <u>Cyprinus carpio</u>		36,000 - 2,208,000 [52]		2 - 5 [52]	Commercial, recreational [59]	Primarily inshore - offshore [52]	Near surface in shallow, weedy areas of lakes, ponds, and streams [52]				
Atlantic Menhaden <u>Brevoortia tyrannus</u>	Ricker spawner-recruit, Ekman transport of larvae important Recruitment low in periods of environmental fluctuations. [12]	38,000-631,000 [52] 113,000 [12]	1 - 3 [24,58]	3 [52]	Commercial: pound nets, gill nets, purse seines [49]	Overwintering movements out of Maryland; no adults return; migrate northward in Atlantic in spring, southward in fall [22,30,45]	Polyhaline; Atlantic Ocean over the Continental Shelf and near mouth of Ches. Bay [52]	10-30 cm Mean length: Age 1 = 173 to 204mm Age 2 = 221 to 275 mm [24]	1 - 6 (in Ches. Bay 1-2) (Cape Cod, 3 and older) [24]	From Long Island Sound to Florida from 1966-1968: instantaneous fishing mortality = 95% natural mortality = 52% [45]	Length by age data: ages I-IV, along the Atlantic Coast [24] Growth rate slows after age IV [47] Length by age data in Ches. Bay [59]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Spot *Leiostomus xanthurus*		70,000 - 90,000 [62]		2 [55]	Commercial: haul seines, otter trawls, fyke and hoop nets; recreational [49]	Migrate offshore in fall for spawning, return to Ches. Bay in spring [14,29,58]	Polyhaline; Atlantic Ocean [58]	In lower Ches. Bay: in spring from 5 to 8 in., in fall from 8 to 14 in. [59]			In Potomac River: age I = up to 13 cm, adults up to 33-35 cm [58] In Ches. Bay, rapid growth during the first summer [59]
Summer Flounder *Paralichthys dentatus*		967,000-1,700,000 [51]	≥ 3 (Commercial) ≥ 2 (Recreational) [84]	3 [59]	Commercial: pound nets, otter trawls, haul seines; recreational [58]	Leave Ches. Bay in fall and overwinter along edge of Continental Shelf (return in spring) [56.58]	Polyhaline; Atlantic Ocean Spawning occurs during offshore migration [56,58,59]				In Ches. Bay: age I = 12 - 18 cm, age I-3/4 = 20 - 26 cm, age II = 27 - 28 cm [59]
White Catfish *Ictalurus catus*		1,000 - 3,500 [52]		1 - 2 [52]	Commercial; pound and fyke nets Recreational [59]	No apparent seasonal migratory tendencies [52]	Still or running water in coastal streams, or tidal estuaries [1,52,59]				In Patuxent River: annual growth = 25-45 mm, length by age data, ages II-XII [1]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
White Perch *Morone americana*	Dominant yearclasses occur (Virginia) [3]	5,210 - 321,000 Mostly between 50,000 and 150,000 [54]		2 - 3 [54]	Commercial: pound nets, fyke nets, haul seines gill nets ; recreational [58]	Anadromous; move shoreward and upstream in spring [29]	In Maryland, in selected tributaries of 0-11 ppt salinity (tidal fresh-oligohaline) [58,59]	In James River, range is 70-254 mm; in York River; 75-270 mm [3]		Annual total mortality James River: 69% for males after Age IV & females after Age VI; York River: males Age III = 59%, females Age V = 57% [3]	Length by age data, all ages, James and York Rivers; first year growth greater than in any later year, in both sexes; average annual growth decreases rapidly after Age II [3] Length by age data, ages I-X, Potomac River [58] Growth rate sex dependent at least to age 5 yr [88,3] Growth rate influenced by density. dependent factors, primarily intra-specific competition for food [88]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Yellow Perch *Perca flavescens*	Dominant year classes occur (in Oneida Lake, N.Y.) [13] Year-classes variable from 1955-1959 in Severn River, Md. [11]	3,035 - 109,000 Mean of 23, 0 [54] 5,000 - 75,000 [2] 5,900 - 109,000 [11] 10,000-157,000 [41]	3 - 12 [11,54]	2 - 3 [11,54]	Commercial: bottom trawls, gill nets; recreational [26,58]	Semi-anadromous; move from lower tributaries to spawning grounds in early spring [54,59]	In Maryland, in selected tributaries of 0-5 ppt salinity [58]	≥ 8 in.TL [11]	≥ 3 yrs [11]	In Severn River (Md.), fishing mortality greater than 13% (all sizes) [11] Mean annual mortality rates: ages I-VI = 70% for males and 51% for females; highest from I-II (87%); lowest from IV-V (15%) (in Missouri River, 1965-1974) [25]	Length by age data, ages II-VIII, Patuxent River [2] In Severn River, length by age data, ages I-XII; females reach legal size (8 in. during age I-II, males during II-III Growth rates decrease with age, especially in males [11] Length by age data, ages I-IX, Missouri River reservoirs. [25] In Red Lake Minn: total first-year growth calculated for 15 years (1952-1967);

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Yellow Perch *Perca flavescens* (cont.)											after second year of life, females grow faster than males; average rate of growth during mid-summer 0.722 mm/day [26] In Lake Michigan, females longer and heavier than males (after age II) Length by age (II-VII) data, Lake Michigan, Lake Erie, Green Bay, and Saginaw Bay [41] Length by age data in Potomac River, ages I-XII [58]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Clam *Mya arenaria*	Strong recruitment in Maryland has occurred every 10-15 years in the Potomac estuary (2 peaks of spawning per year) [15,58] Large annual variations in recruitment in Mass. and fluctuations largely due to natural variation and not to changes in population fecundity [39]	Number of oocytes produced increases exponentially with increasing female body size Average oocyte production in 60mm clam = about 120,000 [39]	2 yr in Mass. [42]	1 - 2 (45 mm shell length, in Mass) [42]	Commercial: conveyors, dredges, tongs [49,50]	None	In Ches. Bay, salinities of 10 ppt in spring and 15 ppt in fall [15]			In Mass., high mortality in pelagic, metamorphic, and settlement stages Rates decrease with age, however [42]	In Prince William Sound, Alaska, length by age (0-XII) data [34] Length by age (0-VII) data from Gloucester, Mass. [42] Linear shell growth rates, yearly growth increments, and size-specific mean seasonal shell growth rates; Von Bertalanffy equation used to investigate relationship between age and linear size (Gloucester, Mass) [90]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Hard Clam *Mercenaria mercenaria*	Little known (setting occurs on a fairly regular annual basis in Great South Bay and Horseshoe Cove, N.J.) [31] Sporadic with occasional major sets; spawning occurs each year and recruitment failure may be due to factors operating on larval stages [76] Setting may be influenced by substrate characteristics; distribution of set may not be influenced by distribution of adults [67]		Over 1 1/2 in. in length; assumed age (3-4 yr) [76,77] Maximum age about 8 yrs [76]	3 [78]	Commercial: dredges; recreational [9] Large Maryland recreational catch [95]	None	Embayments along the western Atlantic coast from Gulf of St. Lawrence to Florida [31]			Most mortality on small (less than 15 mm) individuals; rates decrease with age (in N.C.) [36] Natural mortality data from Southhampton, England, available [76] Annual fishing mortality in one location in Chincoteague Bay was 33% [77]	In Narragansett Bay, average growth (shell length) increments inversely related to initial length; growth rates show high variation in different parts of the Bay; more than half the year's growth occurs before mid-July; growth rates a function of diatom abundance and sediment type (lower growth in higher silt-clay content) [9] In South Carolina (tray experiments) growth did not significantly vary among densities

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Hard Clam <u>Mercenaria mercenaria</u> (cont.)											Average monthly growth rates: Bull Bay = 0.8 mm, Clark Sound - 1.5 mm, Albergottie Creek - 1.8 mm [36] Growth data available from Southampton, England [76]
Blue Crab <u>Callinectes sapidus</u>	Some experimental evidence that megalopae and juveniles responsible for recruitment to estuaries via immigration [7]	700,000-2,000,000 [66,74]	2 - 4 [58]	2 [58]	Commercial: trot lines, crab pots, scrapes; recreational [49,50]	Fertilized females migrate south in Bay to more saline water (17 ppt); juveniles move up Bay and into tributaries [7,46,66]	Lower portion of Ches. Bay (27 ppt) [7,58]	Maryland State law, minimum of 5-in. carapace width; in Chesapeake Bay, 1969 winter modal class about 75 mm wide, spring - about 140 mm [73,74]		Mortality from egg to adult = 0.999999 [66] In Chesapeake Bay, percent winter mortality of adults: 1968 = 3.3% 1969 = 19.3% 1970 = 35% 1971 = 7.6% 1972 = 5.1% 1973 = 11.4% [73,74]	Rapid growth reaching adult size (5-6 in.) 1-1½ yr after hatching; small crabs shed frequently, but time between molts increases as crabs grow larger; each normal shedding, width

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Blue crab *Callinectes sapidus* (cont.)											increases 1/4 - 1/3 the initial size [66] Crabs hatched from eggs spawned in late summer require 18 - 20 months to attain full size [74] Growth peaks in mid-summer in Ches. Bay and declines in fall [73] Growth ceases during the winter months (in Ches. Bay) [91]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
American Oyster *Crassostrea virginica*	Settlement depends on available cultch, water temp., salinity, and dissolved oxygen [58,60] Major sets in Ches. Bay in 1964, 1968, 1974-75, and 1977, but magnitude of set varied markedly by Bay region [81] Settlement variable on different bars in any year and variable on same bar in different years [87]	1×10^5 to 1×10^7 [60]	Over 2 to 3 yr [81]	1 [60,68]	Commercial: hand tongs, patent tongs, dredges [49,50] recreational fishery, limit 1 bushel/person/day [95]	None	Md. waters, meso-polyhaline [58] Greater than 5 ppt [68]	In Delaware Bay: Age / Size I: 0.1-2.4 cm II: 2.5-6.9 cm III & older: 7.0-14.0 cm [72]	Depends on years of dominant sets [81]	In Clambank Creek, S.C., mortality of larvae up to late umbo stage equals 61%; from egg to spat equals 0.99997 [69]	In South Carolina, growth in both length and width is faster for young oysters, declining with age Instantaneous growth rates given show little difference between intertidal and subtidal oysters [93]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Atlantic Croaker *Micropogonias undulatus*	Only successful yearclass recruitments in Maryland in 1974 and 1975 [94] Ekman transport may influence yearclass strength [95]	180,000 [59]		1 - 2 [5,55]	Commercial: pound nets, haul seines, drift nets; recreational [58]	Move up bays and estuaries during spring; oceanward in fall [55,58,59]	Atlantic Ocean, polyhaline [58,59]			Total annual mortality rate 96% in Carolinian Province (short life span) [5]	Length by age (0-11) data in Carolinian Province [5] In Louisiana, growth rates of juveniles from 0.51 to 0.99 mm/day [17]
Striped Bass *Morone saxatilis*	Dominant year-classes occur [58,40]	62,000 - 112,000 eggs are produced for every pound of body wgt [64] 400,000-1,055,000 [63] mean of 2,462,000 [61]	2 - 9 [54,58]	4 - 5 [54]	Commercial: gill nets, pound nets haul seines; recreational [49]	Anadromous with some population segments leaving Md. waters Upriver spawning migrations in April & May [29,58]	In Maryland, waters of 0 - 3.5 ppt salinity (tidal-fresh to oligohaline) [58]	Data available from Choptank and Susquehanna river systems [75]	Data available from Choptank and Susquehanna river systems [75]	Instantaneous fishing and natural mortality rates for populations in Virginia, North Carolina, and California; in Potomac River, 1961, 40% adult mortality in spring fishery; in Ches. Bay, 35% mortality of 3-yr old males in spring fishery; in Hudson River, mortality rates:	Juvenile growth rates average 0.35 mm/day in Albemarle Sound, N.C., average 0.46 mm/day in Hudson River; in Potomac River, average (1975) = 0.45 mm/day (1976) = 0.46 mm/day [61] Length by age data (all age classes) [58,61]

Species	Stock-Recruitment Relationship	Fecundity Eggs Per Female	Effective Exploited Age Group (in Md.)	Age of Sexual Maturity (♀) (yr)	Type of Fishery in Maryland (yr)	Migration	Location of Spawning	Catch-Size Distribution	Catch-Age Distribution (yr)	Mortality Rates	Growth Rates
Striped Bass *Morone saxatilis* (cont.)										Age 0 = .99.96% I = .666% II = .40% [61]	
Weakfish *Cynoscion regalis*	Commercial record in Virginia suggests little density dependence (1890-1959) [85]	45,000 - 1,726,000 [55]	1 - 4 (Va.) [85]	1 - 2 [55]	Commercial: pound nets, otter trawls, haul seines, purse nets; recreational [18,58,59, 85]	Move up bay and return to ocean after spawning [29,55] Possible differential migration by age class [18]	Atlantic Ocean, meso-polyhaline [58] Lower Ches. Bay inlets, coves [55]	175-350 mm with modal length at 225 mm (pound nets, Virginia, 1954-1958) [85]	1 yr - 62% 2 yr - 28% 3 yr - 8% 4 yr - 1% (Virginia, 1954-1958) [85]		In Ches. Bay, length averages 3-1/2 to 6 in. at 1/2 yr, 8 to 10-1/2 in. at 1 1/2 yr [59]
Winter Flounder *Pseudopleuronectes americanus*	Partial recruitment to Mass. fishery in age classes I-IV; Age II - 40% III - 80% IV - 81% [32]	Average 500,000 [56]	> 2 (Mass.) [32]	3 - 5 [56]	Commercial otter trawls, pound nets, fyke nets; recreational [49]	In winter, move toward shallow coastal waters and estuaries to spawn [56,58]	In Maryland waters of >5 ppt salinity, mesohaline; shallow coastal waters and estuaries [58]	In Cape Cod, two peaks: 30 and 40 cm; range, 25-50 cm [32]	Range 2 - 4 (Cape Cod) [32] Sex ratio 70/30 (female to male in Mass.) [89]	Post-recruitment total mortality for 1970 in Cape Cod was instantaneous; mortality rates for: fishing = 24% natural = 11% [32] Instantaneous fishing mortality rates = 21% [89]	In Ches. Bay, newly hatched = 3 - 3.5 mm in length; age I = 108 mm to 178 mm [59]

C. Categorization of Selected Species with Respect to Model Applicability

The type of management model applicable to a species depends on many aspects of the species life history, as noted above. From a regional perspective, however, two characteristics assume major importance: migration patterns and location of spawning. Both are major determinants of whether populations can be considered as unit stocks, a basic requirement of most stock management models.

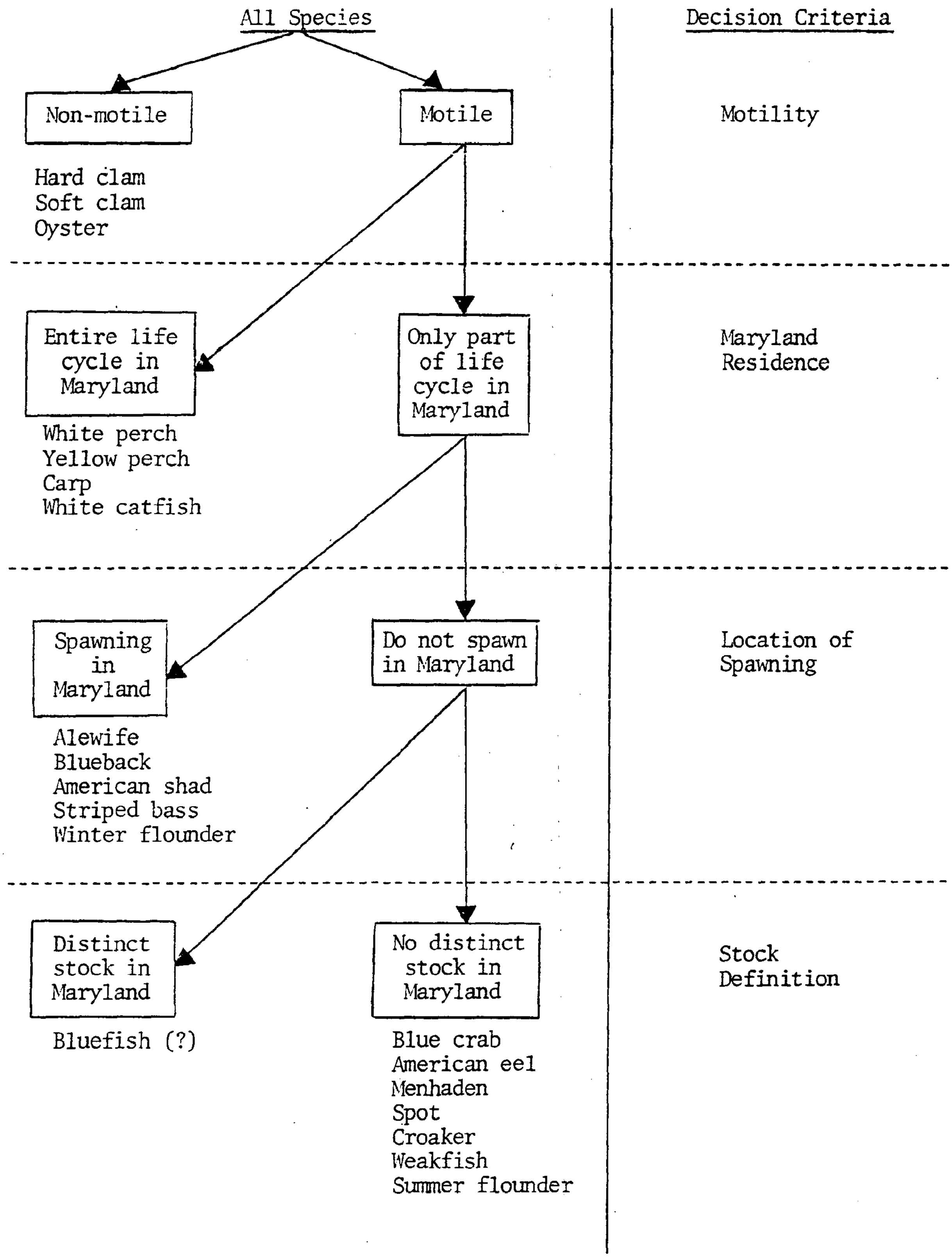
Many of the selected species exhibit similar migration and spawning patterns and can thus be grouped according to these patterns, as, for example, in Fig. V-1. The first criterion used for separation of species is motility. Population levels of non-motile species (hard clams, soft clams, oysters) in a given location are not influenced by movements or migrations. Thus, evaluation of exploitation and/or environmental perturbation is not complicated by abundance changes caused by immigration and emigration.

Motile species can be divided according to the portion of their life cycle spent in Maryland. Four species (white and yellow perch, carp, white catfish) complete their entire life cycles in Maryland waters. As a result, exploitation can be monitored and totally controlled, which is particularly relevant to recommendations on management options. Consequences of environmental degradation can also be clearly defined for these species.

Of species which spend only a part of their life cycles in Maryland, five are considered to spawn here (alewife, blueback, American shad, striped bass, winter flounder). The one non-anadromous species in this group, winter flounder, may exhibit only limited spawning in Maryland. However, because there is some evidence that it spawns in the lower Potomac River (Appendix D, Ref. 58), we are including it in this category.

Fish stocks are often delineated on the basis of spawning location because individuals tend to spawn at the location at which they themselves were spawned. This is dramatically clear in the case of anadromous species, but also holds for others, including many open-ocean spawners (Harden Jones, 1970). This fact is particularly important relative to management in Maryland because spawning success determines the size of a stock available for exploitation. Thus management options for these species would include actions impacting on their spawning success.

Figure V-1. Procedure followed in grouping selected Maryland exploited finfish and shellfish species according to major life history characteristics.



The final species group includes those which spend only part of their life cycle in Maryland and spawn outside Maryland waters. This group might be separable, given sufficient data, into two groups: species in which the same juveniles or adults of a unit stock return each year to Maryland waters (possibly bluefish), and those in which the individuals returning each year represent a random segment of a stock with wide distribution over non-Maryland waters (blue crab, American eel, menhaden, spot, croaker, summer flounder, weakfish). This latter group presents the most complex problem in modeling: how to determine impacts of Maryland exploitation on the source stock.

VI. EVALUATION OF MODEL APPLICABILITY

A. Introduction

Model and species categorizations provide a basis for evaluating the usefulness of various model types as management aids for different Maryland species or species groups. In assessing suitability, data availability plays as great a role as do model structure and assumptions. A generalized discussion of evaluation procedures is presented below, followed by specific discussion of individual species in which model categories are addressed. The resulting evaluations are thus consistent and objective.

B. Model Selection Scheme

The decision as to which of the stock management model types already discussed should be applied to any particular species must be based on data availability, management objectives, and the simplifying assumptions concerning the stock life history characteristics of the individual models. Figure VI-1 presents an example of this process where the management objective is assumed to be the determination of annual yield (either maximal or optimal). The selection method is represented as a two-gate process where data availability singularly determines the potentially applicable model type(s), and model assumptions and species life history characteristics determine the applicability of specific models within a major model category.

Figure VI-2 presents the generalized selection scheme expanded to incorporate the specific model assumptions into the decision criteria. For example, if growth, fishing and natural mortality, yield and effort data were available for species j, yield-per-recruit, surplus production, and statistical stock management models would all be potentially applicable to the modeling of the dynamics of stock j. In general, assumptions concerning the motility, growth, and mortality of species j affect the selection of a specific yield-per-recruit model. If species j is mobile, displays age-dependent growth and mortality, shows no major environmental effects on stock dynamics, and shows no major economic changes in its exploitation,

Figure VI-1. Conceptual overview of model selection process

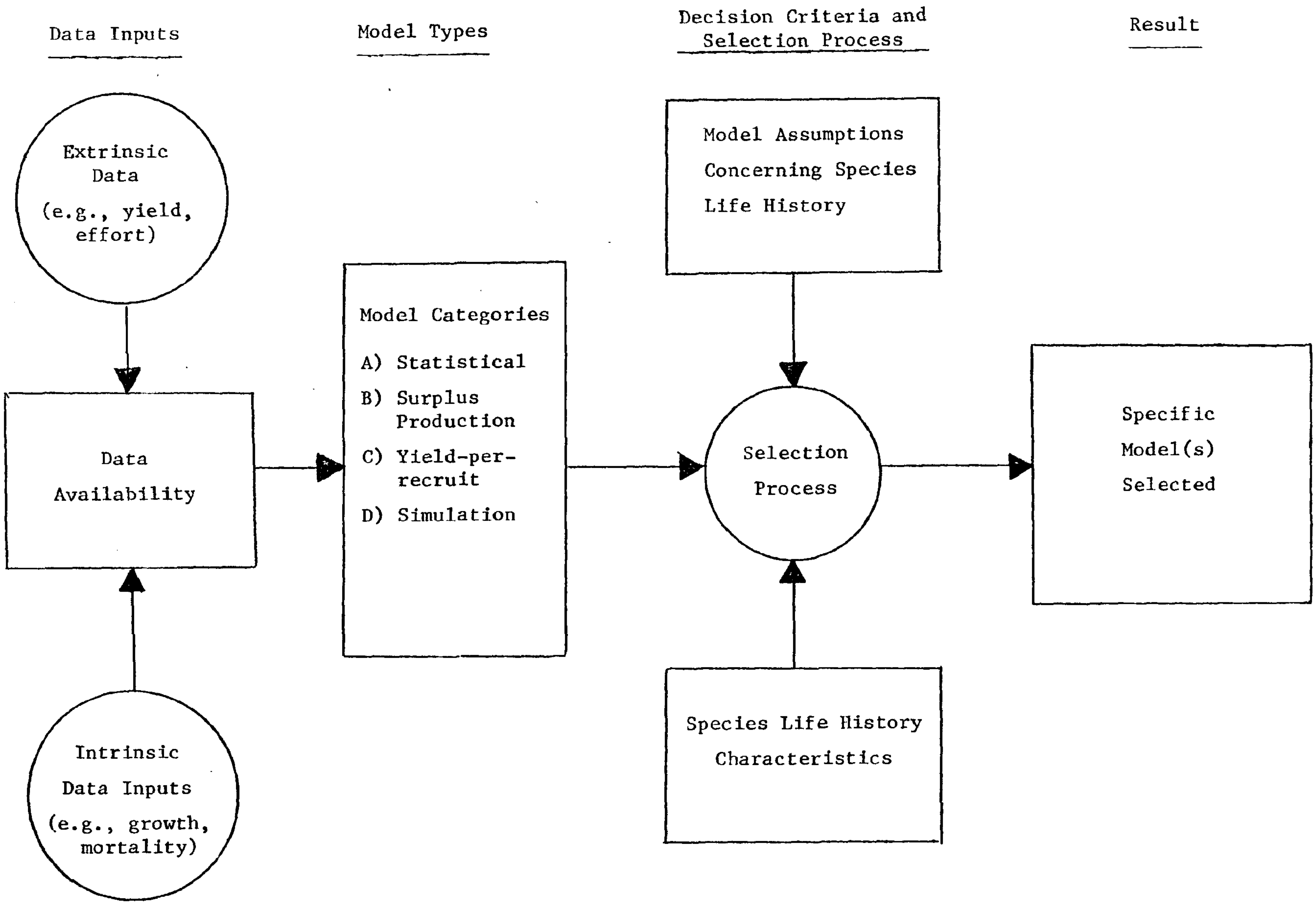
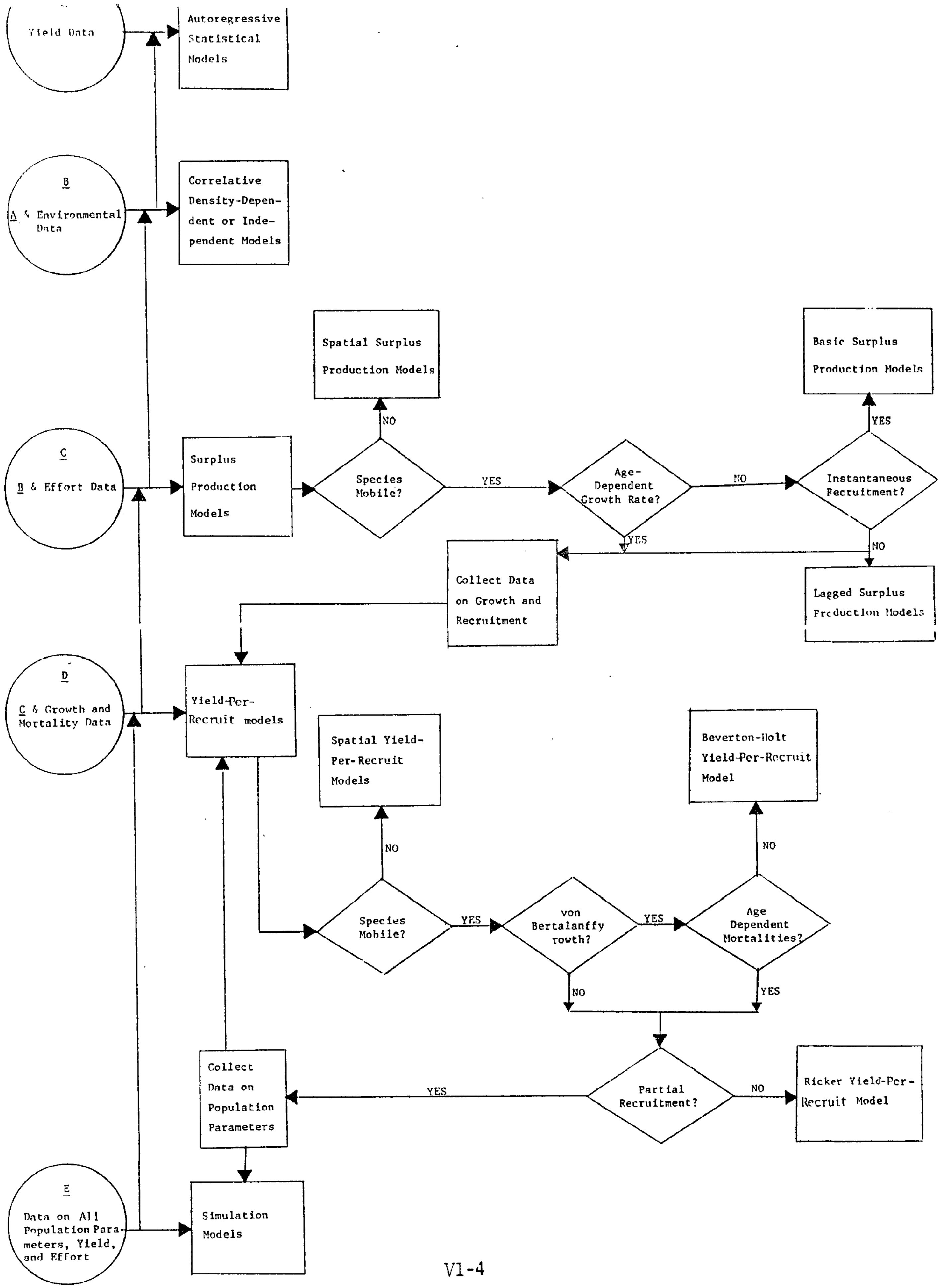


Figure VI-2. Detailed conceptual overview of model evaluation scheme



Yield Data
Autoregressive Statistical Models
B
A & Environmental Data
Correlative Density-Dependent or Independent Models
Spatial Surplus Production Models
Basic Surplus Production Models
NO
YES
C
B & Effort Data
Surplus Production Models
Species Mobile?
YES
Age-Dependent Growth Rate?
NO
Instantaneous Recruitment?
YES
NO
Collect Data on Growth and Recruitment
Lagged Surplus Production Models
D
C & Growth and Mortality Data
Yield-Per-Recruit models
Spatial Yield-Per-Recruit Models
Beverton-Holt Yield-Per-Recruit Model
NO
NO
Species Mobile?
YES
von Bertalanffy rowth?
YES
Age Dependent Mortalities?
NO
YES
Collect Data on Population Parameters
YES
Partial Recruitment?
NO
Ricker Yield-Per-Recruit Model
E
Data on All Population Parameters, Yield, and Effort
Simulation Models

then a Ricker yield-per-recruit model would be the best yield-per-recruit formulation available. In addition, either autoregressive or correlative statistical stock management models could be as potentially useful for the management of stock j as the yield-per-recruit model. According to the arguments presented in Fig. VI-2, surplus production models would be inappropriate because stock j displays age-dependent growth, and a detailed simulation model could not be constructed without additional sources of data. A simple simulation model which incorporated only growth and mortality could be used in this case. Preliminary applications of the procedure described in Fig. VI-2 to each of the selected species are discussed below.

C. Species-Model Evaluations

1. Hard Clam (Mercenaria mercenaria)

- Category -- non-motile; entire life history in Maryland
- Ramifications of category
  - -- All exploitation of Maryland stocks is under Maryland regulatory authority.
  - -- Quality of environment in Maryland can influence all life stages occurring in Maryland: spawning success, growth, and survival.
  - -- The status of stocks might be influenced by the recruitment of larvae from stocks outside Maryland waters.
  - -- The lack of immigration or emigration of harvestable stocks permits management of harvest on an areal (spatial) basis.
- Stock characterization
  - -- From settlement to harvest, stocks can be defined on an areal basis.
  - -- Because of possible recruitment of larvae from outside Maryland waters, a "true" unit stock cannot be defined for Maryland alone; but such a definition might be possible on an interstate basis.
- Stock-recruitment relationships
  - -- No stock-recruitment relationship is documented in the literature; many environmental factors appear to influence setting (Appendix D, Refs. 76, 77); gregarious settlement is documented.
  - -- Low stock densities may limit commercial fishing as a result of the economics of harvesting. If the fecundity of non-harvestable densities is sufficient to generate large sets, stock-recruitment relationships are irrelevant to management.

- Statistical model application
  - -- Relationships between success of set and various potentially important environmental variables could be investigated by use of correlation analyses.
  - -- Statistical models could be used for predictions of years of good sets, which might be of value as inputs for bioeconomic models or as indicators of environmental problems.
- Surplus production model application
  - -- The concept of surplus production has not been applied to shellfisheries in the literature reviewed. Although a theoretical upper limit to population size exists simply by virtue of space limitations, we do not know the growth response of a stock to changes in density, necessary for the application of this model type (See Section III.C.2).
  - -- The assumption of homogeneous distribution of stock and exploitation is probably not met for this species, particularly in Maryland (Appendix D; Ref. 77).
  - -- Current knowledge of the population biology of this species is insufficient for assessing the applicability of this model type.
- Yield-per-recruit model application
  - -- Because natural mortality rates vary with size (Appendix D, Ref. 36), application of a Beverton-Holt model might be limited to upper size ranges, or a Ricker model would have to be used.
  - -- The homogeneous distribution of stock and exploitation assumed in this model structure is certainly violated (Appendix D, Ref. 77), and the consequences would have to be investigated.
  - -- The stock-recruitment relationship is not known; but, if the stock is considered to be at equilibrium, a single estimate of number of recruits could be obtained and used with a Ricker model; some data suggest fairly regular recruitment over periods of several years (Appendix D, Refs. 67,76).
  - -- Yield-per-recruit models would be useful for evaluating the consequences of various exploitation strategies (e.g., the size limits) on yield. They could be used as inputs to bioeconomics models for maximizing monetary return from sets of variable magnitude.
- Simulation model application
  - -- The single shellfish management model found in the literature review was a simulation model of a sea scallop stock (Appendix A, Caddy, 1977). This model accounts for many distinct characteristics of shellfish stocks and fisheries and might prove to be a useful prototype for hard clams; heterogeneous spatial distributions can be divided into zones within which density and exploitation are homogeneous.

-- Simulation models provide a means of accounting for non-homogeneous spatial distribution of stock and fishing effort; they would be most appropriate where precise management decisions are necessary or where precise inputs to bioeconomics models are desirable.

- Summation

  -- The non-motility of clam populations and the possibility that recruitment might be independent of stock size differentiate clam fisheries from most of those which have been modeled in the literature.

  -- The simulation model for scallops described by Caddy (1977), which incorporates a Ricker yield-per-recruit model and spatial partitioning of the stock, would appear to be the most fruitful approach to modeling this species.

2. Soft Clam (*Mya arenaria*)

- Category - non-motile; entire life history in Maryland
- Ramifications of category

  -- Same as for hard clam (1)
- Stock characterization

  -- Same as for hard clam (1)
- Stock-recruitment relationships

  -- No stock-recruitment relationship documented in the literature.

  -- Large sets have occurred occasionally over the last 20 years, but are uncommon (Table V-2); this suggests that major sets are environmentally determined (i.e., stock-recruitment relationships are very weak); one statement appears in the literature that *Mya* is a non-compensatory species (Appendix D; Refs. 39,42); gregarious settlement is documented.

  -- Low stock densities may limit commercial fishing as a result of the economics of harvesting; if the reproduction of non-harvestable densities is sufficient to generate large sets, stock-recruitment relationships are irrelevant to management.
- Statistical model application

  -- Same as for hard clam (1)
- Surplus production model application

  -- This stock does not fulfill the assumption of homogeneous stock and exploitation distributions (e.g., Appendix D, Ref. 80); setting is strongly influenced by substrate type, and fishing intensity is influenced by the density of harvestable clams (Appendix D, Ref. 58).

  -- Many other assumptions may not be met, i.e., the possible weakness of the stock recruitment relationship suggests an equilibrium stock level may not be attainable.

-- The concept of surplus production has not been applied to shellfisheries in the literature reviewed; a theoretical upper limit to population size exists simply by virtue of space limitations; since the species may be non-compensatory (Appendix D, Ref. 42), the concept of surplus production might not apply.

- Yield-per-recruit model application

  -- Because natural mortality rates vary with size (Appendix D, Ref. 36), application of a Beverton-Holt model might be limited to upper size ranges, or a Ricker model would have to be used.

  -- The homogeneous distribution of stock and exploitation assumed is certainly violated (Appendix D, Ref. 58), and consequences would have to be investigated.

  -- Yield-per-recruit models would be useful for evaluating the consequences of various exploitation strategies (e.g., various size limits) on yield; they could be used as inputs to bioeconomics models for maximizing monetary return from sets of variable magnitude.

- Simulation model application

  -- Same as for hard clam (1)

- Summation

  -- The non-motility of clam populations and the possibility that recruitment might be independent of stock size differentiate clam fisheries from most of those which have been modeled in the literature.

  -- The simulation model for scallops described by Caddy (1977) (Appendix A), which incorporates a Ricker yield-per-recruit model, would appear to be the most fruitful approach to modeling this species.

  -- Soft clams in exploited populations have a much shorter life span than hard clams (1-2 yrs vs 3-8 yrs, Table V-1); thus, approaches to management would differ for the two species; for soft clams, where the stock-recruitment relationship is weak, a bioeconomics model might be useful to maximize financial return and allocate effort equitably.

3. <u>Oyster (Crassostrea virginica)</u>

- Category - non-motile; entire life history in Maryland
- Ramifications of category

  -- Same as for hard clam (1)
- Stock characterization

  -- Same as for hard clam (1)

- Stock-recruitment relationship
  - -- Successful sets are dependent on the availability of suitable substrate; however, substrate availability is not sufficient to ensure good sets (Appendix D, Ref. 81).
  - -- Environmental factors (e.g., temperature, salinity) appear to strongly influence the magnitude of a set.
  - -- The sporadic occurrence of major sets over the past 30 years and the localized character of recent major sets (Appendix D, Refs. 81, 87), suggest that the stock-recruitment relationship if any, is very weak.
- Statistical model application
  - -- Same as for hard clam (1)
- Surplus production model application
  - -- Many model assumptions may not be met; for instance, an equilibrium level oyster stock may not be definable, and stock and exploitation distributions are not homogeneous.
  - -- The concept of surplus production has not been applied to shellfisheries in the literature reviewed; a theoretical upper limit to population size exists simply by virtue of space limitations. However, we do not know the response of a stock to changes in density, necessary for application of this model type (see Section 111. C.2).
- Yield-per-recruit model application
  - -- Assumptions of homogeneous stock and exploitation distributions are not met.
  - -- Significant by-catch mortality to pre-recruitment oysters may occur due to fishing of harvestable oysters (Appendix D, Ref. 81); therefore, age-specific mortality rates not only differ, but may actually be interdependent; yield-per-recruit functions cannot directly accommodate such relationships.
  - -- Yield-per-recruit models do not appear to be a practical modeling procedure for oyster management.
- Simulation model application
  - -- Oysters are unique among exploited stocks in that they occur in discrete bars; and stock dynamics vary with location and over time (Appendix D, Ref. 58). Thus, the only feasible modeling approach is simulation modeling, which can be adapted to accommodate high levels of complexity in stock behavior.
  - -- Modeling of stock production might be valuable as a tool in the management of cultured stocks (i.e., those created by seed and cultch planting).
  - -- A simulation model incorporating economic aspects of the fishery also provides a basis for objective allocation of fishing effort among bars.

- Summation
  - -- If a weak stock-recruitment relationship is assumed, management of oyster stocks to ensure successful reproduction appears to have no biological basis.
  - -- Modeling could be directed toward maximizing yield from any set in a given year, maximizing the financial return from such a set, and equitably allocating fishing effort; a simulation model would appear to be the best modeling approach for these purposes.

4. <u>White Perch (Morone americana)</u>

- Category - motile; entire life history in Maryland
- Ramifications of category
  - -- All exploitation of Maryland stocks is under Maryland regulatory authority.
  - -- Quality of environment in Maryland can influence all life stages, spawning success, growth, and mortality.
- Unit stock characterization
  - -- Distinct stocks may occur in different Bay tributaries (Ritchie et al., 1973).
  - -- Degree of intermixing of tributary stocks is unknown, but regional definition of unit stock appears reasonable (e.g., Potomac River, upper Bay).
- Stock-recruitment relationship
  - -- No stock-recruitment relationships are documented in the literature.
  - -- Stunted populations (i.e., high-density populations exhibiting lower than average growth rates) have been documented in Maryland (e.g., Potomac River [Appendix D, Ref. 58]; Susquehanna River, Foerester, 1976); stunting suggests that biomass of juveniles and adults may be at the carrying capacity of the environment but that survival to the juvenile stage is somewhat density independent.
- Statistical model application
  - -- Commercial landing data by zone could be partitioned to define unit stocks (see unit stock characterization above); availability of effort data is not presently known.
  - -- White perch support an extensive recreational fishery (Speir et al., 1977); only limited recreational landing data are currently available; however, a current federally sponsored sportfishing survey (J. Williams, personal communication) may provide this data.
  - -- Environmental data (e.g., river flow, temperature, productivity) are commonly used in statistical fisheries models (Appendix A, Talbot, 1954; Welcomme, 1976). Lengthy records of such data may be available for many segments of Maryland's tidewaters (e.g.,

Potomac River, Appendix D, Ref. 58). Thus, data bases may be available for the construction of statistical models.

- -- Statistical models, whether autoregressive or correlative, provide a means of predicting yield for a certain level of effort where all other relationships remain constant. For white perch they could prove to be of value in determining if production of certain areas is below expected levels, which in turn could be used as an indicator of environmental quality or exploitable excess production.

- Surplus production model application

  - -- Availability of yield and effort data has been discussed above; the absence of extensive data on recreational yield would be a major problem in the application of surplus production models.
  - -- Data over a fairly wide range of effort are necessary for surplus production modeling; range of effort must be examined.
  - -- Assumptions of equilibrium populations and stable age distributions might be met in regions where the stock is currently not heavily exploited; however, if dominant yearclasses occur often, surplus production models would not be applicable.
  - -- By applying surplus production models to white perch populations, we could estimate sustained yield obtainable at different stock levels.

- Yield-per-recruit model application

  - -- Assumptions of constant fishing and natural mortality rates over all ages (see Section III.C.3) may not apply in cases where recreational fishing effort is high, and mortality may be highest on older fish. This suggests that a Ricker model would be most appropriate.
  - -- The stock-recruitment relationship is not known; but, if a stock is considered to be at equilibrium, a single estimate of number of recruits could be obtained and used with a Ricker model.
  - -- Yield-per-recruit models would be useful for evaluating the consequences to yield of various exploitation strategies (e.g., size limits).

- Simulation model application

  - -- Simulation models could be developed which would integrate the management of all stocks defined in Maryland (i.e., a pooled stock approach). The availability of considerable data on various life history aspects of white perch suggests that a simulation model is feasible.
  - -- A simulation model would be most valuable where precise determination of consequences of an action is necessary and where the effect of invalid assumption on the precision of the estimates is of concern.

- Summation
  - -- Relatively large amounts of data are available on white perch and its habitat; thus, all model approaches appear feasible.
  - -- Choice of a modeling approach would depend primarily on the objective of the management plan followed.

5. Yellow Perch (*Perca flavescens*)

- Category - motile; entire life history in Maryland
- Ramifications of category
  - -- Same as for white perch (4)
- Stock characterization
  - -- Since this species is semi-anadromous tributary stock are probably genetically distinct; however, this has not been documented in the literature.
  - -- A regional definition of stocks would appear reasonable, particularly since lack of tolerance to higher salinities prevents movement between Bay regions.
- Stock-recruitment relationship
  - -- Dominant yearclasses are documented in the literature for lake populations (Appendix D, Ref. 13).
  - -- No stock-recruitment relationships have been documented for estuarine stocks.
- Statistical model application
  - -- Same as for white perch (4)
- Surplus production model application
  - -- Same as for white perch (4)
- Yield-per-recruit model application
  - -- Same as for white perch (4)
- Simulation model application
  - -- Same as for white perch (4)
- Summation
  - -- Same as for white perch (4)

6. Carp (*Cyprinus carpio*)

- Category - motile; entire life history in Maryland
- Ramifications of category
  - -- Same as for white perch (4)

- Stock characterization
  - -- Stocks may be definable by tributary since lack of tolerance to higher salinities may limit movement between tributaries throughout the Bay system.
- Stock-recruitment relationship
  - -- No stock-recruitment relationship is documented in the literature.
  - -- No information is available which is applicable to stock-recruitment relationships.
- Statistical model application
  - -- Same as white perch, except that recreational and commercial fisheries may be less extensive, and stocks may not be as definable geographically.
- Surplus production model application
  - -- Most landings of carp are incidental to efforts on other, more valuable species, such as striped bass; as a result, relationships between effort and yield may not be constant, even assuming that stock size remains constant; therefore, the application of surplus production models would be inappropriate.
  - -- The extent of the recreational fishery is unknown; absence of recreational yield data might invalidate use of these models.
  - -- In tributary systems where an intensive fishery directed toward carp exists, this modeling procedure would be useful.
- Yield-per-recruit model application
  - -- No data could be located on growth, fishing mortality, or natural mortality rates in estuarine populations (extensive data may exist for cultured populations); thus, the compatibility of carp life history characteristics with yield-per-recruit model structures cannot be evaluated.
- Simulation model application
  - -- A simulation model could be constructed to integrate models of regional stocks; however, the lack of data on life history characteristics makes it difficult to assess the feasibility of constructing such a model.
- Summation
  - -- The lack of life history data prevents a thorough evaluation of model applicability; surplus production models may be most useful under suitable circumstances.

7. <u>White Catfish (Ictalurus catus)</u>

- Category - motile; entire life history in Maryland
- Ramifications of category
  - -- Same as for white perch (4)

- Stock characterization
  - -- Same as for carp (6)
- Stock-recruitment relationship
  - -- No stock-recruitment relationship documented in the literature.
  - -- No information available which is applicable to stock-recruitment relationships.
- Statistical model application
  - -- Same as for carp (6)
- Surplus production model application
  - -- The extent of the recreational fishery is unknown; absence of recreational yield data might invalidate use of these models.
  - -- In tributary systems where an intensive fishery directed toward catfish exists, this modeling procedure could be useful; one example of such a situation is the upper Potomac estuary (Appendix D, Ref. 58).
- Yield-per-recruit model application
  - -- Same as for carp (6)
- Simulation model application
  - -- Same as for carp (6)
- Summation
  - -- Same as for carp (6)

8. Alewife (*Alosa pseudoharengus*) and Blueback (*Alosa aestivalis*)

- Category - motile; only part of life cycle spent in Maryland; spawns in Maryland
- Ramifications of category
  - -- Exploitation rates experienced by fish in non-Maryland waters cannot be regulated by Maryland.
  - -- The greater the fishing and natural mortality rates outside of Maryland as a proportion of total mortality, the less impact Maryland regulations can have on stock size.
  - -- Environmental conditions on spawning grounds in Maryland can influence reproductive success of the stock and thus affect harvest in Maryland; for this reason, management of the fishery must include regulation of water quality.
- Stock characterization
  - -- As with most anadromous species, adults return to spawn where they were spawned (Appendix D, Ref. 59); thus, unit stocks can be defined in Maryland according to spawning area.

-- Because both species tend to spawn in many small tributaries of the Chesapeake Bay, regional definitions of stock may be somewhat imprecise; ideally, management should be carried out by tributary; however, exploitation is not tributary based, which rules out this possibility.

- Stock-recruitment relationship

-- No stock-recruitment relationship is documented in the literature; in several Virginia rivers, no relationship between stock size and production of juveniles was noted (Appendix D, Ref. 82).

-- For stocks spawning in restricted locations, such as small tributaries, numbers of juveniles produced may be limited by the carrying capacity of the spawning area.

-- The establishment of a relationship between size of the spawning stock in Maryland and subsequent recruitment to the fishery in Maryland is dependent on non-Maryland exploitation rates being either constant or known.

- Statistical model application

-- Most of the commercial landings of alewives are from pound nets located some distance from actual spawning locations (e.g., at the mouth of the Potomac where spawning occurs in the Potomac tributaries as far upstream as Washington, D.C. in Maryland, Appendix D, Ref. 58); thus, relationships between yield data and tributary environmental characteristics might not be clearly definable.

-- If yield data from specific spawning locations could be obtained, correlations with environmental variables might be established.

-- Autoregressive models, rather than correlative, might be useful for establishing stock recruitment relationships; such models assume that exploitation rates and natural mortality are constant.

-- No information is available on the magnitude of the recreational fishery.

- Surplus production model application

-- There has been heavy exploitation of Maryland stocks of anadromous species while they are at sea and/or in non-Maryland waters (Appendix D, Ref. 82).

-- Because surplus production models use yield as a data input, they would be applicable only if: (1) the contribution of Maryland stocks to total harvest outside Maryland could be determined, or (2) if effort outside Maryland was assumed to be constant over all years.

-- Because of the potential difficulties in determining (1) and (2) above, application of surplus production models appears inappropriate.

- Yield-per-recruit model application
  - -- The alewife fishery in Maryland has a much higher age of recruitment than the offshore fishery because harvest in Maryland presumably takes sexually mature fish returning to spawn (ages III to V), while open ocean fisheries take all ages (Appendix D, Ref. 82); thus, age of recruitment (t_r), a model parameter, is difficult to define.
  - -- Because of the existence of offshore and non-Maryland fisheries, an instantaneous fishing rate (F) is difficult to define for the Maryland stock simply on the basis of Maryland fishing rates.
  - -- If non-Maryland fishing rates could be determined and if fishing rates varied with age, then a Ricker model would be more appropriate than a Beverton-Holt model.
  - -- If the non-Maryland fishery were negligible, or non-Maryland fishing effort were constant over many years, it might be possible to develop a yield-per-recruit model; since both of these situations are unlikely, yield-per-recruit models would not appear appropriate for this species.

- Simulation model application
  - -- A simulation model could be developed which would treat the fishery as consisting of several phases, each with its own dynamics.
  - -- For example, submodels of the oceanic fisheries, inshore non-Maryland fisheries, and Maryland fisheries could be developed as major compartments for a total stock model.
  - -- A reproduction submodel for Maryland stocks could be developed to simulate population dynamics and account for the effects of variations in water quality or habitat modification on reproductive success.

- Summation
  - -- Because of the interstate and international nature of the fishery, simulation modeling appears most appropriate for these species; however, the availability of data necessary for development of such a model is questionable.

9. <u>American Shad (Alosa sapidissima)</u>

- Category - motile; only part of life cycle is spent in Maryland; spawns in Maryland
- Ramifications of category
  - -- Same as for alewife and blueback (8)
- Stock characterization

-- Essentially the same for alewife and blueback (8); however, shad spawn in fewer, larger Bay tributaries (e.g., the Potomac, Susquehanna, and Choptank rivers) than do the other two species; because exploitation is often centered on these water bodies, relating Maryland harvests to distinct spawning stocks may be possible.

- Stock-recruitment relationship

  -- On the Hudson River, 85% of the variation in stock size during a given year was attributable to escapement (numbers of adults reaching the spawning ground) 3, 4, and 5 years earlier (Appendix A; Talbot, 1954); this suggests a deterministic stock-recruitment relationship; if Maryland stocks have similar recruitment mechanisms, such a relationship might hold here.

  -- In the Potomac, shad spawn in tidal waters (Appendix D, Ref. 58), while, in other river systems (e.g., the Hudson and Delaware rivers), spawning occurs in the non-tidal, upper reaches of the rivers (Appendix A, Talbot, 1954); such a difference in spawning habitat may influence the degree of determinism of the stock-recruitment relationship.

- Statistical model application

  -- Since landings in Maryland tend to be spawning ground-specific, autoregressive or correlative statistical models appear feasible, as demonstrated by Talbot (1954) (Appendix A).

  -- Little information is available on the recreational fishery; if recreational landings were significant but not known, it would be difficult to develop a statistical model of total yield.

- Surplus production model application

  -- Same as for alewife and blueback (8)

- Yield-per-recruit model application

  -- Same as for alewife and blueback, except that the extent of the offshore fishery is less clear, and age of recruitment to major non-Maryland fisheries (i.e., Virginia) may be the same as for the Maryland fishery.

- Simulation model application

  -- Same as for alewife and blueback (8)

- Summation

  -- Same as for alewife and blueback (8)

10. Striped Bass (*Morone saxatilis*)

- Category - motile; only part of life cycle in Maryland, spawns in Maryland

- Ramifications of category
- Same as for alewife and blueback (8)

  -- Essentially the same as for American shad, except that striped bass spawn lower in tributaries than shad (Appendix D, Ref. 58).

- Stock-recruitment relationship

  -- Dominant yearclasses are observed (Appendix D, Ref. 58) suggesting that the stock-recruitment relationship is weak, and that environmental variation accounts for most of the variation in yearclass success (e.g., Ulanowicz and Polgar, in press).

- Statistical model application

  -- Statistical models have been applied to striped bass stocks as predictors of yearclass strength (e.g., Appendix B, Stevens, 1977); further applications to Maryland stocks could be developed.

- Surplus production model

  -- The occurrence of the dominant yearclass phenomenon indicates that a striped bass stock is not an equilibrium population; in the absence of a deterministic stock-recruitment relationship, a surplus production model cannot be applied.

- Yield-per-recruit model application

  -- Because of the existence of non-Maryland fisheries, an instantaneous fishing rate (f) is difficult to define for the Maryland stock simply on the basis of Maryland fishing rates.

  -- If non-Maryland fishing rates could be determined, and if fishing rates varied with age, then a Ricker model would be more appropriate than a Beverton-Holt model.

  -- If the non-Maryland fishery were negligible or the non-Maryland fishing effort constant over many years, it might be possible to develop a yield-per-recruit model; since both of these situations are unlikely, yield-per-recruit models would not appear appropriate for this species.

- Simulation model application

  -- Numerous simulation models of striped bass have been developed for environmental assessment (e.g., Appendix A, Van Winkle et al., 1974); such models could be expanded and applied to management problems.

- Summation

  -- Because of the complex migrations of these species and the interstate nature of the fishery, simulation modeling would appear most appropriate for management purposes.

11. Winter Flounder (Pseudopleuronectes americanus)

- Category - motile; only part of life cycle in Maryland; spawns in Maryland.
- Ramifications of category
  - -- Same as for alewife and blueback (8)
- Stock characterization
  - -- Extent of spawning is not clearly defined; spawning has been noted in the lower Potomac estuary (Appendix D, Ref. 58); if specific spawning areas in Maryland were delineated, and if it could be demonstrated that distinct spawning stocks used these areas, stocks could be defined by spawning location.
  - -- The proportion of Maryland-harvested winter flounder which were spawned in Maryland is not known; if a significant portion of the Maryland harvest was spawned in non-Maryland waters, approaches to stock management would be very complex.
- Statistical model application
  - -- Because of the poor definition of spawning areas, statistical models, other than autoregressive, would appear difficult to develop.
- Surplus production model application
  - -- Movements of flounder spawned in Maryland are unknown; thus, degree and location of exploitation cannot be determined, and total yield from stocks spawned in Maryland cannot be estimated.
  - -- It appears that surplus production models cannot be applied to this species for management in Maryland.
- Yield-per-recruit model application
  - -- Data are available on growth, natural mortality, and fishing mortality rates for this species (Appendix D, Refs. 32,59,89).
  - -- A yield-per-recruit model could be developed as a basis for determining optimal harvesting strategies; using empirical information on yearclass sizes, such an approach would de-emphasize the importance of the stock-recruitment relationship.
- Simulation model application
  - -- A lack of information on movements of Maryland and non-Maryland stocks makes it difficult to construct a simulation model; partitioning of in-state and out-of-state fishing mortalities would not be possible.
  - -- Migration data would have to be obtained for all spawning stocks contributing to the Maryland harvest before a simulation model would be feasible.
- Summation
  - -- A current lack of stock definition would make application of any model extremely difficult at the present time.

12. Bluefish (Pomatomus saltatrix)

- Category - motile; only part of life cycle (non-spawning) in Maryland; possible distinct stock in Maryland
- Ramifications of category
  - -- If it could be established that the same subunit of a given stock returned to the same nursery or feeding area in Maryland each year, a relationship between management actions and responses of the stock might exist.
  - -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities to stock maintenance.
- Stock characterization
  - -- Bluefish spawn along the continental shelf; there is some indication that the Chesapeake Bay stock may be a distinct subunit of the east coast bluefish population (Appendix D, Ref. 28).
  - -- How the stock partitions itself between Maryland and Virginia waters is unknown.
- Stock-recruitment relationship
  - -- Yearclass strength may be determined by coastal circulation pattern (Appendix D, Ref. 4).
  - -- Thus, environmental factors may be more important in determining reproductive success than stock (i.e., the stock-recruitment relationship is not deterministic).
- Statistical model application
  - -- If sufficient data were available, it would be possible to use statistical models to investigate environmental variables which might influence the extent of migration of a stock into Maryland waters.
  - -- Such a relationship could be used to determine possible consequences to the stock of variations in exploitation rates in Maryland.
- Surplus production model application
  - -- Same as for striped bass; also, recreational harvest is large and undocumented; total yield data do not exist.
- Yield-per-recruit model application
  - -- Because of the existence of non-Maryland fisheries, an instantaneous fishing rate (F) is difficult to define for the Maryland stock simply on the basis of Maryland fishing rates.
  - -- If non-Maryland fishing rates could be determined and if fishing rates varied with age, then a Ricker model would be more appropriate than a Beverton-Holt model.

-- If the non-Maryland fishing effort were assumed constant, it might be possible to develop a yield-per-recruit model which combines the non-Maryland fishing mortality with natural mortality; however, no mortality data are available in the literature.

- Simulation model application

  -- If a distinct Chesapeake Bay stock were assumed, a simulation model could be developed consisting of Virginia and Maryland compartments and a reproductive submodel incorporating the influence of environmental factors, such as coastal currents.

  -- Such a model could be used to examine the consequences of management actions in both states as well as the interdependency of these actions; however, data required for development of such a model appear unavailable.

- Summation

  -- Same as for striped bass (10).

13. Atlantic Menhaden (Brevoortia tyrannus)

- Category - motile; only part of the life cycle (non-spawning) in Maryland

- Ramifications

  -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities.

- Stock characterization

  -- The Chesapeake Bay population of menhaden appears to be a random segment of the east coast stock (Appendix D, Ref. 22).

  -- Currently, Chesapeake Bay landings (i.e., Maryland and Virginia) account for approximately 60% of total landings from the east coast stock (Appendix D, Ref. 83); since most of these fish are not sexually mature, it appears that Chesapeake Bay is the major nursery area for the total east coast stock; thus, Maryland management decisions could influence the status of this stock.

- Stock-recruitment relationship

  -- Yearclass strength is determined by both stock size and coastal circulation patterns (Appendix D, Ref. 12).

  -- Because environmental factors (coastal currents) dominate recruitment to the fishery, the stock-recruitment relationship is non-deterministic.

- Statistical model application

  -- Same as for bluefish (12)

- Surplus production model application
  - -- If there is no deterministic stock-recruitment relationship, the stock cannont attain an equilibrium level; thus, a surplus production model cannot be applied.
- Yield-per-recruit model application
  - -- Because of the existence of non-Maryland fisheries, an instantaneous fishing rate (F) is difficult to define for the Maryland stock simply on the basis of Maryland fishing rates.
  - -- A menhaden Ricker yield-per-recruit model has been developed at the NMFS, Beaufort Laboratory (Appendix D, Ref. 83); some modification of this model might be applicable for management in Maryland.
- Simulation model application
  - -- The NMFS, Beaufort Laboratory, is developing a menhaden stock simulation model, compartmentalized by geographic region; the Chesapeake Bay is one of the compartments in the model; a cooperative effort with NMFS might be possible to further partition the Chesapeake Bay submodel into Maryland and Virginia portions.
- Summation
  - -- Same as for striped bass (1)

14. <u>Blue Crab (Callinectes sapidus)</u>

- Category - motile; only part of life cycle (non-spawning) in Maryland
- Ramifications of category
  - -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities in stock maintenance.
- Stock characterization
  - -- The Chesapeake Bay population of blue crab may be a relatively distinct stock, since spawning occurs in the lower Bay or near the mouth of the Bay (Appendix D, Ref. 66).
  - -- Migrational patterns differ between sexes; males entering Maryland waters may remain over their entire life; females migrate between Maryland and Virginia; thus, the Maryland portion of the stock is not a clearly defined segment of the Bay stock.
- Stock-recruitment relationship
  - -- No stock-recruitment relationship is documented in the literature.
  - -- Large fluctuations in annual landings over the last 100 years (Appendix D, Ref. 66) suggest the irregular occurrence of dominant yearclasses; the stock-recruitment relationship may be weak.

- Statistical model application
  - -- Same as for bluefish (12)
- Surplus production model application
  - -- Same as for striped bass (10); also recreational harvest is large and undocumented; total yield data do not exist.
- Yield-per-recruit model application
  - -- Since crab growth is through molts, models employing constant growth functions (e.g., von Bertalanffy) are inappropriate; growth rate based on weight increase could possibly approach a constant.
  - -- Since crab growth is influenced by salinity, growth rates vary by region in the Bay; a single model is inapplicable for all Maryland waters.
  - -- Standard yield-per-recruit models appear inapplicable to blue crabs, but versions using modified growth functions could be developed.
- Simulation model application
  - -- Same as for bluefish, except that environmental factors influencing reproduction success would include non-tidal up-Bay transport, salinity, etc., rather than coastal currents.
  - -- Also, since growth is salinity dependent, Bay waters would have to be partitioned according to salinity and different growth models developed for each salinity zone.
- Summation
  - -- Same as for striped bass (10)

15. American Eel (*Anguilla rostrata*)

- Category - motile; only part of life cycle (non-spawning) in Maryland
- Ramifications of category
  - -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities to stock maintenance.
- Stock characterization
  - -- Since all eels in North America originate from a single spawning location in the Sargasso Sea in the Atlantic Ocean (Appendix D, Ref. 59), all must be considered to be a single stock.
  - -- Although not documented, it is highly unlikely that the elvers (juvenile eels) entering the Bay each spring are progeny solely of the adult stock which emigrated from the Bay the previous fall; thus, the "stock" of Chesapeake Bay is not reproductively distinct.

- Stock-recruitment relationship
  - -- A stock-recruitment relationship for the eel could be established only on a continental basis.
  - -- The size of the stock in Maryland at any given time would have little influence on size of stocks in subsequent years.
- Statistical model application
  - -- If numbers of elvers entering different tributaries or portions of the Bay could be monitored, statistical models could be developed to investigate environmental factors influencing recruitment to those locations.
  - -- Biomass production rates of eels may differ by location or region; statistical models could be developed to correlate these differences with various environmental variables.
- Surplus production model application
  - -- Because of the absence of a stock-recruitment relationship, no equilibrium population could be defined for the eel; thus, a surplus production model would not be appropriate.
- Yield-per-recruit model application
  - -- If recruitment is defined as the numbers of elvers reaching a nursery area, a yield-per-recruit model is feasible; however, little data are available on growth, natural mortality, and fishing mortality rates, and the eel presents a very difficult sampling problem.
- Simulation model application
  - -- Fisheries for elvers have been established in various parts of the United States; a simulation model would relate fishing mortality of elvers to loss of potential eel production at the adult level; a yield-per-recruit model would be likely to be a major component of such a model.
- Summation
  - -- Because of the unique nature of the life history of this species and the complex relationship between fisheries for both juveniles and adults, a simulation model approach would appear most appropriate for this species.

16. Spot (Leiostomus xanthurus), Atlantic Croaker (Micropogonias undulatus), and Weakfish (Cynoscion regalis)

  - o Category - motile; only part of life history (non-spawning) in Maryland
  - o Ramifications of category
    - -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities.

- Stock characterization
  - -- These species spawn either offshore or near the mouth of the Bay (Appendix D, Ref. 59); the existence of distinct Chesapeake Bay stocks is uncertain; fish present in the Bay and in Maryland waters may represent random segments of a southeast coast stock (Appendix D, Ref. 86).
  - -- Weakfish, which may spawn in the lower Bay (Appendix D, Ref. 85), probably could be defined as having a Bay stock; but the portion of that stock which enters Maryland waters is probably not distinct.
- Stock-recruitment relationship
  - -- No stock-recruitment relationships have been documented in the literature for these species.
  - -- Several strong yearclasses of croaker and weakfish have appeared in recent years after long periods of very low stocks (Appendix D, Refs. 58,85), suggesting a nondeterministic stock-recruitment relationship.
  - -- Abundance of spot juveniles in Maryland waters has remained consistently high over the last 5 to 7 years (Hixon et al., 1979), suggesting that the stock may currently be at some equilibrium level; lower abundances in earlier years indicate that this might be a transient phenomenon.
- Statistical model application
  - -- Because of the nature of spawning location, certain environmental variables might influence the numbers of larvae entering Maryland waters; statistical models could be developed as predictors of juvenile abundance.
  - -- If sufficient data were available, statistical models could be used to investigate environmental variables that might influence the extent of migration of a stock into Maryland waters.
  - -- Such a relationship could determine possible consequences to the stock of variations in exploitation rates in Maryland.
- Surplus production model application
  - -- For croaker and weakfish, same as striped bass (10); also, recreational harvest may be large and undocumented; thus, total yield data do not exist.
  - -- For spot, a surplus production model may be applicable if an equilibrium population currently exists; however, because of the recreational and interstate nature of the fishery, determination of yield and effort would be difficult.

- Yield-per-recruit model application
  - -- Same as for bluefish (12)
- Simulation model application
  - -- If a distinct Chesapeake Bay stock were assumed, a simulation model could be developed consisting of Virginia and Maryland compartments and a reproductive submodel incorporating the influence of environmental factors, such as coastal currents.
  - -- Such a model could be used to examine the consequences of management actions in both states as well as the interdependency of these actions; however, data required for development of such a model appear unavailable.
  - -- Croaker and spot, with offshore spawning, present the same types of problems for management as do menhaden; given sufficient data, a simulation model compartmentalized by geographic region could be developed.
- Summation
  - -- Same as for striped bass (10)

17. Summer Flounder (*Paralichthys dentatus*)

- Category - motile; only part of life cycle (non-spawning) in Maryland
- Ramifications of category
  - -- The proportion of mortality due to fishing and natural mortality in Maryland would determine the importance of Maryland regulatory activities.
- Stock characterization
  - -- This species spawns offshore; the Maryland population in any year may be a random segment of two distinct east coast spawning stocks (P. Scarlett, N.J. Division of Fish, Shellfisheries and Wildlife, personal communication); management of this species is currently being reviewed by the State-Federal Marine Fisheries program because of the wide distribution of these stocks.
- Stock-recruitment relationship
  - -- No stock-recruitment relationships documented in the literature.
- Statistical model application
  - -- Because no Maryland stock can be defined, application of statistical models appears inappropriate.
- Surplus production model application
  - -- Without knowledge of the population dynamics of the species, no judgement can be made about the applicability of surplus production models.

- Yield-per-recruit model application
  - -- Because the individual fish present in Maryland waters at any given time represent a random segment of stock distributed over a much wider range, application of this model type to fish in Maryland would appear inappropriate.
- Simulation model application
  - -- A simulation model could reasonably be applied only to stocks contributing to Maryland landings, with Maryland waters representing a geographical compartment of the model; however, without data on the extensive undocumented recreational fishery for this species, model development would not be possible.
- Summation
  - -- Same as for striped bass (10)

VII. COMMUNICATIONS WITH MANAGEMENT AGENCIES

A. Objective

The purpose of this task was to determine if mathematical models were being used in the fisheries management programs of various state, federal, and international agencies and, if so, the nature of the models in use and the degree of success of their application.

B. Interview Procedure

Initial contacts were made by telephone with federal laboratories known to be actively involved in fisheries model development (e.g., Woods Hole NMFS Northeast Fisheries Laboratory). Individuals contacted were then asked for names of persons in other organizations who were also involved in the development and/or application of fisheries models. Most contacts were made in this way.

In telephone conversations, information requested included: name and position of the individual contacted, species being managed, types of models being employed, and evaluation of success of the application.

Written requests have been made to the United Nations Food and Agriculture Organization and to the Fisheries Research Board of Canada for any available reports on application of fisheries management models. The requested information has not yet been received.

C. Results

Table VII-1 summarizes the results of phone and letter communications with staff members of various fisheries management agencies. Because most of the information was received verbally, any inaccuracies in representation occurring are the responsibility of the authors. In many cases, precise answers to questions were not possible, and some degree of interpretation of comments was employed by the authors.

Because of the time-consuming nature of these activities and difficulties in contacting many individuals, all potential contacts have not yet been made. This part of the project will be continued into Phase II.

Table VII-1. Individuals and agencies providing information on current use of fisheries models in management programs (only those contacts from which information was received are listed).

Individual	Organization	Type of Information Provided	Current Use of Models	Comments
Dr. Michael Sissenwine, Deputy Chief, Resource Assessment Division	Northeast Marine Fisheries Center, National Marine Fisheries Service, Woods Hole, Mass.	Verbal plus publications	Stock assessments of many major species in the northwest Atlantic made using cohort analysis; Beverton-Holt yield-per-recruit models frequently used to choose ranges of F's for stock assessments; model use summarized in Sissenwine et al., 1979 (Appendix A).	Model application here appears to be as advanced as at any other agency contacted; large data bases (both survey and landings) are available; however, management decisions are made by Regional councils; NMFS provides technical support to the councils.
Walter Nelson, William Schaaf	Southeast Marine Fisheries Center, National Marine Fisheries Service, Beaufort, North Carolina	Verbal	Most modeling work deals with menhaden; models developed include one dealing with recruitment (Nelson et al., 1977, Appendix A) and a Ricker yield-per-recruit model; development of a simulation model based on regional compartments is underway.	Because menhaden is an inshore species, it is under regulatory authority of the States; the Atlantic States Marine Fisheries Commission is developing a management plan for this species; the NMFS people serve as technical advisors to the Commission.

Table VII-1. Continued.

Individual	Organization	Type of Information Provided	Current Use of Models	Comments
Dr. Felix Favorite	Northwest Marine Fisheries Center, National Marine Fisheries Service, Seattle, Wash.	Verbal (publications not yet received)	An ecosystem model of the eastern Bering Seafisheries has been developed (documentation of the model has not yet been received).	Application of this model was not determined.
Dr. Guy Marchesseault, Senior Biologist	New England Regional Fisheries Management Council	Verbal and publications	Level of modeling varies by species; surplus production and yield-per-recruit models have been used in making management decisions on the scallops fishery; extensive bio-economic modeling being done.	Much of the work being done is in conjunction with the Northeast Marine Fisheries Center; all stock assessment data comes from NMFC; the council staff mainly evaluates biological and economic consequences of various management alternatives.
Dr. John Mason, Ann Williams	Mid-Atlantic Regional Fisheries Management Program	Verbal (publications not yet received)	No models are currently being used by council staff.	Council staff are provided with stock assessment data by NMFC; NMFC also provides technical assistance for development of management plans.
Irwin Alperin	Atlantic States Marine Fisheries Commission	Verbal and written	No modeling being done directly by committees set up by the Commission.	Chairmen of Scientific and Statistical Committees for menhaden, striped bass, and summer flounder, were asked for information on modeling; being done concerning menhaden; this work is being done by W. Nelson of NMFS (see above).

Table VII-1. Continued.

Individual	Organization	Type of Information Provided	Current Use of Models	Comments
Michael Street	North Carolina Marine Fisheries, Morehead, North Carolina	Verbal (publications not yet received)	A predictive statistical model is currently in use, with salinity and temperature as independent variables.	The shrimp work is the only modeling work currently going on; work is being done in cooperation with R. Derisa at the University of North Carolina.
Lawrence Six	Pacific Fishery Management Council, Portland, Oregon	Verbal	Surplus production and cohort analyses are being used in stock assessment of some non-pelagic fish populations.	Modeling work is being done by technical advisors (NMFS) to the Council.

D. General Overview

From the contacts made thus far, it is evident that the level of modeling effort and the sophistication of models employed vary widely among agencies and locations. Lack of information on stock characterization and life history was most often cited as the reason for lack of greater modeling efforts.

VIII. REFERENCES*

Brody S., 1945. Bioenergetics and Growth. Reinhold Publishing Corp., New York. 1023pp.

Brody, S. 1927. Growth rates. University Missouri Agric. Exp., Sta. Bull. 97.

Foerster, J.W. 1976. Assessment of the effect of hydroelectric water discharge from the Conowingo Dam on the spawning fish in the lower Susquehanna River. Final Report. Prepared for Maryland Department of Natural Resources, Power Plant Siting Program. 320 pp.

Hixson, J.H., and T. Capizzi. 1979. Fish bottom trawling. In Non-radiological Environmental Monitoring Report, Calvert Cliffs Nuclear Power Plant, January - December 1978. Baltimore Gas and Electric Company, Baltimore, Maryland.

Kaplan, W. 1962. Operational methods for linear systems. Addison-Wesley Publishing Company, Reading Mass., 577pp.

Montgomery, D.C., and L.A. Johnson. 1976. Forecasting and time series analysis. McGraw-Hill, London. 304 pp.

Ritchie, D.E., H.J. King, and A.J. Lippson. 1973. White perch. pp.34-35. In A.J. Lippson (ed.). Johns Hopkins University Press, Baltimore, Maryland. The Chesapeake Bay in Maryland - An Atlas of Natural Resources.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator -- review and evaluation. J. Fish. Res. Bd. Canada 31:663-588.

Schaaf, W.E., and G.R. Huntsman. 1972. Effects of fishing on the Atlantic menhaden stock: 1955-1969. Trans. Am. Fish. Soc. 101:290-297.

Spier, H., D.R. Weinrich, and R.S. Early. 1977. 1976 Maryland Chesapeake Bay sport fishery survey. Final Report to U.S. Department of Interior, Fish and Wildlife Service, Project No. F-32-R.

Ulanowicz, R.E., and T.T. Polgar. In press. The influences of anadromous spawning behavior and optimal environmental conditions upon year class strength. Submitted to J. Fish. Res. Bd. Canada.

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* This reference list consists of literature not cited in attached appendices.

A REVIEW AND EVALUATION OF FISHERIES STOCK MANAGEMENT MODELS

Part II - Appendices

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APPENDIX A

An annotated bibliography of stock management models

The categorization indicated in the upper right corner of each page was based on a preliminary reading of each article; those articles deemed "applicable" were considered to be potentially useful in real world situations without further theoretical development.

Abramson, N.J. (ed.). 1971. Computer programs for fish stock assessment. F.A.O. Fish. Tech. Paper 101. F.A.O., Rome, Italy.

Applicable

Abstract

This book represents a collection of computer applications for the calculation of a fishery's yield and the estimation of several parameters such as mortality and effort.

Comment

This collection will be very helpful in this project, particularly in an actual application phase.

Adams, C.F., and C.H. Olver. 1977. Yield properties and structure of boreal percid communities in Ontario. J. Fish. Res. Bd. Canada 34:1613-1625. Applicable

Abstract

A synoptic review of yield data for 70 northern Ontario lakes from 1917 to 1973 showed that percids, mainly walleye (Stizostedion vitreum vitreum) constituted about one-third, by weight, of the total fish yield. This relationship, which was independent of fishing effort, lake size, and lake productivity, is considered to be an emergent property of this type of fish community and represents a degree of homeostasis within the community under exploitation. The relation of percid yield to theoretical yield (based on the morphoedaphic index--MEI) reflected organizational structure and suggested the existence of a community (percid) component within the MEI, and from this we recommend upper limits of percid harvest for boreal percid lakes.

Most (83%) of the 70 lakes had an average total yield of less than 2.5 $kg \cdot ha^{-1} \cdot yr^{-1}$, 53% (37 lakes) yielding less than one-half of the theoretical yield (average 3.4 $kg \cdot ha^{-1} \cdot yr^{-1}$). Long-term average yields exceeded the theoretical maximums in only 11 lakes. Mesotrophic to slightly eutrophic waters appeared as optimum for percid yields.

Inferences from the data suggest an unexploited boreal percid community is characterized by high community stability and low net community production with resiliency low because of the low productive capacity of the waters. A yield index (RYI), which was assumed to reflect both effort and vulnerability to exploitation, showed that fishing intensity tended to be higher on the smaller, less productive lakes in this study.

Comment

The approach would appear to have limited applicability to tidal waters, where fish communities and environmental conditions are very variable. It may be utilizable in the case of recreational fisheries in relatively enclosed tidal waters.

Agnew, T.T. 1979. Optimal exploitation of a fishery employing a non-linear harvesting function. Ecol. Modelling 6:47-57. Applicable

Abstract

A harvesting function is developed to describe the rate of removal of fish from a fish population. The function incorporates the effects of both the handling or processing time of the catch and the competition, between boats in the fleet, for the fish.

It is assumed that the growth rate of the fish population can be modelled with a concave, dome shaped growth curve. With this assumption, it has been shown that if the rate of harvesting the fish is linearly related to both effort (which can be thought of as some measure of the number of boats in the fleet) and the population size, then the population will tend towards a single equilibrium level which is globally stable. This paper shows that the saturation effects due to the handling time may generate two equilibrium levels (one stable, one unstable) rather than a single globally stable equilibrium. The results of competition between boats are economically undesirable because of the decrease in efficiency. However, this competition may be beneficial to the exploited fish population.

Using the harvesting model derived earlier, the steady state or long term optimal harvesting policies as well as the transition paths to these states are developed. The only constraint is on the maximum allowable effort which is effectively an upper limitation on the fleet size or number of man-hours of fishing.

Comment

This method can possibly be utilized in a fisheries management context. It is a theoretical model, incorporating some novel views of factors influencing fishing mortality. Its main weakness is the use of only the logistic model for growth response of the exploited population.

Ahmed, N.U., and N.D. Georganas. 1973. Optimal control theory applied to a dynamic aquatic ecosystem. J. Fish. Res. Bd. Canada 30:576-579.

Non-applicable

Abstract

In this report a dynamic model is presented for an aquatic ecosystem consisting of a single species living in a polluted environment. Considering the dynamics of growth of the species and increase in pollution, optimal control theory is applied to obtain species removal and pollution reduction rates at minimum cost.

Comment

This paper explores the use of optimal control theory on a fisheries problem. The specificity of the problem discussed limits the general applicability of the material presented.

Allen, K.R. 1973. Analysis of the stock recruitment relation in Anarctic fin whales (Balaenoptera physalus). Con. Per., Inter. L'Exploration de la Mer, Rapports No. 164:132-137.

Applicable for parameter estimation

Abstract

The author discusses a technique for the estimation of recruitment rates from age compositions of catches taken from an exploited population and examines the nature of the stock recruitment relationship in southern hemisphere stocks of the fin whale. Recruitment is not shown to increase with a decrease in stock size. However, inaccuracies in estimates of age distributions may have caused this unexpected finding.

Comment

The paper presents a means of deriving estimates of recruitment. It might be useful in developing recruitment functions for other models.

Allen, K.R. 1974. The influence of random fluctuations in the stock-recruitment relationship on the economic return from salmon fisheries. Con. Per., Inter. L'Exploration de la Mer, Rapports No. 164:350-359. Applicable

Abstract

The author examines the effects of random variation in the stock recruitment relationship of a salmon stock on the optimum strategy for managing a fishery by regulation of exploitation. Consequences of various management strategies to future stock sizes and harvests are investigated by runs of a model based on a 50-year data set. None of the exploitation strategies resulted in extinction of the run. The runs suggested management strategies which could be adjusted to achieve various economic objectives.

Comment

The procedures followed in this paper may be useful as a means of developing optimal strategies. However, the model and management strategies are specifically oriented toward salmon, and may not be directly applicable to any Maryland species.

Allen, R.L. 1975. Models for fish populations. A review. N.Z. Oper. Res. Q. 4:1-20.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Allen, R.L., and P. Basasibwaki. 1974. Properties of age structure models for fish populations. J. Fish. Res. Bd. Canada 31:1119-1125. Non-applicable

Abstract

The behavior of a class of dynamic population models that can be described as a life table operating on a population with a stock recruit relation formed by the product of the egg production and a survival function was examined. A combination of analytical and simulation methods were [sic] used to find necessary conditions for the stability of equilibrium populations and the properties of fluctuations about the equilibrium. Regular oscillations that occurred in populations with an unstable equilibrium were of most interest and these were considered as possible causes of the regular fluctuations in populations of fish such as sockeye salmon, Oncorhynchus nerka, or blue pike, Stizostedion vitreum glaucum.

Comment

This theoretical model requires too many nonexistent types of data to be applicable to real situations.

Andersen, K.P., and E. Ursin. 1977. A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorus circulation and primary production. Meddr. Danm. Fisk. og Havunders 7:319-435.

Applicable

Abstract

Interaction between species in a marine ecosystem is described by expressions for food consumption and grazing mortality which are consistent with each other and with the Beverton and Holt model of the population dynamics of individual species. A model of primary production is introduced in order to make possible an account of nutrient circulation (as exemplified by phosphorus) within and nutrient flow through the system. It is demonstrated in an application to North Sea fisheries that recent changes in total yield can be described in some detail under the terms of the model as a function of fishing mortality alone. The composition of the North Sea fauna in the virgin state is discussed and also the conditions under which total yield could be increased above the 1970 level.

Comment

This paper presents the most advanced multi-species production model in the literature. It may be of great value for this program.

Anderson, L.G. 1973. Optimum economic yield of a fishery given a variable price of output. J. Fish. Res. Bd. Canada 30:509-518. Non-applicable

Abstract

The majority of work done in the economics of fisheries uses the assumption of a fixed price of output. This paper describes the effects on the traditional fisheries model of relaxing this assumption, the most important of which, as far as regulatory agencies are concerned, are the negation of marginal cost of effort equaling marginal revenue of effort as the criterion for a social optimum, and the introduction of the possibility of multiple equilibria and multiple industry profit maxima. Also, some new insights on fishery management with variable price and different assumptions about the number of fisheries and the number of countries involved are pointed out.

Comment

The paper is a theoretical discussion of the bioeconomics of fisheries. The author acknowledges that "...empirical investigation based on the general model will be very difficult...." It will not be useful for our study.

Anderson, L.G. 1975. Optimum economic yield of an internationally utilized common property resource. Fish. Bull. 73:51-65.

Non-applicable

Abstract

The exploitation of a common property resource, specifically a fishery, by nationals of two countries is discussed using a simple general equilibrium analysis. The interdependence of their production possibility curves is used to describe the open-access equilibrium yield, local maximum economic yields, and a true international maximum economic yield. Finally a complete description of the conditions necessary for this international maximum economic yield and why they are different from those in a national fishery is presented.

Comment

Principles explored here appear to have little relevance to Maryland, even if management is viewed as an interstate problem.

Anderson, L.G. 1975. Analysis of open-access commercial exploitation and maximum economic yield in biologically and technologically interdependent fisheries. J. Fish. Res. Bd. Canada 32:1825-1842.

Applicable

Abstract

Fisheries may be interdependent because of biological relationships that exist between their stocks or because the gear of one affects mortality in the stock of the other. The problems of defining a maximum sustainable yield in these cases are discussed. A graphical analysis is used to describe the combinations of effort from both fisheries where concurrent exploitation is possible and which of these combinations will result in a simultaneous equilibrium. Finally the conditions for a combined maximum economic yield (MEY) are presented and it is shown that they will not hold if each fishery is managed to obtain an individual MEY.

Comment

The paper investigates the consequences of species interactions on a fishery but does not really present predictive equations. The framework might be used to integrate other models in some way.

Austin, H.M., and M.C. Ingham. 1979. Use of environmental data in the prediction of marine fisheries abundance. pp. 93-108 In Climate and Fisheries. U. of R.I. Center for Ocean Management Studies, Kingston, R.I. 135 pp.

Non-applicable

Abstract

The authors critically evaluate methods which have been used in relating fisheries yields to environmental variables, noting the weaknesses of methods used and the possible erroneous conclusions which may result. They then discuss factors which should be taken into consideration in designing studies for the purpose of investigating climatic effects on fisheries populations.

Comment

The paper presents an informative discussion of the problems encountered in relating environmental variables to fish abundance. However, no models are presented.

Balsinger, J.W. 1974. A computer simulation model for the Eastern Bering Sea king crab population. Ph.D. Thesis. U. Wash., Seattle, Washington. 198 pp. Applicable

Abstract

A Ricker yield per recruit model and a simulation model were constructed for an Alaskan king crab population. From the results recommendations were made concerning the fishery policies for the exploitation of that species. Several submodels (i.e., growth, mortality) were also developed.

Comment

This paper presents an excellent combination of classical yield and simulation models and submodels for the Alaskan king crab fishery. It could prove helpful in this project.

Beddington, J.R., and R.M. May. 1977. Harvesting natural populations in a randomly fluctuating environment. Science 197:463-465.

Non-applicable

Abstract

As harvesting effort and yield are increased, animal populations that are being harvested for sustained yield will take longer to recover from environmentally imposed disturbances. One consequence is that the coefficient of variation (the relative variance) of the yield increases as the point of maximum sustained yield (MSY) is approached. When overexploitation has resulted in a population smaller than that for MSY, high effort produces a low average yield with high variance. These observations accord with observed trends in several fish and whaling industries. We expect these effects to be more pronounced for a harvesting strategy based on constant quotas than for one based on constant effort. Although developed in a MSY context, the conclusions also apply if the aim is to maximize the present value of (discounted) net economic revenue.

Comment

This is a theoretical paper looking at the possible consequences of differing management strategies, given different population dynamics. Nothing presented is directly applicable to a real-world problem.

Béland, P. 1974. On predicting the yield from brook trout populations. Trans. Am. Fish. Soc. 103:353-355.

Applicable

Abstract

The predicted yield from an unstable population is compared to that from a stable population. It is shown that an unstable population will reach a stable structure, following which the yield will not fluctuate but go steadily down. Data from the population indicate that it is on its way towards extinction, even without additional mortality imposed on any age group.

Comment

This paper represents the application of a yield model to a set of real data. It will be worthwhile to evaluate further.

Beverton, R.J.H. 1953. Some observations on the principles of fishery regulation. J. Cons., Cons. Int. Explor. Mer. 19:56-68.

Applicable

Abstract

An alternative method of calculating equilibrium yield per recruit is advanced which is age dependent and related to Brody-von Bertalanffy growth rates. The relationships of yield and recruitment age in conjunction with fishing mortality are discussed graphically. The concepts of eumetric fishing and yield curves are discussed.

Comment

This paper is one of the classical equilibrium yield-per-recruit presentations. It will be helpful in this project for species where Beverton-Holt type recruitment occurs.

Beverton, R.J.H.. and S. J. Holt. 1956. A review of the method for estimating mortality rates in fish populations, with special reference to sources of bias in catch sampling. Rapp. P.-V. Reun., Cons. Int. Explor. Mer. 140:67-83.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Beverton, R.J.H., and S.J. Holt. 1957. On the dynamics of exploited fish populations. Min. Agr. Fish. and Food (U.K.), Fish. Invest. Ser. II, 19. 533 pp.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Bledsoe, L.J., J. Buss, N. Ehrhardt, and C. Lee. 1974. NEPAC -- A system for evaluating the consequences of regulatory structures in northeastern Pacific fisheries. Tech. Rept. 55, NR 15, NORFISH, Univ. of Washington Sea Grant.

Non-applicable

Abstract

The report describes specifications for a proposed model of the northeastern Pacific fisheries. Discussed are:

1. A series of population dynamic submodels for the stocks in various locations.
2. A series of assumptions about different strategies employed in fishing by various fishing vessels.
3. A complex bookkeeping system for accumulating and summarizing biological and economic yield data over a period of simulated time.

Comment

The paper is, in essence, a proposal to develop a detailed simulation model of a fishery. The concepts presented may be useful, but the detailed information is not applicable to Maryland fisheries.

Bledsoe, L.J., and P. Katz. 1976. Management information for regional fishery systems with special reference to the northeast Pacific. Tech. Rept. 62, NORFISH NR 27, University of Washington Sea Grant. Non-applicable

Abstract

The paper discusses factors and processes which must be incorporated into any modeling effort aimed at a multi-species, geographically dispersed fishery.

Comment

The paper presents interesting and useful approaches to development of models for management purposes. However, no mathematical formulations are presented.

Bonar, A. 1977. Relations between exploitation, yield, and community structure in Polish pikeperch (Stizostedion lucioperca) lakes, 1966-71. J. Fish. Res. Bd. Canada 34:1576-1580. Non-applicable

Abstract

A review of official fishery records maintained on 43 Polish pikeperch (Stizostedion lucioperca) lakes during 1966-71 showed that yield was dependent on exploitation intensity and community structure. Community structure was studied on the basis of three groups of fish: predatory, undesirable, and valuable nonpredatory. The percent of predatory fish was used as an index of community structure. An increase of 1 unit of exploitation intensity increased yield by 0.42 - 0.50 kg/ha and a 1% increase in predatory decreased yield by 0.45 - 0.49 kg/ha. Undesirable fish predominated in lakes with high yields and predatory fish predominated in lakes with low yields. The largest catches of predatory fish species occurred when their percentage in the total catch reached 25. A more effective regulation of predatory and nonpredatory fish populations may be achieved through controlled exploitation.

Comment

The relationships presented in this paper appear to be site specific with little relevance to general fisheries yield models.

Booth, D.E. 1972. A model for optimal salmon management. Fish. Bull. 70:497-506. Non-applicable

Abstract

Considerable attention has been given in the literature recently to continuous time dynamic maximizing models for fisheries in general, but the time discreteness and interdependency problems encountered in the case of most salmon fisheries have been largely ignored. Hence, a discrete time profit maximizing model for a salmon fishery is developed in this paper, and it is shown that a correct salmon management policy takes the form of an investment decision with respect to the level of escapement and that a management policy of maximum sustained yield may be incorrect from an economic standpoint. It is hoped that continued research including construction of a working model will provide some indication of the difference between the magnitude of spawner stocks selected on the basis of maximum sustained yield and stocks selected on the basis of economic optimality.

Comment

This paper is too species specific to be of use in this project. Optimization procedures can be applied only to a working yield model.

Brown, B.E., J.A. Brennan, and J.E. Palmer. 1979. Linear programming simulations of the effects of bycatch on the management of mixed species fisheries off the Northeastern Coast of the United States. Fish. Bull. 76:51-860.

Applicable for parameter estimation

Abstract

The results of using historic bycatch (incidental catch) ratios in adjusting fishing regulations by linear programming techniques are evaluated. They used both 1971 and 1973 bycatch ratios separately to assess the sensitivity of the results to the reported changes in bycatch ratios in estimating the total 1975 catch of countries fishing in the northwest Atlantic. For 4 of the 11 countries for which data were examined, the difference between the percentage of a country's species total allowable catches (i.e., those catches allowed a country by regulation) using the 1971 and 1973 bycatch ratios, was at least 20%. Only four countries were predicted to catch at least 80% of their species total allowable catches. The predicted total catches of all countries and all species was only 60% of the total species quotas. The simulated directed fisheries constituted only 70% of the total catch using 1971 bycatch ratios and only 73% using 1973 bycatch ratios. Examination of the reported 1975 catches indicated that the total allowable catches for herring were most frequently limiting a country's catch. Except for U.S.S.R., the differences between reported and simulated catches were less than 50 metric tons, with the difference less than 10 metric tons for 6 of the 11 countries. There was little difference in reported versus simulated catches between the schemes using the 1971 and 1973 bycatch ratios.

Comment

The paper discusses a simple bycatch/yield ratio, which is important as a management tool or to incorporate into other models. It falls into the category of parameter estimation.

Caddy, J.F. 1975. Spatial model for an exploited shellfish population, and its application to the Georges Bank scallop fishery. J. Fish. Res. Bd. Canada 32:1305-1328.

Applicable

Abstract

Existing fisheries models employ the "unit stock" concept that makes no explicit allowance for spatial distribution of biomass and effort over a fishing ground. The utility of the unit stock concept rests largely upon the "dynamic pool" assumption. However, this is both invalid for sedentary species, and difficult to apply when information on spatial distribution by statistical subunits is available, as for the Georges Bank (lat. 42°N, long. 67°W) scallop population. By reference to the Georges Bank scallop fishery, more realistic general assumptions for a spatial model of shellfish populations are:

a) Recruitment occurs in patches of random size and location with the constraint that local biomass does not exceed the virgin biomass of each unit area.

b) The fraction of effort expended within each statistical area of a fishing ground is either determined by available local biomass alone (proportional effort allocation) or in combination with "traditional fishing practice."

Therefore, a spatial model (YRAREA) simulating nonrandom recruitment and harvesting of sedentary organisms is postulated and applied to Georges Bank scallop stocks. Some of the general predictions of this model differ significantly from those employing the unit stock concept, as follows:

1) Under proportional effort allocation, overall yield declines more sharply with increasing effort subsequent to maximum sustained yield (MSY) than under dynamic pool assumptions. 2) Peak mortality and the apparent point of full recruitment on the catch curve occur progressively earlier in life (even at partially recruited ages) with increased effort or degree of clumping of the population, and subsequently decline with age, except where "fully recruited" ages coincide spatially with the "target" age-group making up the largest biomass component. This may be of general relevance to

fisheries under intensive exploitation with sophisticated methods of navigation and fish finding; peak mortality may occur earlier in life than predicted from the gear selection ogive, if year-classes are independently distributed and there is no size limit regulation. 3) Variance in biomass/unit area is predicted to fall with age.

For the Georges Bank scallop population, the model described herein predicts that a substantial increase in yield would result from diversion of effort from the Northern Edge to less heavily fished areas of the bank.

Comment

This paper describes in great detail a realistic yield model. It appears to be very relevant to the management of other shellfish species.

Carlander, K.D. 1977. Biomass, production, and yields of walleye (Stizostedion vitreum vitreum) and yellow perch (Perca flavescens) in North American lakes. J. Fish. Res. Bd. Canada 34: 1602-1612.

Non-applicable

Abstract

Compilation of available data indicated that walleye (Stizostedion vitreum vitreum) biomass in lakes averaged 16 kg/ha, but the data were not adequate to show relationships with mean depth, alkalinity, latitude, or morphoedaphic indexes of the lakes. Yellow perch (Perca flavescens) biomass also failed to show relationships with these factors. In small lakes and ponds with only perch, biomass ranged from 39 to 215 kg/ha, but in lakes with other species, perch biomass was under 65 kg/ha. Annual production of walleye was from 1.2 to 4.1 $kg \cdot hg^{-1} \cdot yr^{-1}$ and that of yellow perch was 21.9 $kg \cdot ha^{-1} \cdot yr^{-1}$. Average commercial yields of walleye ranged up to 3.06 $kg \cdot ha^{-1} \cdot yr^{-1}$, and sport fish yields averaged 3.7 $kg \cdot ha^{-1} \cdot yr^{-1}$. Annual commercial and sport yields decreased with latitude. Area of lake was negatively correlated with sport yield, but positively with commercial yield. The latter situation is believed to be an artifact of the sample and not a general trend. Commercial yield increased with total dissolved solids of the lakes. Lack of other correlations may be related to the fact that walleye biomass and yield do not bear a constant relationship to total biomass and yield.

Comment

The procedures presented here appear inapplicable to estuarine and marine environments, which exhibit wide environmental variability.

Carlson, E.W. 1969. Bio-economic model of a fishery. Working Paper No. 12. Bureau of Commercial Fisheries, Division of Economic Research.

Applicable

Abstract

This paper is an attempt to restructure the economic theory of fisheries along the lines of received microeconomic theory. This approach has many virtues not the least of which is that the power of traditional microeconomic theory can be marshalled to help solve various problems that might arise. Another benefit is that if used fishery economists will be able to communicate among themselves and other economists more readily.

The main thrust of the model is that there is a divergence between the social cost and the private costs of harvesting that is partly because of the probabilistic nature of fish capture and because of the density dependent growth of the fish population.

Actual implementation of the model in its present form is perhaps not possible because the growth curve for a fish population does not exist in such a predetermined fashion. Rather for most exploited fisheries the growth of the population is to a large extent determined by the birth of the fish which appears to have an extremely high variance. The proper management of a fishery will take this into account so that each year class will be exploited optimally. The method for fishery management under these conditions is outside the scope of this paper.

Comment

The paper presents what may be useful approaches to modeling the economics of a fishery.

Caswell, H. 1972. A simulation study of a time lag population model. J. Theor. Biol. 34:419-439.

Non-applicable

Abstract

The lack of terms representing time lags is a widely recognized weakness of the Volterra-Gause formulations of population growth and interaction. A number of analytical attempts to include time lag terms have been made in the past, but they have provided relatively little ecological insight.

In this paper the Volterra-Gause equations for a predator and two competing prey are modified to include a number of time lags, and studied by simulation. The modifications include lags in the response to intra- and inter-specific competition and food supply, and terms that represent the "hunger" of the predator population. Predation is made size-selective as a function of hunger, and refuges are provided for the prey.

Adding these factors greatly increases the variety of behavior exhibited by the model. Refuges for some minimum number of prey are required to assure persistence of the system. If the system persists its behavior ranges from damped to undamped oscillations of varying amplitude. Time lags in response of the predator to changes in prey abundance, the physiological food requirements of the predator, and the heterogeneity of the environment (as measured by prey refuges) all affect the form of the oscillations. The time lag terms can reverse the outcome of competition in some cases. In this model selective predation stabilizes otherwise unstable competitive relations.

Certain results of laboratory predator-prey studies are difficult to explain in terms of the standard Volterra-Gause formalism. It is suggested that some of these features can be explained in terms of time lags in various population responses.

Comment

The theoretical material presented does not appear to be applicable generally to fisheries yield models.

Chapman, D.G. 1973. Spawner-recruit models and estimation of the level of maximum sustainable catch. Con. Per., L'Exploration de la Mer, Rapports No. 164:325-332. Applicable

Abstract

The author discusses various mathematical formulations of spawner-recruit relationships (e.g., Ricker, Beverton-Holt, etc.) and the relationships of these formulations to each other. Advantages and disadvantages of the formulations are discussed relative to actual application to a fishery. A non-parametric method of estimating optimum catch is presented and applied to a fur seal population.

Comment

This paper presents a valuable discussion of stock recruitment models and develops a method of estimating optimum catch which may be useful in Maryland.

Chen, C.W., and G.T. Orlob. 1972. Ecologic simulation for aquatic environments. Prepared for Office of Water Resources Research, U.S. Dept. of the Interior. Applicable

Abstract

A mathematical model for computer simulation of aquatic ecosystems was developed and adapted to lake and estuarial systems. The model is capable of simulating the annual cycle of ecologic successions involving algae, bacteria, zooplankton, fish and benthic animals and the interdependent relationships between biota and abiotic substances carried in the natural aquatic system. It is water quality oriented, predicting the temporal and spatial distributions of temperature, dissolved oxygen, biochemical oxygen demand, pH, conservative constituents (e.g., salinity, TDS, etc.), toxicity, nitrogen (three forms), carbon dioxide, and phosphorus as well as the biomass of each trophic level in the system. The basic formulations in the model are based on kinetic principles and the law of Conservation of Mass. Algal growth kinetics are governed by a Michaelis-Menton relationship including light, temperature, carbon, nitrogen, and phosphorus.

A demonstration of simulation capability of the Lake Ecologic Model was performed on Lake Washington using the data of W.T. Edmundson covering the periods 1962-63 and 1967-69 for comparison. The earlier period corresponded to a condition of incipient eutrophication and the latter period to recovery of the lake after diversion of waste water inflows. The model reproduced with fair reliability the major quality changes that were observed over the annual cycle in each of the two periods. A demonstration of the Estuary Ecologic Model was performed on the San Francisco Bay-Delta System using data gathered by the University of California. The model simulated closely the actual response of the system. It was further tested for several alternative conditions of water quality control involving waste water treatment, relocation of outfalls and flow regulation.

Comment

This paper describes a very detailed ecosystem model. Parts of this model and the approaches used in integrating its components may be of use in this study.

Christensen, S.W., D.L. DeAngelis, and A.G. Clark. 1978. Development of a stock-progeny model for assessing power plant effects on fish populations. pp. 195-225 In W. Van Winkle (ed.). Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Administration, and Electric Power Research Institute.

Applicable for parameter estimation

Abstract

A multi-age-class model, based on simple but general biological principles, is developed to assess the impact of power plants on fish populations. The model is then parameterized in order to produce a variety of stock-progeny relationships, assuming that the stock is always at stable age distribution. The predicted response of the fish stock to power plant cropping of young-of-the-year fish is investigated for each of these stock-progeny relationships. In general, the sensitivity of the equilibrium stock size to cropping is positively related to the slope of the stock-progeny curve at the equilibrium point and, to a lesser extent, negatively related to the slope of the curve at the origin. In addition, the timing of power-plant-induced mortality that can be tolerated by the stock can be calculated from the slope of the curve at the origin. Application of the model to specific cases will likely need to utilize time-series simulations in addition to the steady-state approach investigated here.

Comment

The model described here is not directly applicable to yield, but has possibilities as a recruitment submodel.

Clady, M.D. 1975. The effects of a simulated angler harvest on biomass and production in lightly exploited populations of smallmouth and largemouth bass. Trans. Amer. Fish. Soc. 104:270-276.

Applicable

Abstract

Harvests of 13 to 21%, mostly of larger, older fish, were imposed for two years on populations of smallmouth and largemouth bass (*Micropterus dolomieui* and *M. salmoides*) that previously had been virtually unfished. Another population of smallmouth bass served as a control. Using trap nets, estimates of the number of bass and their size were made for one year before and two years after initial harvest. From these data, annual natural mortality, growth, standing crop and production were computed. There were no strong and consistent changes in any parameter which could be attributed to reductions in numbers of fish. Changes in growth unrelated to population density apparently resulted in declines of ratios of production to biomass following harvest. Possible causes of the lack of compensatory responses to harvest include the relatively short period of study and time lag in changes in growth and mortality.

Comment

The approach is possibly useful in situations where a unit stock is known. The approach is primarily applicable to lake/stream (enclosed waterways) situations but may be a good approach for species such as white catfish.

Clark, C.W. 1972. The dynamics of commercially exploited natural animal populations. Math. Bio. 13:149-164. Applicable

Abstract

A simple model is analyzed to describe the temporal behavior of a natural animal population that is subject to economically optimal exploitation. It is shown that the population will reach an optimal equilibrium level, at which the marginal growth rate of the stock equals the accepted interest rate. (In some cases, an a priori constraint, prohibiting destruction of the stock, is required to reach this conclusion.) Since the optimal equilibrium yield is necessarily smaller than the maximum sustainable yield, it follows that the exploiting agency will experience a degree of overcapitalization once the optimal level is reached. Failure to observe this phenomenon would lead to overexploitation of the resource.

Comment

The paper describes a means of determining an optimum (in an economic sense) yield from a resource population. It may be of value in developing bioeconomics models of Maryland stocks.

Clark, C.W. 1973. The economics of over-exploitation. Science 181: 630-634. Applicable

Abstract

The general economic analysis of a biological resource presented in this article suggests that overexploitation in the physical sense of reduced productivity may result from not one, but two social conditions: common-property competitive exploitation on the one hand, and private-property maximization of profits on the other. For populations that are economically valuable but possess low reproductive capacities, either condition may lead even to the extinction of the population. In view of the likelihood of private firms adopting high rates of discount, the conservation of renewable resources would appear to require continual public surveillance and control of the physical yield and the condition of the stocks.

Comment

This paper is very theoretical in nature adding no new information beyond that in Clark et al. (1973); however, it may prove helpful in the analysis of bio-economics models.

Clark, C.W. 1976. A delayed-recruitment model of population dynamics, with an application to baleen whale populations. <u>J. Math. Biol.</u> 3:381-391.

Non-applicable

Abstract

A simple delay of harvested populations has been considered. A necessary and sufficient condition for stability of the natural equilibrium has been presented. Harvest policies that maximize discounted economic rent have been described. These policies are characterized by optimal equilibrium levels of escapement. It is argued that, although the theoretically optimal dynamic policy requires an asymptotic approach to equilibrium, in practice the "most-rapid" (or "bang-bang") approach policy is at worst only marginally suboptimal. The results are applied to the Antarctic fin whale fishery.

Comment

This approach is not useful as it adds little new information to that presented in earlier works.

Clark, C., G. Edwards, and M. Friedlaender. 1973. Beverton-Holt model of a commercial fishery: optimal dynamics. J. Fish. Res. Bd. Canada 30:1629-1640.

Applicable

Abstract

The problem of optimal regulation of a fishery is discussed. Of special interest is the problem of regulating an overexploited fishery by reducing effort to allow the fish population to build up to a suitable level.

It is argued that the problem requires an economic analysis based on the concept of maximization of present value. From this concept we then deduce a simple, general rule, the "Fisher Rule," which we subsequently use to determine optimal exploitation. Among the principal results are the following: (a) an optimal mesh-size is determined, which, because of the discounting of future revenues, is smaller than the size corresponding to maximum sustainable yield; (b) the optimal recovery policy for an overexploited fishery is deduced; it consists of a fishing closure permitting the fish population to reach an optimal age; (c) the optimal development of an unexploited fishery is deduced; an initial development stage characterized by large landings and profits is rapidly transformed into a situation of optimal sustained yield, in which both landings and profits may be significantly reduced; (d) the optimal policy is deduced for a fishery in which gear limitations are impractical; the result may be a strongly unstable fishing industry; (e) the effect of high discount rates, which might be employed by private fishing interests, is discussed; such rates may result in overfishing similar to the case of a common-property fishery.

Comment

This paper develops the concept of an optimal sustained economic yield. It may be useful as a means of adding economics to production models. Optimal age, length, and weight in an economic framework can also be determined by this approach.

Clark, C.W., and G.R. Munro. 1975. The economics of fishing and modern capital theory: A simplified approach. J. Environ. Econ. Manag. 2:92-106. Applicable

Abstract

While the link between fisheries economics and capital theory has long been recognized, fisheries economics has, until the last few years, developed largely along nondynamic lines. The purpose of this article is to demonstrate that, with the aid of optimal control theory, fisheries economics can without difficulty be cast in a capital-theoretic framework yielding results that are both general and readily comprehensible.

We commence by developing a dynamic linear autonomous model. The static version of the fisheries economics model is seen to be the equivalent of a special case of the dynamic autonomous model. The model is then extended, first by making it nonautonomous and second, nonlinear. Problems arising therefrom, such as multiple equilibria, are considered.

Comment

This model appears useful for the determination of optimal standing stock level and harvest level in an economic context. It seems to ignore the concept of steady-state populations.

Clark, R.D., and R.T. Lackey. 1975. Computer-implemented simulation as a planning aid for state fisheries management agencies. Dept. of Fish. and Wildlife. Virginia Polytechnic Institute and State University. FWS-3-75. 179 pp. Non-applicable

Abstract

A basic job of fisheries management agencies is to forecast the demand and produce the necessary supply of fishing opportunities. Present day angling consumption rates often exceed managers' ability to supply fishing opportunities of the desired quality. Therefore, a primary means for improving fisheries management may be to regulate angling consumption. Operations research techniques are well suited for handling the complexities involved with planning multiple action policies for regulating angler consumption.

PISCES is a computer-implemented simulator of the inland fisheries management system of Tennessee, but is adaptable for use in any state. The purpose of PISCES is to aid in planning fisheries management decision policies at the macro-level. PISCES generates predictions of how fisheries management agency activities will affect angler use for a fiscal year. Subjective probability distributions for random variables and Monte Carlo simulation techniques are employed to produce an expected value and standard deviation for each prediction. Test runs under realistic hypothetical situations and discussions with personnel of Tennessee Wildlife Resources Agency suggest that PISCES may help fisheries management agencies to improve budget allocation decisions, to formulate multiple action policies for regulating angler use, and to enhance fisheries development. A hypothetical application of PISCES in Tennessee is given.

Comment

The model presented deals with angler use of areas rather than yields. It does not appear useful in this study.

Clark, R.D., Jr., and R.T. Lackey. 1976. A technique for improving decision analysis in fisheries and wildlife management. <u>Va. J. Sci.</u> 27:199-201.

Applicable for parameter estimation

<u>Abstract</u>

Computer implemented modeling has clearly benefited managers in industrial and military management positions. Improvements in the cost effectiveness of computer use should allow fisheries and wildlife managers to make increasing use of computerized decision models. A modeling technique developed for industrial purposes to utilize the full state of knowledge of a decision problem is presented here and proposed for use in fisheries and wildlife management. The technique uses the Weibull function for subjective probability assignment to help solve the problem of making decisions based upon incomplete or inadequate data.

<u>Comment</u>

This paper presents a good method of estimating non-quantitative variables and their probability density functions.

Cliff, E.M., and T.L. Vincent. 1973. An optimal policy for a fish harvest. <u>J. Optim. Theory Appl.</u> 12:485-496.

Non-applicable

Abstract

A dynamical model for harvesting a fish population system is proposed by introducing control into the known Verhulst-Pearl model. An optimal control problem including some parameters is stated, and the usual necessary conditions are applied. For specific parameter values, the candidate control policy is deduced, and optimality is verified by applying a sufficiency theorem. The optimal trajectories may contain maximum and minimum control arcs as well as a singular subarc. The significance of the singular arc is interpreted in terms of the system dynamics.

Comment

This paper does not appear very useful. It uses optimal control theory to minimize cost but ignores other externalities.

Crutchfield, J.A. 1973. Economic and political objectives in fishery management. Trans. Am. Fish. Soc. 102:481-491.

Non-applicable

Abstract

The changes in attitudes from MSY to optimal sustained yields and extensions of bioeconomic fishing theory are discussed in relation to their inherent social goals. The role of political and administrative objectives as they relate to fishery management are also discussed from this perspective.

Comment

This paper is not useful for this project. It represents discussion of the social goals of fishery management and is beyond the present scope of the project.

Cushing, D.H., and J.G.K. Harris. 1973. Factors affecting recruitment and mechanisms of recruitment control. Rapp. P.-V. Reun., Cons. Inter. Explor. Mer. 164:142-155.

Non-applicable

Abstract

This paper is in three parts: (a) an examination of the biology of fishes which suggests that the larval drift in the plankton from spawning ground to nursery ground is the stage in the life history at which density dependence is most marked. It will be suggested that density dependent growth and mortality are linked and that both competition and the natural regulation of numbers may take place during the larval drift; (b) Cushing (1968, 1971) related density dependence to fecundity; fish with low fecundities were expected to have near-linear curves of recruitment on parent stock, whereas the dome-shaped curves would be characteristic of fish with high fecundities. An index of density dependence was derived from a log-log plot of recruitment on parent stock, which is a rough way of averaging the multifarious range of data. The tentative conclusion, that density dependence was a function of fecundity, should be tested and in this paper the same data are re-examined and fitted to a stock and recruitment curve, with an estimate of error; (c) any curve of recruitment on parent stock expresses the ratio of density dependent to density independent mortality at different stock levels. Obviously an estimate of this ratio independent of the data on recruitment and parent stock is needed. As a first step towards this, a model of the generation of density dependent mortality in the North Sea plaice has been developed.

Comment

This paper is a good review of stock-recruitment relationships but is of little direct use in the application of fish yield models.

DeAngelis, D.L. 1976. Application of stochastic models to a wildlife population. Math. Biosci. 31:227-236. Applicable

Abstract

Two stochastic population models, a birth-and-death model and a stochastic difference equation model, are compared, using data for a giant-Canada-goose population. The quasistationary probability distribution predicted by the stochastic difference equation agrees well with values of the population mean and variance computed from several years of data.

Comment

The birth and death model was shown to be inapplicable to populations which are very stable, unlike most fisheries. The stochastic difference equation model is very simplistic, but could be derived from empirical data. It might be useful in some instances.

DeAngelis, D.L., S.W. Christensen, and A.G. Clark. 1977. Responses of a fish population model to young-of-the-year mortality. J. Fish. Res. Bd. Canada 34:2124-2132.

Applicable

Abstract

A multiple-age-class model is used to examine the effects of increases in density-independent young-of-the-year mortality caused by power plan entrainment of larval fish. It is demonstrated analytically that in all realistic cases, an increase in such mortality results in a smaller equilibrium population density of adult fish. The stability of the population with respect to perturbations about its equilibrium point is increased in these cases. However, situations can occur where a slight increase in mortality causes a catastrophic population decline. The model is used to generate autoregression graphs of population numbers that can be compared with field data.

Comment

The model incorporates some novel ideas into a population model, and it could have some value to this study.

DeAngelis, D.L., W. Van Winkle, S.W. Christensen, S.R. Blum, B.L. Kirk, and C. Ross. 1977. A generalized fish life-cycle population model and computer program. ORNL/TM-6125. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 176 pp.

Applicable

Abstract

A generalized fish life-cycle population model and computer program have been prepared to evaluate the long-term effect of changes in mortality in age class 0. The general question concerns what happens to a fishery when density-independent sources of mortality are introduced that act on age class 0, particularly entrainment and impingement at power plants. This paper discusses the model formulation and computer program, including sample results.

The population model consists of a system of difference equations involving age-dependent fecundity and survival. The fecundity for each age class is assumed to be a function of both the fraction of females sexually mature and the weight of females as they enter each age class. Natural mortality for age classes 1 and older is assumed to be independent of population size. Fishing mortality is assumed to vary with the number and weight of fish available to the fishery. Age class 0 is divided into six life stages. The probability of survival for age class 0 is estimated considering both density-independent mortality (natural and power plant) and density-dependent mortality for each life stage. Two types of density-dependent mortality are included. These are (1) cannibalism of each life stage by older age classes and (2) intra-life-stage competition.

Comment

This paper represents an excellent example of a simulation model which utilizes Leslie matrices, incorporates fishing mortalities, and explicitly calculates yield. While the data requirements of this model are large, its generalized form appears applicable for several Maryland fisheries such as striped bass and herring.

Doubleday, W.G. 1976. Environmental fluctuations and fisheries management. Int. Comm. Northwest Atl. Fish. Sel. Pap. 1:141-150. Non-applicable

Abstract

The effect of random fluctuations in production on the success of fisheries management schemes is examined using a discrete version of Schaefer's (1954) model. Control of stock biomass, catch, and effort are [sic] considered. The average yield taken is shown to be inversely related to yearly fluctuations in yield. Control of stock biomass maximizes the average yield at the cost of large fluctuations in catch. Control of catch requires a large reduction in average yield to obtain stability. The effects of controlling effort lie between those of controlling biomass and controlling catch.

The restoring force of an exploited stock to deviations from equilibrium is examined and the presence of a critical zone of biomass less than one fourth of the virgin biomass in which further displacement weakens the restoring force and from which recovery of stock biomass is slow is noted. It is shown that control of effort at a level corresponding to an equilibrium biomass of two thirds the virgin stock instead of one half as is commonly recommended achieves a reduction in catch variance of from 60% to 75% and an increase of catch per unit effort of 33-1/3% with a loss in yield of 11%. The biomass buffer between equilibrium biomass and the critical zone is increased 133%, making the stock more resilient to depletion by a succession of weak year classes and reducing the need for rapid changes of regulations based on preliminary estimates of incoming year-class strength.

Comment

This paper, while demonstrating the importance of production and recruitment fluctuations in assessing MSY levels, includes numerous parameters (such as virgin equilibrium biomass level) which are unlikely to be determinable for Maryland fisheries. Thus, while the paper is instructive, it does not appear directly applicable to this project.

Dow, R.L., F.W. Bell, and D.M. Harriman. 1975. Bioeconomic relationships for the Maine lobster fishery with consideration of alternative management schemes. NOAA Technical Report, NMFS-SSRF-683. — Applicable

Abstract

A bioeconomic model is formulated using basic Schaefer relationships coupled with cost-profit analysis. Plots of steady state functions typifying population steady-state ($\frac{dx}{dt} = 0$) and cost-profit equilibrium ($\frac{dk}{dt} = 0$) result in optimal economic population yield level.

Comment

The method presented here may be useful for this project. The lack of accounting for biological variables other than population size may be a problem.

Dyer, T.G.J., and J.F. Gillooly. 1979. Simulating fish production using exponential smoothing. <u>Ecol. Modelling</u> 6:77-87. Applicable

Abstract

The variation over time of the total annual production of pelagic fish for South Africa and the United Kingdom has been described quantitatively using the exponential smoothing technique. The exercise was repeated on annual mackerel landings for the same two countries. It is suggested that in some cases, the production figure for the current year can be used to simulate the following year's value. The greater variations in South Africa's annual production probably gave rise to the poorer results for these data.

Comment

The model is very simplistic and unrealistic in many ways. However, as a technique distinct from standard fisheries models, it may be worthwhile to evaluate it further.

Eberhardt, L.L. 1977. Relationship between two stock-recruitment curves. J. Fish. Res. Bd. Canada 34:425-428.

Non Applicable

Abstract

The Beverton and Holt and Ricker stock-recruitment curves can be used to generate population growth curves. The Beverton and Holt curve is then identical to a difference equation model for the logistic growth curve, and may be derived in terms of equations for linearly density-dependent population relations.The same equations lead to the Ricker curve if the density-regulating effect is assumed to depend only on population size at the beginning of the interval between generations. At low rates of population growth, the Ricker curve approaches that of Beverton and Holt. The two curves appear to represent certain concepts known in population biology as "$\underline{r}$ and K selection."

Comment

The analysis suggests that Beverton-Holt is appropriate for populations that can only attain modest increases from generation to generation, whereas Ricker may be appropriate for species which can exploit particularly advantageous conditions. Material presented here provides no methods or procedures which would appear useful to this project.

Eberhardt, L.L., and D.B. Siniff. 1977. Population dynamics and marine mammal management policies. J. Fish. Res. Bd. Canada 34:193-190. Applicable

Abstract

Some criteria for appraising population level relative to the maximal or carrying capacity point are listed. Simple population-dynamics models are then used to explore some of the criteria. Age at first reproduction does not seem as important as in some more prolific and shorter-lived species, being at most equivalent to a few percentage points of adult survival. Age-specific reproductive rates are very much the same for a number of pinniped species. For most marine mammal species, survival through immature stages is an unknown quantity, but appears to be a factor of major importance in determining population trend. Data on the Pribilof fur seals (Callorhinus ursinus) lead to the speculative conclusion that the maximum sustained yield (MSY) point may be to the right of the median value frequently assumed, so that "optimal" population levels may be closer to the asymptotic or carrying capacity level. Such a view is proposed as a conservative management policy.

Comment

The model should be evaluated for use here, since it represents application of a production model. Even though the population parameters of marine mammals may be very different from those of most exploited fish species, the analysis could still prove useful.

Edwards, R.L., and R.C. Hennemuth. 1975. Maximum yield: Assessment and attainment. Oceanus 18:3-9.

Non-applicable

Abstract

The authors review fisheries management directed toward maximum yield and critique the procedures commonly used in developing management programs.

Comment

The paper presents no actual models, but does provide some useful insights into problems encountered in developing management strategies.

Englert, T.L., J.P. Lawler, F.N. Aydin, and G. Vachtsevanos. 1976. A model study of striped bass population dynamics in the Hudson River. pp. 137-150 In M. Wiley (ed.), Estuarine Processes, Vol. I, Academic Press, New York.

Applicable

Abstract

Present and planned operation of electric power generating stations along the Hudson River may have an impact on the Atlantic striped bass population due to the use of river water in once-through cooling systems at the plants. Withdrawal of river water for cooling purposes can have two principal effects on the young-of-the-year striped bass spawned in the Hudson: (1) Eggs, larvae and early juvenile fish may be entrained in the water which is circulated through the plant's cooling system and returned to the river; (2) later juvenile fish may be impinged on the debris screens at the plant intakes.

Population models of the Hudson River striped bass are useful in making predictions of the impact of entrainment and impingement at the power plants. In the model study presented here, results from a detailed simulation of the young-of-the-year population are input to a model of the adult bass population in order to predict short- and long-range impacts on the population.

The young-of-the-year model traces development of the early life stages of the bass from eggs through the larvae and juvenile stages. Egg production rates calculated from field data are used to initialize the population model. The temporal, spatial and age distributions of the early life stages are simulated by equations which include the effects of hatching period, natural mortality, plant withdrawal rates and the convective and dispersive effects of the Hudson's hydrodynamics. The hydrodynamic simulation is intra-tidal or real-time. The spatial distribution of the organisms is calculated at twenty-nine longitudinal grid points in both the upper and lower layers of the river.

Comparisons of model results and field data provide a measure of the verification of the model.

Comment

The model requires detailed knowledge of environmental and population parameters. However, it should be reviewed in depth to evaluate its potential value.

Eraslan, A.H., W. Van Winkle, R.D. Sharp, S.W. Christensen, C.P. Goodyear, R.M. Rush and W. Fulkerson. 1976. A computer simulation model for the striped bass young-of-the-year population in the Hudson River. Oak Ridge Nat. Lab., Oak Ridge, Tenn. ORNL/NUREG-8.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Everitt, R.R., N.C. Sonntag, M.L. Putterman, and P. Whalen. 1978. A mathematical programming model for the management of a renewable resource system: The Kemano II development project. J. Fish. Res. Bd. Canada 35:235-246.

Non-applicable

Abstract

This paper considers a mathematical programming model for the management of a salmon fishery and watershed. Management objectives are specified as bounds and desirable target levels for certain important variables. The mathematical program consists of minimizing the deviation from these targets subject to natural and policy constraints. A detailed application studying the effect of the proposed Kemano II development project on the salmon fisheries of northwestern British Columbia is presented. Parametric programming is used to compare several development scenarios on the basis of the sensitivity of the system to reduced runoff in a specified year.

Comment

The specific fisheries models used are not applicable to this study as production models. However, the mathematical programming technique could be applicable in the resolution of conflicts in resource allocation.

Fletcher, R. 1978. On the restructuring of the Pella-Tomlinson system. Fish. Bull. 76:515-521.

Applicable

Abstract

The time-dependent analysis of an earlier work is extended to the equilibrium case of the Pella-Tomlinson system, and the relationships between the equilibrium and nonequilibrium versions of the restructured system are developed. The dual formulations of the conventional analysis are avoided and maximum sustainable yield is separated from the indeterminacy of the system. All arbitrary coefficients are eliminated and the management components incorporated directly into the system equations. The source of the statistical degeneracy in the model is revealed and explicitly formulated.

Comment

The theoretical discussion presented here suggests an improved means of applying a Pella-Tomlinson system to an exploited stock. However, its application is apparently covered in a follow-up paper (Rivard and Bledsoe, 1978; Appendix B).

Flowers, J.M., and S.B. Saila. 1972. An analysis of temperature effects on the inshore lobster fishery. J. Fish. Res. Bd. Canada 29:1221-1225. Applicable

Abstract

In the past, water temperature has been utilized in combination with some measure of fishing effort in the development of economic estimator or predictor equations for the yield of the lobster, Homarus americanus. The hypothesis that the inshore lobster fishery in the United States has been overfished since the end of World War II to the point where increases in fishing effort since that time have had only minor effects on the yields was examined. It was shown that suitable yield prediction equations could be developed using only lagged and present temperatures as the independent variables. Comparisons were made of equations developed for the Maine fishery and sections of the Canadian fishery. Further analyses were done comparing equations developed using winter vs. summer temperatures and surface vs. bottom temperatures.

Comment

This paper presents a good example of the use of statistical techniques to model fishery yield. The methods may be of some use in the project.

Fox, W.W., Jr. 1970. An exponential surplus-yield model for optimizing exploited fish populations. Trans. Am. Fish. Soc. 99:80-88.

Applicable

Abstract

A surplus-yield model of fishery dynamics which assumes the Gompertz growth function is developed, resulting in an implied exponential relationship between catch per unit effort and fishing effort, and in an asymmetrical yield curve. A maximum sustainable yield, predicted by the exponential model, is obtained from a population size which is about 37% of the environmentally limited maximum size. Three methods for estimating the parameters of the exponential model, adapted from those used for the linear model of Schaefer (1954, 1957), are presented. The exponential model is compared with the linear model using examples of the fisheries for the California sardine, *Sardinops caerulea* (Girard), and yellowfin tuna, *Thunnus albacares* (Bonnaterre) of the eastern tropical Pacific and western Atlantic oceans. Management implications are discussed.

Comment

This article is excellent, dealing with derivation of model parameters as well as the basis for using different model forms.

Francis, R.C. 1974. TUNPØP, a computer simulation model of the yellowfin tuna population and the surface tuna fishery of the eastern Pacific Ocean. Inter-Am. Trop. Tuna Comm. Bull. 16:235-258. Applicable

Abstract

Mathematical documentation of TUNPØP, an age-structured computer simulation model of the yellowfin tuna population and surface tuna fishery of the eastern Pacific Ocean, is described. Example runs of the model are presented and discussed, and the sensitivity of the model output to changes in various parameters is examined.

Comment

This paper presents excellent documentation for TUNPØP, an age-structured simulation model of yield and population dynamics which employs variable recruitment levels. This generalized structure, which subdivides stock into unit areas of exploitation, may be applicable to Maryland fisheries which suffer interstate and/or international exploitation.

Francis, R.C. 1974. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock production model. J. Fish. Res. Bd. Canada 31:1539-1542.

Applicable for parameter estimation

Abstract

The often-used approximation that, for a stock of fish under exploitation, the instantaneous fishing mortality rate equals the instantaneous natural mortality rate at the point of the maximum sustainable yield is examined with respect to its mathematical roots and practical utility. Examples from two diverse fisheries are utilized.

Comment

The paper presents a means by which stock-recruitment relationships can be evaluated. It also disproves an assumption commonly made in the application of the Schaefer model.

Fransz, H.G. 1979. Estimation of birth rate and juvenile mortality from observed numbers of juveniles in a mammal population with normally dispersed reproduction. Ecol. Modelling 7:125-133.

Applicable for parameter estimation

Abstract

The increase in the number of juveniles in a mammal population with a normally dispersed reproduction is simulated using a computer. The effect of juvenile mortality and its age-dependency on the recruitment curve is discussed. The maximum number of juveniles is reached before all juveniles are born. The ratio of the period of time between the beginning of the reproduction period and the maximum of juveniles and of births (the coeffecient of reduction of the apparent reproduction period) is related to the juvenile mortality rate and the ratio of the maximum number of juveniles to the total number of births. These relationships can be used to estimate the total number of births and the juvenile mortality rate from a series of counts of the juveniles. The simulation model used is programmed in CSMP-III.

Comment

The model presented here would generally not be useful. The approach is applicable to contained populations with low seasonal fecundities (1-5 offspring per female) typical of mammal populations and would thus be of little use in Maryland fisheries. However, methods for estimating mortality rates may be of value.

Gales, L.E., and J.A. Buss. 1975. NEPTUNE: A FORTRAN-based hybrid simulator for fishery systems. Univ. Wash. Sea Grant, Seattle Wash., Norfish Tech. Rept. 65. 39 pp.

Non-applicable

Abstract

Over the past 15 years a great variety of computer models have been developed for the study of complex systems. Despite this variety, most models can be classified as:

1. CSCT - continuous space, continuous time,
2. DSCT - discrete space, continuous time,
3. DSDT - discrete space, discrete time.

CSCT models view the world as a continuous spatial field which is expressible in terms of partial differential equations; DSCT models view it as a set of lumped objects whose behavior is governed by ordinary differential equations; and DSDT models view it as a set of discrete objects that are activated and de-activated at discrete points in time.

This paper describes a hybrid DSCT-DSDT simulation system which is implemented in CDC FORTRAN and CDC UPDATE. It draws heavily upon the concepts and nomenclature of SIMULA 67, and provides some of the simulation and data structuring features of that language, but with the many practical advantages of FORTRAN.

Comment

This paper presents a discrete space-discrete time, discrete space-continuous time interactive simulation model of a fishery. Because the text of the paper discusses only the programming aspects of the model, an evaluation of applicability to Maryland fisheries based on model assumptions is not possible.

Gales, L.E., J.A. Buss, and L.J. Bledsoe. 1977. Simulation concepts for fishery systems. J. Fish. Res. Bd. Canada 34:2374-2380.

Non-applicable

Abstract

Computer models for analysis of fishery systems may involve complex applications of mathematics and computer science. While the mathematical aspects of these models have been thoroughly studied, less attention has been paid to methodologies for their computer implementation. As a result, some models excessively simplify fishery systems to avoid difficulties in implementation. This study presents an advanced computer technique (linked lists) which permits the inclusion of complex time simulations and data structures in fishery models with little additional effort. Examples of application to complex information arrays and an age-structured population model are included.

Comment

This article does not present a model, but could prove useful in the application of a model or in the computerization of a data base.

Gatto, M., and S. Rinaldi. 1976. Mean value and variability of fish catches in fluctuating environments. J. Fish. Res. Bd. Canada 33:189-193.

Non-applicable

Abstract

The mean value of the catch and its variability due to environmental fluctuations are analyzed for a very general stock-recruitment model. Particular attention is devoted to the comparison of two standard fishing strategies (constant effort and constant escapement) in terms of mean catch, variance in catches, and maximum deviation of catch. It is demonstrated analytically that constant escapement policies should always give higher mean catch, but should give higher catch variance and more extreme catches only under certain conditions of environmental variability.

Comment

The model presented here does not have general utility. It represents a statistical attempt to interpret the consequences of constant escapement versus constant effort management policies. This evaluation is essentially identical to earlier literature.

Gatto, M., S. Rinaldi, and C. Walters. 1976. A predator-prey model for discrete-time commercial fisheries. Int. Inst. Appl. Syst. Anal., Laxenburg, Austria, Res. Rep. Ser. 75-5. 38 pp.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Geaghan, J.P. 1978. Development and application of the Schaefer model in fisheries management. Unpublished manuscript.

Non-applicable

Abstract

The development of the logistic-based surplus production model of Schaefer is traced from its inception in 1954 through its adapted form in bioeconomic models. Comparative evaluations of the equilibrium and non-equilibrium forms of this model type are made statistical using the American lobster and tuna as examples.

Comment

While providing an excellent overview of the development of the Schaefer surplus production model, this paper provides little in the way of new information concerning this model type. It will not be directly applicable to Maryland fisheries other than as a review of surplus production model techniques.

Goh, B.S. 1969. Optimal control of a fish resource. Malayan Scientist 5:65-70.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Graham, M. 1935. Modern theory of exploiting a fishery, and application to North Sea trawling. J. Cons., Cons. Inter. Explor. Mer. 10:264-274.

Applicable

Abstract

This classical fisheries paper explores that concept that a "certain proportion of the time and money of fishermen is...devoted to reducing their catch or is at least wasted." The theory of the "economy of effort" has essentially two postulates: (1) reduction in mortality (i.e., by reducing fishing rate) will increase the mean age of the population and the inverse holds true; and (2) there is a most profitable age to harvest a fishery. The concept of maximum sustainable yield is developed.

Comment

This paper represents an early attempt to incorporate the logistic growth concept into fisheries management and is one of the initial uses of the concept of MSY. It could be applicable to Maryland fisheries.

Grant, W.E. and W.L. Griffin. 1979. A bioeconomic model of the Gulf of Mexico shrimp fishery. Trans. Am. Fish. Soc. 108:1-13. Applicable

Abstract

A bioeconomic model of the brown shrimp (*Penaeus aztecus*) fishery in Galveston Bay, Texas, and adjacent offshore waters accurately predicts the general trends in the seasonality of shrimp harvet and the distribution of the harvest in relation to size of shrimp and water depth.

Comment

This paper presents a valuable first attempt to explicitly integrate population dynamics and economic price-cost analysis. It could prove useful.

Gulland, J.A. 1964. Manual of methods for fish populations analysis. FAO Fish. Tech. Pap. 40. 60 pp.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO Man. Fish. Sci. 4. 154 pp.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Hackney, P.A., and C.K. Minns. 1974. A computer model of biomass dynamics and food competition with implications for its use in fishery management. Trans. Am. Fish. Soc. 103:215-225. Applicable

Abstract

A model useful for managing interacting fish species, based on concepts of food competition, is developed and tested.

The model consists of differential equations. One, in the Pearl-Verhulst idiom, specifies organisms which can serve only as food resources for consumers of higher trophic status. A "storage" equation describes ingestion and assimilation of food by a consumer. Another equation derived with the storage equation describes growth and attrition (i.e., metabolic and mortality costs) in terms of energy.

Further, consumers may prey upon each other in addition to the resources and the equations are shown to be adequate for describing food webs. The model is essentially one of energy flow and deals with biomass, instead of numerical, dynamics.

Coded in a computer language (PL/I), the model simulates competition and clarifies aspects of yield and harvest strategies in systems of interacting populations.

The model is illustrated with hypothetical populations which have variable turnover rates and the Lake-Trout-Burbot system in Lake Opeongo, Ontario.

Comment

This model may be applicable for competitive species and predator-prey systems, although it is useful only in density-dependent situations. A number of the model parameters may be difficult to obtain.

Hammond, D.E., and T. Lackey. 1976. Analysis of catchable trout fisheries management by computer simulations. Trans. Am. Fish. Soc. 105:48-56. Non-applicable

Abstract

Although strategies to meet most management objectives are relatively clearcut in single-species, catchable trout programs, strategies become much more complex when two or more species are involved. A difficult problem that must be faced in evaluating catchable trout fisheries management strategies is defining management objectives. One approach to testing alternative management strategies in complex resource systems, such as catchable trout fisheries, is system simulation. A computer-implemented CAtchable Trout Fishery Simulator (CATS) was developed to evaluate fishery response under various management strategies in a multispecies stocking program. The user of CATS can select alternative management strategies and functions which generate predictions of fishing pressure in a particular fishery. To evaluate the effect of each system component, CATS was exercised over a wide range of potential, athough entirely hypothetical, system component alternations. Predominant stocking of brook trout appreciably increased average catch per angler hour and percentage return to creel. Altering the stocking ratio to favor brown trout substantially increased the number of angler hours. Stocking predominantly rainbow trout produced results intermediate between those caused by stocking predominantly brook or brown trout. Estimates of expected angling pressure and catchability coefficients of each species stocked are of primary importance because of their considerable effect on other system components. A user must have a sound objective before deciding where, when, which species, and how many fish to plant. The primary utility of CATS is to enable the user to evaluate management strategies prior to implementation.

Comment

The model is not really usable. The methodology presented is not quantified beyond a functional stage. All functional parameters are essentially left to the wishes of the user.

Hashagen, K.A., Jr. 1973. Population structure changes and yields of fishes during the initial eight years of impoundment of a warmwater reservoir. Calif. Fish. and Game 59:221-244.

Non-applicable

Abstract

Data from creel census and netting programs were used to study changes in the relative abundance, age, and species composition of fish during the first 8 years of impoundment of Merle Collins Reservoir, Yuba County, California. The effects of the changes on fish yields are discussed.

High survival of the first (1964) year class of largemouth bass (*Micropterus salmoides*) produced a large population of slow growing bass that dominated the fishery through 1967. These fish limited survival and recruitment of all centrarchids in 1965 and 1966 and depressed initial yields.

Largemouth bass and green sunfish (*Lepomis cyanellus*) declined numerically after 1968. Bluegill (*L. macrochirus*) and redear sunfish (*L. microlophus*) increased dramatically. Catfish remained stable and were probably underexploited. Salmonids, introduced in late 1966, increased total pressure and effort and raised annual yields.

Age composition of centrachids changed from adult fish and fish of the initial year class to a structure in which several year classes and all sizes were represented by the end of the 8-year study.

Anticipated changes in species composition failed to develop as numbers of nongame species remained extremely low throughout the study.

High initial yields customarily associated with new impoundments were not obtained. Yields ranged from 2.3 to 10.7 lb/acre.

Comment

This paper is not applicable to the project as it simply describes historical alterations in total yield from the reservoir. No models of production or yield are presented.

Hilborn, R. 1976. Optimal exploitation of multiple stocks by a common fishery: A new methodology. J. Fish. Res. Bd. Canada 33:1-5. Applicable

Abstract

Optimal harvest rates for mixed stocks of fish are calculated using stochastic dynamic programming. This technique is shown to be superior to the best methods currently described in the literature. The Ricker stock recruitment curve is assumed for two stocks harvested by the same fishery. The optimal harvest rates are calculated as a function of the size of each stock, for a series of possible parameter values. The dynamic programming solution is similar to the fixed escapement policy only when the two stocks have similar Ricker parameters, or when the two stocks are of equal size. Normally, one should harvest harder than calculated from fixed escapement analysis.

Comment

The procedure presented here may be usable in situations where population dynamics are modeled adequately, as a method of determining multi-stock relationships and for the optimization of recruitment for several species.

Horst, T. J. 1977. Use of the Leslie matrix for assessing environmental impact with an example for a fish population. Trans. Am. Fish. Soc. 106:253-257. Applicable

Abstract

The Leslie matrix model for discrete population theory is examined for the assessment of the effects of environmental alterations on a species population using an eigenvalue analysis. This analysis provides estimates of population growth rate and stable age distribution. A sensitivity analysis is conducted for changes in elements of the population matrix and the resultant effect on population growth rate and stable age distribution. An example of this technique is presented for the cunner (*Tautogolabrus adspersus*). This example considers the effect of entrainment of cunner eggs and larvae at the intakes of power stations.

Comment

The procedure presented here may be applicable if environmental impact can be considered equivalent to fishing mortality.

Hrbacek, J. 1969. Relations between some environmental parameters and the fish yield as a basis for a predictive model. Internationale Vereinigung fur Theoretische und Angewandte Limnologic Verhandlungen 17:1069-1081.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Huang, C.C., I.B. Vertinsky, and N.J. Wilimovsky. 1976. Optimal controls for a single species fishery and the economic value of research. J. Fish. Res. Bd. Canada 33:793-809. Applicable

Abstract

Mathematical proofs and analyses of solution methods are presented for determining optimal policies for the management of a single species fishery under equilibrium conditions. Previous intuitive arguments for solution of optimal policies controlling mesh size and fishing rate given complete information are explicitly proven. The analysis is extended to the case where some of the parameters describing the dynamics of the population are known only imprecisely to the manager. Using probability distributions for those unknown parameter values the problem is cast as a stochastic program where expected sustained net revenues from the fishery are maximized. The associated problem of optimal allocation of research resources under uncertainty conditions is considered by evaluating the direct value of such information to management activities.

Examples and algorithms are presented for the class of problems discussed.

Comment

The model presented here may be useful, but only after a population dynamics model is completed. It develops a methodology to determine optimal age of capture and its associated yield (i.e., by regulation of mesh size). optimal yield by controlling fishing rate, or a combination of the two.

Jacquette, D.L. 1972. A discrete time population control model. Math. Biosci. 15:231-252. Non-applicable

Abstract

A discrete time stochastic model is assumed to describe the growth behavior of a natural animal, pest, or even epidemic population. Periodically, control action representing, for example, harvesting or exterminating can be taken to modify the future growth of the population. Dynamic programming can be used to generate optimal control policies for models where growth and control produce economically measurable benefit or cost. This paper uses dynamic programming to find conditions under which the classically simple "single critical number policy" is optimal. These conditions are then expanded to include a wide range of control models and the optimal policy obtained is characterized as a "single critical function policy."

Comment

This paper presents an optimal control stochastic model of population dynamics. It is very theoretical in nature and its parameters are not biologically realistic. This model approach is beyond the scope of this study (optimization) and it is somewhat doubtful that it can be applied to Maryland fisheries at all.

Jenkins, R.M. 1976. Prediction of fish production in Oklahoma reservoirs on the basis of environmental variables. Ann. Okla. Acad. Sci. 5:11-20. Applicable

Abstract

To maintain productivity of fishery resources in Oklahoma reservoirs, the managers of these reservoirs must know the environmental factors that control fish production and harvest. The present study, using correlation and regression analysis, indicates that of the ten environmental variables examined, low storage ratios, i.e., high water-exchange rates, most favor high standing crops of fish. Revised estimates of standing crop values, made in part by correcting for the difference in recoveries from coves and from a larger area, indicate much larger and dominant populations of bottom feeders. The potential of various reservoirs for production of sport fish is evaluated on the basis of water quality, and fishing pressures on the reservoirs are estimated.

Comment

While this paper is not directly related to Maryland fisheries, it may prove helpful in the adaptation of a morphoedaphic index (MEI) to estuarine situations. The relationship used concerns standing crop and discharge or storage rates rather than total dissolved solids. Since earlier versions of the MEI assume negligible flushing, and this approach assumes variable flushing (more realistic when considering estuaries), the latter approach may be applicable for producing statistical management models for Maryland fisheries.

Jenkins, R.M. 1978. Prediction of fish biomass, harvest and prey-predator relations in reservoirs. pp. 282-296 In W. Van Winkle (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy and Development Administration and Electric Power Research Institute.

Non-applicable

Abstract

Regression analyses of the effect of total dissolved solids on fish standing crops in 166 reservoirs produced formulas with coefficients of determination of 0.63 to 0.81. These formulas provide indexes to average biotic conditions and help to identify stressed aquatic environments. Simple predictive formulas are also presented for clupeid crops in various reservoir types, as clupeids are the fishes most frequently impinged or entrained at southern power plants. A method of calculating the adequacy of the available prey crop in relation to the predator crop is advanced to further aid in identification of perturbed prey populations. Assessment of stress as reflected by changes in sport fishing success can also be approached by comparison of the predicted harvest potential with actual fish harvest data. Use of these predictive indexes is recommended until more elaborate models are developed to identify power plant effects.

Comment

The procedures presented here are not useful in the sense of a prediction of yield. They would be of little use in the project.

Jensen, A.L. 1972. Population biomass, number of individuals, average individual weight, and the linear surplus-production model. <u>J. Fish. Res. Bd. Canada</u> 29: 1651-1655. Applicable

Abstract

The identity $B_t = N_t\bar{W}_t$, where B_t is the population biomass, N_t is the population size, and $\bar{W}_t$ is the average individual weight for all ages, is applied to develop simultaneous equations for change in biomass, number of individuals, and average individual weight for the linear surplus-production equation. It is shown that equations for all three variables cannot be simultaneously logistic. The relation between $\log_e N_t$ and $\log_e \bar{W}_t$ predicted by the linear surplus-production model is compared with observations of bluegill population densities and average weights estimated from 10 years of cove rotenone sampling in five large TVA reservoirs. The fit of the model to the data is fairly good, but it accounts for only a small amount of the total variation observed.

Comment

This paper presents a good discussion of the interrelationships of numbers and biomass in surplus-production models. However, the material presented is not significantly different from a Schaefer model.

Jensen, A.L. 1973. Relation between simple dynamic pool and surplus production models for yield from a fishery. J. Fish. Res. Bd. Canada 30:998-1002.

Non-applicab

Abstract

Dynamic pool models without self-regenerating properties are continuous age models, and surplus production models are continuous time models. Self-regenerating dynamic pool models are continuous age-discrete generation models and, also, discrete time-discrete age models. In a steady state, specification of the regulatory function and direct estimation of biomass results [sic] in the surplus production model. Estimation of biomass by specifying the functions with respect to age for size of a cohort and individual weight and application of the coefficient of fishing mortality result in the dynamic pool model. A third approach, not applied in fisheries, is to specify the regulatory function and functions with respect to age of cohort size and individual growth in weight. In a steady state, all methods for calculating yield give the same results if the functions specified are realistic. Specification of the functions requires that many assumptions be made. The dynamic pool model may be more accurate than the surplus production model because the regulatory function may be more difficult to determine than the functions with respect to age of cohort size and growth in individual weight.

Comment

This paper presents a good discussion of similarities of Beverton-Holt and Schaefer-like models, but presents no material significantly different from those models.

Applicable for parameter estimation

Jensen, A.L. 1976. Relation between yield and fishing mortality for Ricker's yield equation. J. Fish. Res. Bd. Canada 33:275-277.

Abstract

A method is presented that can be applied to examine the relation between yield and magnitude of fishing mortality for Ricker's dynamic pool yield equation. The magnitude of fishing mortality is measured by the norm of the vector of interval specific instantaneous fishing mortality coefficients. The method is applied to a bluegill sunfish (*Lepomis macrochirus*) population.

Comment

The paper is interesting, but not directly applicable to yield estimation. It simply discusses the relationship of total mortality to yield in a cohort model.

Johnson, F.C. 1978. Salmon Fisheries Systems Analysis. Washington Department of Fisheries Completion Report for Project No. 1-99-D, for the Period July 1973 - September 1976. 81 pp. Applicable

Abstract

The Catch/Regulation Analysis Model (the fishery model) has been developed by the National Bureau of Standards for the Washington Department of Fisheries to serve as a salmon fisheries management tool for analyzing the economic and biological effects associated with changes in salmon fishery regulations. The goal of the model is to provide a common methodology for quantifying the impact of alternate sets of fishing regulations on fisheries performance and salmon stock abundance and stability. It has been used to examine and evaluate over a total of 100 different sets of fishing regulations for the 1976, 1977 and 1978 salmon fishing seasons. Personnel in the Washington Department of Fisheries have been trained in data preparation for the model and in the mechanics of running the model on the Control Data computer system at the University of Washington, Seattle, Washington. The purpose of this document is to provide a non-technical description of the model and to provide realistic input and output examples. The fishery model is a large and complex model which contains over 6000 FORTRAN statements.

Comment

This methodology appears useful when large data sets are available. It may not be directly applicable to any Maryland species. The actual model is delineated in an earlier paper and it is impossible to evaluate assumptions without the earlier paper.

Jones, R. 1964. Estimating population size from commercial statistics when fishing mortality varies with age. Rapp. P.-V. Reun., Cons. Int. Explor. Mer. 55:210-214.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Jørgensen, S.E. 1976. A model of fish growth. Ecol. Modelling 2:303-313. Non-applicable

Abstract

A fish model based upon mass balances is set up. Several of the parameters have been determined by experiment. The remaining parameters are based upon literature values and it was not necessary to find any parameter by calibration. The model was validated with a completely acceptable result.

The model includes equations giving the fish growth, the production of ammonia and organic matter, the oxygen consumption, and the influence of the temperature.

The model can be used for management of fish farms and as a submodel for a total aquatic system.

Comment

This model is a simplistic formulation, which is applicable to very controlled situations. It appears unusable in a non-stable, natural environment.

Kitchell, J.F., J.F. Koonce, R.V. O'Neill, H.H. Shugart, Jr., J.J. Magnuson, and R.S. Booth. 1974. Model of fish biomass dynamics. Trans. Am. Fish. Soc. 103:786-798.

Abstract

A model of fish biomass dynamics is developed based on principles of physiology, popluation biology and trophic ecology. The model is designed to incorporate measurable parameters for simulating seasonal changes in a natural population. All parameters were implemented for the bluegill (Lepomis macrochirus) and simulation results compared with independently derived laboratory and field data. Applications of the model to thermal enrichment problems are given as an example of future potential use.

Comment

This model represents a synthesis of many different factors which influence fish production. Its complexity may limit its applicability, but it should be considered for use in this program.

Kitchell, J.F., D.J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). J. Fish. Res. Bd. Canada 34: 1922-1935.

Applicable for parameter estimation

Abstract

A simple energy budget equation is developed to yield a bioenergetics model designed to simulate fish growth. Parameters for the model are estimated from the literature for application to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). Simulations are presented that demonstrate model output as functions of body size, activity level, ration level, food quality and environmental temperature. Sensitivity analyses identify the importance of food consumption, activity and excretion as biological processes represented in the parameters. On the basis of temperature conditions in selected lakes and specified feeding levels, simulations are presented to quantify the importance of year-to-year variation of temperature in determining growth. In heterothermal systems, temperature selection by percids can have a significant effect on growth. For walleye on fixed rations, annual growth can vary from zero to twofold increments due entirely to differences in summer temperatures. Variations in food quality have lesser effects.

Comment

The models presented require detailed information which may be unavailable for many species. However, it should be considered as a possible input model. Sensitivity analysis is included.

Knight, W. 1970. A possible optimization experiment in fishery management. J. Fish. Res. Bd. Canada 27:961-963.

Non-applicable

Abstract

A tag-recapture method for deciding whether a change in effort governing regulations will improve a fishery or the opposite is proposed. When the criterion is weight of catch, this reduces to seeing whether the total weight of fish recaptured in a certain tag-recapture experiment exceeds the total weight of fish released. Most of the many practical objections besetting this experiment are common to any method depending on tag-recapture methods to estimate rate of exploitation.

Comment

This paper does not present a model of yield or production and is thus not suitable for use in this study.

Kutty, M.K., and S.Z. Qasim. 1968. The estimation of optimum age of exploitation and potential yield in fish populations. J. Cons., Cons. Int. Explor. Mer. 32:249-255.

Applicable

Abstract

Some methods for estimating the optimum age of exploitation (t_y) and the potential yield (Y) in fish populations have been described under allometric and isometric conditions of growth. The relative constancy of t_y and Y under all conditions of exploitation indicates that these parameters, in the absence of a long series of data, could be used for measuring the fishing efficiency.

Comment

This paper presents a review of the Beverton-Holt yield model under the conditions of allometric and isometric growth. While offering little new information, this paper could prove valuable in a management framework for the determination of the optimal age of exploitation.

Lackey, R.T. 1975. Fisheries and ecological models in fisheries resource management. pp. 241-249 In C.S. Russel (ed.), Ecological Modeling in a Resource Management Framework, Resources for the Future, Inc., Washington, D.C.

Non-applicable

Abstract

The author reviews the use of fisheries and ecological models in fisheries management. He discusses the basic types of models (i.e., habitat, biological and social) and how they have been integrated to generate the types of models in general use. He also discusses problems encountered in applying models to decision-making processes.

Comment

This paper presents a good, brief background discussion of the types of models used in fisheries management. However, it does not present actual models and is thus not useful for this program.

Laevastu, T., and F. Favorite. 1978. Numerical evaluation of marine ecosystems. Part I. Deterministic bulk biomass model (BBM). Northwest and Alaska Fish. Center Proc. Rept. NOAA.

Applicable

Abstract

The wise management of marine fishery resources requires the consideration of the total marine ecosystem in a given region, as the components are interacting and the fishery on one or more species will, in many instances affect the abundance and distribution of other species as well, i.e., the abundance of one species might be declining, the other increasing.

A deterministic method to estimate either the minimum sustainable and/or saturation biomasses of species and/or groups of ecologically similar species in a given region is described. This method can also be applied to unexploited or underexploited resources. Trophodynamic approaches are used that permit the quantitative determination of the major component of the natural mortality -- the predation or grazing mortality. The error limits depend on the accuracy of some trophodynamic data. Migration is not considered because detailed migrations are an integral part of the large ecosystem model -- DYNUMES, for which the present model serves as one of the initial input subroutines.

Comment

While appealing, the ecosystem model for determining system carrying capacity (several species or species groups) cannot be utilized for Maryland fisheries without numerous studies to evaluate the feeding coefficients necessary for the model's implementation. The model, assuming the data are available, provides a good estimate of trophic carrying capacity and maximum sustained yields.

Laevastu, T., and F. Favorite. 1978. Numerical evaluation of marine ecosystems. Part 2. Dynamical numerical marine ecosystem model (DYNUMES III) for evaluation of fishery resources. Northwest and Alaska Fish. Center Proc. Rept. NOAA.

Applicable

Abstract

A method of numerical dynamical deterministic reproduction of a marine ecosystem with emphasis on applications to fisheries problems is presented. Although such simulations are location dependent -- i.e., greatly determined by the nature of the specific ecosystem components present in the region and by the availability of local research and survey results as well as by the intensity and nature of the exploitation of marine resources by man in the given region -- the method gives a general basic framework of one type of marine ecosystem simulation model. Objectives, principles, and major computational formulas of the model, which has been applied by NWAFC to the eastern Bering Sea and the area around Kodiak Island in the Gulf of Alaska, are also presented. More detailed discussions on the input of local knowledge, other specific data and their validity, results of model applications, and the computer program documentation are available in NWAFC Processed Reports.

Comments

The model present in this report is very complex with state variables varying in 4 dimensions (3 spatial and 1 time). While the approach is ecologically satisfying (i.e., approaches a realistic biological situation), the data requirements, particularly for ecosystem processes, are too large and difficult to obtain to be of much use to Maryland fisheries. This procedure may be instructive in the formulation of data acquisition schemes to obtain this type of information for potential ecosystem management models at a later date.

Laevastu, T., F. Favorite, and H.A. Larkins. 1979. Resource assessment and evaluation of the dynamics of the fishery resources in the NE Pacific with numerical ecosystem models. Northwest and Alaska Fish. Center Proc. Rept. 79-17.

Applicable

Abstract

The development of offshore fisheries in the vast NE Pacific is relatively recent. Exploratory surveys in the late 1950's demonstrated the abundance of groundfish in this region. The resource surveys in the large area are expensive and without an inordinantly large field effort the accuracy of the results is low. Due both to the lack of conventional fisheries and biological data and the inherent shortcomings of single species models, those models are of questionable value for managing the multination, multispecies fisheries of the northeastern Pacific Ocean.

Two biomass-based, holistic, ecosystem models are being developed and are used at NWAFC for the evaluation of the abundance and dynamics of the fishery resources and for the study of the response of these resources to exploitation and to environmental changes (anomalies). The general background of these models is given... and a simplified version of one of them is given in skeleton form in the Appendix.

Equilibrium biomasses, as computed with the PROBUB model for the eastern Bering Sea and the western Gulf of Alaska, are given in this paper. These are computed (validated) with conventional trawling survey results, which have been converted with catchability and availability factors.

The nature of the dynamics of the biomasses in space and time is briefly described and the effect on the resource assessment is demonstrated with some results from the DYNUMES model.

Comment

This paper presents several ecosystem simulation models for the Pacific Northwest fisheries. Single population models are inapplicable in these cases due to the high degree of species interaction caused by predation. The large number of parameters necessary to construct this model makes its application difficult to Maryland fisheries, but this type of simulation formulation is the most ecologically complete type of management model described in the literature.

Larkin, P.A. 1963. Interspecific competition and exploitation. J. Fish. Res. Bd. Canada 20:647-678. Non-applicable

Abstract

The consequences of exploitation of either or both of a pair of competing species are examined using the Lotka-Volterra equations. The removal of a fixed proportion of a population on an instantaneous basis shifts the equilibrium population sizes for both the exploited species and its competitor. Similar shifts occur when both species are exploited. The maximum sustained yield of a species can be estimated under various degrees of exploitation of its competitor. The maximum combined sustained yield can be estimated for various relative values of the two species. From this analysis it is observed (1) harvesting only one species may provide a mistaken underestimate of capacity for sustained yield, (2) harvesting two species but relating yield to the fishing mortality rate of only one of the two may give a misleading overestimate of further capacity for sustained yield. Similar conclusions can be drawn if exploitation rate is proportional to abundance.

A stochastic version of the model is given for study of the effects of exploitation on small populations of competitors.

Fixed percentage exploitation and abundance proportional exploitation may be considered in depicting respectively the mode of action of density-independent and density-dependent factors. Accepting these parallels, the model may demonstrate some widely discussed properties of mechanisms of population regulation. Variability in factors both density dependent and density independent which are extrinsic to the biological system can be simulated in the model by random variates.

A discrete time model is described which was used with a computer for study of transitions from one steady state to another and extinction probabilities. The computer results confirm the theoretical predictions of the model. In addition it is suggested that there is no apparent difference in the result when competitors are exposed to the same or different random sequences of environmental effects of the same average intensity.

It is concluded that this formulation of interspecific competition together with variations could be applied to laboratory or natural situations to test its usefulness as a basis for prediction.

Comment

This paper represents a novel inclusion of competition theory in yield exploitation but its data and parameter requirements are too large to merit its possible use for Maryland fisheries.

Larkin, P.A., and A.S. Hourston. 1964. A model for simulation of the population biology of Pacific salmon. J. Fish. Res. Bd. Canada 21:1245-1265. Non-applicable

Abstract

A model simulating the population dynamics of the stocks of salmon spawning in a large river system is constructed, incorporating (1) a series of theoretical reproduction curves operating in successive stages during the life history of each stock producing compensatory or depensatory effects, (2) a device for simulating environmental variability (extrapensatory effects), (3) the effects of a joint fishery on mixed stocks, (4) the effects of multiple age of spawning on fluctuation in abundance of a single stock, (5) the consequences to yield of various degrees of stabilization of the fishery, and (6) the inheritance of age at maturity in salmon. Application of the model is illustrated by two examples. The first simulates the production of cyclic dominance by the inheritance of age of maturity and depensation in the freshwater stage. In the second example, five stocks differing in relative abundance, age composition, environmental variability, and rate of compensation are subjected to a common fishery which is selective for age and provides for complete stabilization of the escapement for the combined run as a whole. Comparisons between various combinations of the five stocks show the effects of these factors on the various stocks and on the run as a whole over a simulated period of 120 years.

Comment

This model is probably too data intensive and site-/species-specific to be useful in this project.

Laurence, G.C. 1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, Pseudopleuronectes americanus, larvae during the period from hatching to metamorphosis. Fish. Bull. 75:529-546.

Non-applicable

Abstract

A bioenergetic model was developed which simulated effects of temperature, prey density, and larval size on ability of winter flounder, Pseudopleuronectes americanus, larvae to obtain food energy to provide for experimentally determined growth and metabolism. Larval feeding at constant temperature and as a function of prey concentration was exponential and more sharply asymptotic in younger fish than in those near metamorphosis. Specific growth rates were exponentially related to prey concentrations and ranged from 5.72 to 8.70%/day at survival prey concentrations of 2.3 to 21.7 cal/liter. Daily required feeding time was directly related to prey availability. Critical plankton densities below which larvae did not have enough time during the day to obtain adequate food for growth and metabolism varied with age and ranged from 2.1 to 5.7 cal/liter. Simulated physiological energy utilization and required caloric food intake were inversely related to prey concentration and varied with larval stage of development. Food requirements expressed as numbers of copepod nauplii consumed per day ranged from 19 for first feeding larvae to 235 for metamorphosed juveniles. Predicted gross growth efficiencies were directly related to prey concentration and increased with age from 5 to 33%. All indications pointed to a "critical period" of larval survival during the period of exogenous feeding initiation and immediately after.

Comment

The model presented here is a standard bioenergetics model with no real modifications. Its application is to larval growth, which is beyond the scope of this project. Because it is similar to other models to be considered for parameter estimation, it should not be reviewed further.

Lefkovitch, L.P. 1965. The study of population growth Applicable in organisms grouped by stages. Biometrics 21:1-18.

Abstract

In this extension to the use of matrices in population mathematics, the division of a population into equal age groups is replaced by one of unequal stage groups, no assumptions being made about the variation of the duration of the stage that different individuals may show. This extension has application in ecological studies where the age of an individual is rarely known. The model is briefly applied to three experimental situations.

Comment

The paper presents a modified Leslie matrix model. It might be a useful modification for application to exploited stocks.

Leslie, P.H. 1945. On the use of matrices in certain population mathematics. Biometrika 33:183-212. Applicable

Abstract

The author describes the application of matrices to analysis of population dynamics, using estimates of age-specific fecundity and mortality as inputs and changes in age distribution over time as output.

Comment

This paper is one of the classic papers of Leslie describing the application of matrices to the study of animal populations. It will be useful for evaluating the appropriateness of this approach to fisheries management.

Leslie, P.H. 1959. The properties of a certain lag type of population growth and the influence of an external random factor on a number of such populations. Physiol. Zool. 32:151-159. Applicable

Abstract

The author considers the growth in numbers of a population of a single species, living in a limited environment, in which it is assumed that the fertility and mortality of each age-group depend not only on the existing state of the population at some given time t but also on the state of the population at some previous time $t - x$, when the individuals forming a particular age-group, aged between x and $x + \Delta x$ were born. This is partly a "lag" form of population growth in which the period of lag varies from age-group to age-group depending on the length of time the individuals have lived in the population. It is shown that this type of population, living under optimum constant conditions as regards the environment, would oscillate in numbers, with amplitude of the oscillations, which initially may be quite marked, gradually damping out as an approach is made to the stationary state in numbers.

A further problem which is considered is the influence of an external seasonal factor on a number of oscillating populations of this type, which are situated in the same geographic region. This common factor is here regarded as being a hierarchy of five possible classes of "season," ranging from "very good" to "very bad," which are assumed to follow one another in a random order. It appears that the effect of an external random factor of this type, acting independently of age and numbers, is to bring the oscillations of such geographically isolated systems gradually into phase.

Comment

This is one of the original presentations of the Leslie matrix population model, which is applied to fish populations in more recent literature. It should be included in this study, grouped with the application papers.

Lett, P.F., W.T. Stobo, and W.G. Doubleday. 1975. A system simulation of the Atlantic mackerel fishery in ICNAF subareas 3, 4, and 5 and Statistical Area 6; with special reference to stock management. Int. Comm. Northwest Atl. Fish Res. Doc. 75/32. 10 pp.

Applicable

Abstract

The international commercial catch of Atlantic mackerel (Scomber scombrus) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 increased from 6,831m.t. in 1961 to 419,306m.t. in 1973 (Anderson MS 1975a). The estimated value of F in 1973 was 0.60; the recommended level by the ICNAF ad hoc mackerel working group (Redbook 1973, Part 1).

A stock recruitment relationship was derived for Atlantic mackerel which spawn in the Gulf of St. Lawrence (Lett et al. MS 1975b). Using the determined relationships, a system simulation was constructed to investigate the effects of different levels of fishing intensity on stock biomass, catch and recruitment. These effects are examined when temperature is held constant and treated as a stochastic variable.

It is anticipated that the validity of maximum sustainable yield being determined at a fishing mortality of 0.6 could also be investigated. Furthermore, a test is made of Ricker's (1963) hypothesis that small increases in effort beyond maximum sustainable yield cause rapid declines in stock biomass, recruitment, and catch.

Comment

This paper presents a good methodology for testing the consequences of variable fishing pressures, using a yield-per-recruit Beverton-Holt formulation coupled with statistical models of egg production, and larval and prerecruit survival. This model may be helpful in constructing management models for Maryland fisheries.

Lett, P.F., and T. Benjaminsen. 1977. A stochastic model for the management of the northwestern Atlantic harp seal (Pagophilus groenlandicus) population. J. Fish. Res. Bd. Canada 34:1155-1187.

Non-applicable

Abstract

Advice from the scientific advisers under the auspices of ICNAF to the international commissioners for 1977 was that the total allowable catch (TAC) for harp seals (Pagophilus groenlandicus) should not exceed 170,000. This advice, in part, was based on the scientific arguments presented in this paper. A stochastic model is developed that takes into account the variations in natural mortality and the landsmen's high arctic and Greenland catches. The Canadian-Norwegian large vessel hunt is controlled under quota regulations. The model is nonlinear, a result of changes in fertility and fecundity rates in response to shifts in population size. The maximum sustainable yield (MSY) 1+ population size is determined to be 1.6 million seals, or a breeding stock size of 375,000 seals. The MSY is approximately 240,000 seals, assuming the hunt continues its present pattern. The 240,000 can further be split into 200,000 pups and 40,000 1+ seals. Present stock size is approximately 1.2 million and a TAC of 170,000 seals will allow the population size to reach to MSY level in 10-15 years. A number of other management strategies are considered, in addition to prospects for further research.

Comment

The paper presents a simulation of a harp seal fishery based on cohort analysis. Techniques presented here are covered in other papers reviewed, and other specific information presented appears irrelevant to this study.

Lett, P.F., A.C. Kohler, and D.N. Fitzgerald. 1975. Role of stock biomass and temperature in recruitment of southern Gulf of St. Lawrence Atlantic cod, _Gadus morhua_. _J. Fish. Res. Bd. Canada_ 32:1613-1627.

Applicable

Abstract

A multivariate approach was used to elucidate the simultaneous effects of temperature and estimated parent stock biomass on the recruitment mechanism of Gulf of St. Lawrence cod. The second order effects of temperature and estimated stock biomass were key factors in determining egg abundance levels. In addition, egg abundance was closely related to the growth rate of cod. The numbers of larvae increased with the interaction of temperature with egg abundance but decreased with the interaction of egg abundance and time. The most important step in the recruitment mechanism occurs during the juvenile state, the degree of density dependence being reliant on total biomass of the adult cod stock. A system simulation was constructed amalgamating the equations of early life history of cod with the effects of exploitation on stock biomass. Regular 12-yr oscillations were demonstrated at low levels of catch, while the population became more stable at higher fishing efforts in the absence of environmental effects. The optimal fishing mortality for the Gulf of St. Lawrence cod was found to be $F_{0.4}$ with a maximum sustainable yield of 42,000 metric tons.

Comment

This paper presents a very detailed, deterministic population model which requres an extensive data base for application. It represents an advanced management tool.

Lewis, E.R. 1976. Applications of discrete and continuous network theory to linear population models. Ecology 57:33-47.

Applicable

Abstract

The well-established methods of network construction and analysis are adapted to the problem of modeling single populations. A major advantage of the resulting approach is that it allows explicit incorporation of key processes in the life cycle of the organism being modeled, with feedback loops providing economy of representation where they are allowed. Thus, network structures provide heuristic vehicles by which population models can be developed and modified. When a model is linear and has parameters that do not vary with time, a characteristic dynamic function can be derived by inspection from a simple transform of the network representation. The zeros of the function can be found (analytically or by commonly available numerical methods) and used directly to deduce the modeled population's dominant growth pattern and its propensity to sustain oscillations. In addition, under certain conditions (i.e., that the network model not contain both time delays and integrators), a straightforward method (partial fraction expansion) is available for deduction of the modeled population's specific responses to a variety of perturbations.

Comment

This approach offers a secondary method of linear time scaling through networks where events define the boundaries of stages rather than age as in the Leslie matrix. This method offers little new and will probably prove to be of little use in the project, but it should be reviewed.

Lewis, E.R. 1977. Linear population models with stochastic time delays. Ecology 58:738-749. Non-applicable

Abstract

Previously it was shown that reproductive-cycle parameters such as time to maturity, ovulation interval, gestation period, duration of regression, duration of nonreproductive lactation period, and the like, can be incorporated into population models rather easily through the use of a simple network approach. In this paper, the network approach is extended to include the same types of reproductive parameters when their values are not necessarily fixed, but may vary randomly from one member of a population to the next and/or for a given member from one time to the next. It is shown that linear transforms of the parameter distribution functions can be incorporated directly into the network models and that analysis of the resulting dynamics follows in a straightforward manner, the characteristic dynamical equation being obtainable by direct analysis in simple cases or by well-established numerical methods in complicated cases. The roots themselves can be interpreted directly in terms of dominant patterns of population growth and deduced propensity of the population to sustain oscillations triggered by external stimuli. In the case of a simple natality cycle with gamma, negative binomial, and binomial distributions of maturation times, it is shown that the dominant growth pattern approximates rather closely that expected for a nonrandom maturation time equal to the mean of the distribution, and that the propensity to sustain population oscillations decreases markedly both with increasing standard deviation and with increasing (positive) skewness in the distribution.

Comment

This paper offers very little that would be useful in this project. The concept of stochastic event-initialized time will probably not be appropriate for yield conceptualizations.

Lipschultz, F., and G. Krantz. 1978. An analysis of oyster hatchery production of cultched and cultchless oysters utilizing linear programming techniques. Proc. Nat. Shellfish. Assoc. 68:5-10.

Non-applicable

Abstract

Manpower and operational requirements for cultched and cultchless oyster production schedules in a large-scale hatchery were compared using a system of linear equations and a computer optimization program. The matrix of equations defined the operational sequence within the oyster hatchery, the resource requirements, and restrictions, if any. The optimization program minimized a cost objective function within the constraints defined by the system matrix.

Data for the calculations of the matrix coefficients were taken from records of the University of Maryland small-scale hatchery and from Dupuy (1973). The hatchery data provided estimates of manpower requirements for each activity, oyster mortality rates, and equipment costs. Dupuy's paper provided space and density requirements. The temporal sequence of oyster development stages was based on well-documented literature and observations at the model hatchery.

Results show that labor was the major cost component in all types of hatchery schedules. The optimal solution involved purchase of large amounts of equipment which remained idle most of the year, being fully utilized in two pulses during the year. Constant maximal use of equipment required less equipment but more labor and therefore increased production costs. Use of the cultched mode of hatchery operation as opposed to the cultchless resulted in approximately 45% savings in production costs.

This study represents the first phase of a long-term project to optimize production scale oyster hatchery operations. Several problem areas indicated by this model will be investigated and changes incorporated into a revised formulation.

Comment

The model presented here deals explicity with hatchery oyster culture and has little applicability to natural oyster populations.

Lord, G.E. 1976. Decision theory applied to the simulated data acquisition and management of a salmon fishery. Fish. Bull. 74:837-846.

Non-applicable

Abstract

A salmon fishery management model utilizing statistical decision theory has been constructed. The model provides for the successive acquisition of data that can be used to formulate and maintain an optimum management strategy. The Bayes risk is defined as the expected economic loss resulting from a set of fishery management decisions and the criterion of optimality is taken to be the strategy that minimizes the Bayes risk. Specific functional forms are assumed where necessary in order to obtain a closed form expression for the Bayes risk. Bayes risk in units of numbers of fish, can then be computed for any particular sequence of fishery managment decisions.

Comment

The model presented here deals with management of a fishery in which there is sequential acquisition of additive knowledge about stock size during a fishing season, and management decisions are made during acquisition of this information. It also depends on escapement from the fishery being the sole determinant of future stock size. The approach appears inappropriate for Maryland fisheries.

Loucks, R.H. and W.H. Sutcliffe, Jr. 1978. A simple fish-population model including environmental influence, for two western Atlantic shelf stocks. J. Fish. Res. Bd. Canada 35:279-285.

Applicable

Abstract

For several Scotian Shelf and Gulf of Maine stocks, correlations have been observed between ocean temperatures, subsequent fish catches, and fishing effort. We consider a simple fish-population model relating these elements. We suggest that variation in ocean climate triggers corresponding fluctuations in fish stock-recruitment and subsequent abundance and catch. Two pathways between abundance and catch are recognized: (1) catch is simply proportional to abundance (direct influence); and (2) in some cases at least, fishermen traditionally have sensed the abundance of stock and adjusted their fishing effort accordingly; therefore, in periods of less favorable climate for a stock, catch would diminish indirectly because of reduced or "responsive" effort. In such cases, where the fishermen act to stabilize the stock, fishing effort and fish catch are correlated with ocean climate. In any case, ocean climate and "responsive" effort merit consideration as potentially significant factors in population models of these stocks.

Comment

The model presented here may possibly be useful for species which exhibit recruitment as a function of enviromental variables.

MacCall, A.D. 1978. A note on production modeling of populations with discontinuous reproduction. Calif. Fish and Game 64:275-227.

Non-applicable

Abstract

A general exponential population model is adapted to incorporate situations where discontinuous reproduction takes place.

Comment

This model might be utilizable in cases of distinct seasonal reproduction but overall generates more assumptions than other models. Its only major accomplishment is the removal of the assumption of continuous reproduction. The method is not applied to any data in the paper, and it is unknown if it can be applied to real populations.

Macketts, D.J. 1973. Manual of methods for fisheries resource survey and appraisal. FAO Fish Tech. Pap. 124. 40 pp.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

MacKinnon, J.C. 1973. Analysis of energy flow and production in an unexploited marine flatfish population. J. Fish. Res. Bd. Canada 30:1717-1728. Non-applicable

Abstract

The seasonal pattern of production processes in an unexploited resident population of American plaice (*Hippoglossoides platessoides*) in St. Margaret's Bay, N.S., was analyzed with an energetics model which represents an extension of the analytical approach used in fishery theory. During summer, production is about twice the annual net production of 1.5 $kcal/m^2$ by fish aged 1 and up. The ecological efficiency is 17% with larvae and 0+ fish accounting for some 20% of total population ingestion and 34% of net population production. Metabolic expenditures constitute the largest fraction (62%) of population energy intake and about 80% of this amount is consumed during summer. Plaice ingest about half the yearly estimated production (25 $kcal/m^2$) of benthos in the deeper parts of the Bay.

Comment

This model represents a modification of standard bioenergetic models. Yield is not incorporated as an explicit variable but is instead incorporated into the natural mortality term. Also, a large number of parameters (many of which would be very difficult to obtain) are necessary for application of the model. It appears to be unusable.

Mann, S.H. 1970. A mathematical theory for the harvest of natural animal populations when birth rates are dependent on total population size. Math. Biosci. 7:97-110.

Non-applicable

Abstract

Natural animal populations are considered in which members of the population are harvested for their own value, either esthetic or monetary. Population growth is assumed to be dependent on total population size. The parameters of population growth are allowed to be random variables whose joint distribution function is described by an associated Markovian distribution process. Revenue and cost structures are defined for these populations and harvesting policies are described that minimize the expected economic loss to be realized in the duration of time in which management of the system is anticipated.

Comment

While this paper presents a population harvest model incorporating density-dependent, sex-dependent growth, mortality rates, and economic factors, the model is presented in a theoretical form which has little utility for the actual construction of management models.

Marchesseault, G.D., S.B. Saila, and W.J. Palm. 1976. Delayed recruitment models and their application to the American lobster (Homarus americanus) fishery. J. Fish. Res. Bd. Canada 33:1779-1787.

Applicable

Abstract

A delayed recruitment model intended for use in developing dynamic strategies for fisheries management is proposed. The conceptual and analytical properties of the model are elaborated and compared with those of the instantaneous model of Schaefer and the delayed recruitment model recently suggested by Walter. Of the three models discussed, the delayed recruitment model proposed herein constitutes the more biologically meaningful tool for use in management decision making with fisheries characterized by a multiple year delay between spawning and recruitment. The proposed delay and Schaefer models are fitted to catch and effort data from the Rhode Island inshore pot lobster fishery, and the generated coefficients are examined with respect to their interpretation and relative importance. Values of optimum equilibrium catch and effort are calculated for the proposed delay and Schaefer models, and we show that the delay model's estimates of these management indices are more conservative than those derived from Schaefer's model. The proposed delay and Schaefer models are compared in a dynamic analysis of the fishery, in which perturbations in the stock level and fluctuations in the applied effort are simulated to predict the subsequent behavior of the stock.

Comment

This method may be applicable to a number of Maryland species, particularly blue crabs. The altered Schaefer model presented may be useful when little information other than catch statistics is available.

Marchesseault, G., J. Mueller, L. Vidaeus, and W.G. Willette. 1979. Bio-economic simulation of the Atlantic sea scallop fishery. NATO Symp. Appl. Oper. Res. Fish. August 1979. Trondheim, Norway. Applicable

Abstract

A bio-economic simulation framework for evaluation of harvest strategies in the Atlantic sea scallop fishery is presented. Lacking a time series of stock assessment data, a Bayesian approach is used to specify a probabilistic recruitment function. Stock abundances may be stochastically simulated over a defined plan period in response to alternative harvest strategies.

Linked to the biological simulation model is an economic framework for evaluation of harvesting strategies, consisting of a price forecasting model, a sector catch model, and a financial (net income) simulator. In a preliminary application six alternative harvest strategies targeted towards two different terminal stock goals and describing different annual catch trends are evaluated. Alternative assumptions regarding fleet size, factor prices, and the appropriate discount rate are used. To enhance the usefulness for management decision making, several aspects of the biological and economic components of the model are being refined.

Comment

This paper presents a relatively unique method of modeling the management of a fishery for maximum economic return. It incorporates a probability function of yearclass success (the stock-recruitment relationship is unknown) stochastically as a biological submodel. The approach may be applicable for the hard clam, soft clam, and possibly oyster fisheries in Maryland.

Marten, G.G. 1978. Calculating mortality rates and optimum yields from length samples. J. Fish. Res. Bd. Canada 35:197-201. — Applicable

Abstract

An equation is derived for yield per recruit of a fishery (or other exploited animal population) as a function of fishing intensity and age of first capture. The equation has the advantage that it does not require explicit estimates of natural mortality or individual growth rate parameters. Linear length growth is assumed until maximum size is reached, and mortality parameters are expressed relative to growth rate. Mortality parameters are estimated from average length samples of separate populations experiencing different fishing efforts in the same fishery. The equation may be used to compare existing fishing efforts and age of first capture with optimal values. Samples of the catfish, *Bagrus docmac*, from Lake Victoria (East Africa) are used to illustrate the method.

Comment

This model may provide a method of estimating potential yield. The means of estimating mortality and some assumptions concerning the similarity of different populations are subject to some criticism.

Matuszek, J.E. 1978. Empirical predictions of fish yields of large North American lakes. Trans. Am. Fish. Soc. 107:385-394. Applicable

Abstract

Regression analyses have been used for over 2 decades to develop useful statistical relationships between estimates of fish catch and various members of a set of abiotic and biotic variables. In this study a number of conceptual and data refinements have been attempted with respect to certain lake data. More complete data are now available than was the case with earlier authors such as D.S. Rawson and R.A. Ryder. Rather than use average long-term catch, approximate estimates of maximum sustainable yield (MSY) were derived. The MSY of all species combined, C_t, was estimated as well as the MSY of a preferred taxa, C_s, comprising lake trout (*Salvelinus namaycush*) plus lake whitefish (*Coregonus clupeaformis*) plus walleye (*Stizostedion vitreum*) plus sauger (*S. canadense*). The most significant predictive relationships included only one independent variable, average dry weight of bottom fauna standing crop, which explained 83% of the variation of C_t per unit water area in a semilog relationship, and 80% of the variation of C_t per unit area and C_s per unit area in log-log relationships. The best relationships incorporating solely abiotic variables included mean depth and total dissolved solids concentration as the only significant independent variables, and explained less than 70% of the variation. Other factors analyzed included the annual cumulative degree days above 5.6°C, the presence or absence of thermal stratification, and the average dry weight of net plankton standing crop.

Comment

This statistical method using regression of morphoedaphic factors seems of little use in estuarine fisheries. However, the use of benthic standing stock as an indicator of fish yield may be applicable to the project.

May, R.M., J.R. Beddington, C.W. Clark, S.J. Holt, and R.M. Laws. 1979. Management of multi-species fisheries. Science 205:267-277. Applicable

Abstract

With the overexploitation of many conventional fish stocks, and growing interest in harvesting new kinds of food from the sea, there is increasing need for managers of fisheries to take account of interactions among species. In particular, as Antarctic krill-fishing industries grow, there is a need to agree upon sound principles for managing the Southern Ocean ecosystem. Using simple models, we discuss the way multispecies food webs respond to the harvesting of species at different trophic levels. These biological and economic insights are applied to a discussion of fisheries in the Southern Ocean and the North Sea and to enunciate some general principles for harvesting in multispecies systems.

Comment

This is a well-presented paper demonstrating the importance of the use of multi-species concepts in the determination of optimal exploitation. The model presented may be useful for application to the menhaden-bluefish-striped bass-white perch food web.

McConnell, W.J., S. Lewis, and E. Olson. 1977. Gross photosynthesis as an estimator of potential fish production. Trans. Am. Fish. Soc. 106:417-423.

Non-applicable

Abstract

Fish yield and gross photosynthesis were highly correlated in six ecosystems. Gross photosynthesis of phytoplankton and attached plants was measured as diel oxygen changes in unconfined water. Fish yield was measured by capture of all fish at the end of the experiments. Fish yield as live weight ranged from 0.54 to 2.48% of gross photosynthesis. The range of percentages was attributed to differences in foods used and to differences in stocking densities. Species of fish were rainbow trout (*Salmo gairdneri*), channel catfish (*Ictalurus punctatus*), goldfish (*Carassius auratus*), and tilapia hybrids (*Tilapia mossambica* x *Tilapia hornorum*).

Comment

While the relationship of gross photosynthesis and yield may prove to be significant, the artificiality of the ponds used and the differences in stocking methods and densities make this paper unusable. The paper ignores the effects of reduced circulation on nutrient availability and thus on photosynthesis.

Melack, J.M. 1976. Primary productivity and fish yields in tropical lakes. Trans. Am. Fish. Soc. 105:575-580.

Non-applicable

Abstract

Measurements of primary productivity can improve assessment of the fish yields from tropical lakes. In tropical African and Indian lakes commercial fish yields increase logarithmically as primary productivity increases arithmetically. The regression equation describing the relation between fish yields (FY) and gross photosynthesis (PG) for eight African lakes is log FY = 0.113 PG + 0.91. The coefficient of determination is 0.57. The regression equation based on fifteen tropical Indian lakes, log FY = 0.122 PG + 0.95, corroborates the relation for Africa.

Comment

This statistical approach would not be useful in an estuarine situation due to difficulties introduced by tidal flow and flushing. The paper is not directly applicable.

Nelson, W.R., M.C. Ingham, and W.E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden, Brevoortia tyrannus. Fish. Bull. 75:23-41.

Applicable for parameter estimation

Abstract

A Ricker spawner-recruit model was developed for Atlantic menhaden, Brevoortia tyrannus, from data on the 1955-70 year classes. The number of eggs produced by the spawning stock was calculated as the independent variable to account for changes in fecundity due to changes in population size and age structure. A survival index was developed from deviations around the Ricker curve and was regressed on several environmental parameters to determine their density-independent effects. The recruit-environment model accounted for over 84% of the variation in the survival index. Zonal Ekman transport, which acts as a mechanism to transport larval menhaden from offshore spawning areas to inshore nursery grounds, was the most significant parameter tested. Ricker functions for good and poor environmental years were developed, indicating the wide range of recruitment that can be expected at different stock sizes. Comparisons of spawner-recruit relations for Pacific sardine and Atlantic menhaden indicated striking similarities. Surplus yield for the Atlantic menhaden fishery was calculated from observed and predicted survival, and compared with the actual performance of the fishery.

Comment

This paper will be useful to estimate successful recruitment for menhaden. It will have to be adapted to include yield.

Oglesby, R.T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. J. Fish Res. Bd. Canada 34:2271-2279.

Non-applicable

Abstract

Fish yield is related to annual primary production, summer phytoplankton standing crop, and the morphoedaphic index for lakes representing a wide variety of typologies by a series of models in the form of log-log regressions. Tentative boundary conditions are established by which lakes inappropriate to the models can be excluded. Confidence intervals for predicted values about the mean are given for the fish yield-phytoplankton standing crop regression. From this relation, potential yields for the lakes studied are reduced from a range of 10,000 to one of 25-fold. Efficiences with which carbon is transferred from primary production to fish yield vary by 2 to 3 orders of magnitude and are highest for small, intensively managed ponds and lowest for large, deep, cold-water lakes. Models based upon fish yield as a function of phytoplakton production or standing crop are inherently more accurate and subject to fewer exceptions than are those related to morphoedaphic factors. The former appear to be capable of substantial refinement but even in their present state might be employed to make useful predictions for groups of lakes. A suggested supplement to existing approaches in fishery management involves the following sequence: (1) use of expectation-variability diagrams to obtain an overview of the problem; (2) selection of an appropriate model or models to predict yield; (3) prediction of a range of yields; and (4) implementation of regulations proved successful for other lakes in the same yield category.

Comment

The statistical relationship presented in this paper does not appear to be strong in water bodies of low residence time (<0.2 yr) as typified by local estuarine situations. Thus, while the concept may be useful as a secondary approach, its application may prove fruitless. This same procedure is described in several other papers.

O'Heeron, M.K., Jr., and D.B. Ellis. 1975. A comprehensive time series model for studying the effects of reservoir management on fish populations. Trans. Am. Fish. Soc. 104:591-595.

Non-applicable

Abstract

We describe a linear modeling technique that derives functions (parameters) of the predictor variables in a tabular form using a Fourier transformation technique. The result is a complex multiple regression model that is actually a series of models independently describing each parameter. This technique (1) provides an approximation to nonlinear modeling that is not restricted to a small number of variables, (2) does not require precisely formulated theoretical functions for each variable, and (3) avoids many of the restricting assumptions normally required for nonlinear modeling. The estimate of the total systematic information (variance) in the system and the amount of information predicted by the model can be used as a measure of the efficacy of the model. A production form of the model is being completed for use on the Missouri River mainstem reservoir system for predicting the effects of reservoir management practices on the indigenous fish populations.

Comment

The method is possibly useful, if a large data base exists, to construct a holistic system model of all species. The approach seems interesting, but the authors do not provide sufficient information on parameter estimation and use of time series analysis to properly evaluate the technique.

Orach-Meza, F.L., and S. B. Saila. 1978. Application of a polynomial distributed lag model to the Maine lobster fishery. Trans. Am. Fish. Soc. 107:402-411.

Applicable

Abstract

Time series data on catch and effort for the American lobster (*Homarus americanus*) from the state of Maine during the period 1933 to 1974, as well as mean annual sea surface temperatures for the same period were examined by means of a polynomial distributed lag model. The model was described and shown to be sufficiently flexible to take into account environmental influences over specific life history stages as well as over the entire life history of the species. The significance of lagged temperature effects and the fit of the model to the observed data were demonstrated.

Comment

The method presented here appears to be a useful technique, especially for species with a combination of lagged density-dependent recruitment and environmentally dominated growth and survival rates during the lag period. The technique may prove useful for blue crab, menhaden (Ekman transport of larvae), or possibly shellfish.

Orth, D.J. 1978. Computer simulation models for predicting population trends of largemouth bass in large reservoirs. Proc. Okla. Acad. Sci. 58:35-43. — Applicable

Abstract

Two computer simulation models of population dynamics of largemouth bass (Micropterus salmoides) are described. Model I is an age-structured, deterministic model with numbers as the only state vector. Constant age-specific fecundities and survival rates are required inputs. Model I simulates population trends based on an equilibrium population. Sensitivity analysis of this model indicates that density of bass is most sensitive to variations in survival from egg to age I. Multiple regression equations with water level during spawning and water level fluctuation since the end of the previous growing season as predictor variables resolved 88.2% of the observed variation in year class strength and 86.7% of the observed variation in mortality from egg to age I of largemouth bass in Lake Carl Blackwell. Model II is similar to Model I except that the effect of reservoir water level and water level fluctuation on survival of the young-of-the-year is included. Predictions of number of age I recruits from Model II agree closely with population estimates for Lake Carl Blackwell.

Comment

This paper presents a management model for lake bass which combines a Leslie matrix and statistical techniques to assess survivorship and age structure. While the model is not directly applicable to Maryland species, it may be adaptable to freshwater situations for bass.

Orth, D.J. 1979. Computer simulation model of the population dynamics of largemouth bass in Lake Carl Blackwell, Oklahoma. <u>Trans. Am. Fish. Soc.</u> 108:229-240.

Applicable

<u>Abstract</u>

The computer simulation model described predicts year-class strength, production, and yield of largemouth bass (*Micropterus salmoides*) populations. It is an age-structured, deterministic model with numbers, average weights and lengths, biomass, yield in weight and numbers, and gross and net production as state vectors. Mortality from egg to age I is estimated by a multiple regression equation; water level during spawning and water level fluctuation since the end of the previous growing season are predictor variables. Predictions of year-class strength, production and yield compare favorably with estimates made in previous studies on Lake Carl Blackwell. Sensitivity analysis indicates that predictions of production, yield, and catch (numbers) are most sensitive to variation in rate of mortality from egg to age I. Growth rates of the younger age-groups are next in importance in predicting production, yield and catch. The model may be useful for predicting year-class strength, population trends, and the response of largemouth bass populations to minimum length limits, water level fluctuations or manipulations, and supplemental stockings.

<u>Comment</u>

The paper presents the application of the Leslie matrix to yield estimation. The method may be appropriate for use in this project depending on the available data base.

Palm, W.J. 1975. Fishery regulation via optimal control theory. <u>Fish. Bull.</u> 73:830-837. Applicable

<u>Abstract</u>

This paper attempts to show how control theory can be used to formulate a regulatory scheme for fisheries. The regulatory mechanism considered is a limit imposed on fishing effort. It is shown that static optimization methods, such as maximum equilibrium yield analysis, need to be supplemented with dynamic methods, such as optimal control theory, which take into account the variable nature of a fishery. The dynamic analysis is used to show that the size of a limit on effort should be a feedback function of the variables in the state of the fishery. The concept of the Linear-Quadratic Optimal Control Problem is introduced as a method for devising such a feedback scheme for fishery regulations.

A single-variable logistic model is used to introduce the basic concepts. A model with three variables is then analyzed to show how the techniques are easily extended to the general multivariable case. Details of the general method are given in an Appendix.

<u>Comment</u>

This is an excellent paper which explains the practical uses of optimal control theory for the determination of optimal regulatory actions in fisheries management.

Paloheineo, J.E. 1961. Studies on estimation of mortalities. 1. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Bd. Canada 18:645-662.

Abstract

Comment

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Parks, W.W. 1975. A Pacific salmon fisheries model for the study of gear regulation: An application to the Washington troll fishery. Univ. Wash. Sea Grant, Seattle, Wash., Norfish Tech. Rep. 58. 165 pp.

<u>Abstract</u>

<u>Comment</u>

This paper is unavailable for review but has been requested through interlibrary loans. It will be reviewed when received.

Parrish, J.D. 1975. Marine trophic interactions by dynamic simulation of fish species. Fish. Bull. 73:695-715. Applicable

Abstract

A mathematical model was developed for performing dynamic simulations of groups of interacting animal species. The energy balance of the individual animal was modeled so that growth and reproduction respond to food consumption after metabolic expenses are met. Populations change in response to recruitment (based on parental spawning) and mortality from natural causes, predation, starvation and (where applicable) human exploitation. The forms of the various component mathematical functions were derived from the available ecological sources. Functions and parameters are especially applicable to marine fish species. Trophic webs of any size or form can be constructed using this basic species model. Computer solution of the essentially continuous differential model gives a time history of trophic and population variables for all species in the web.

Models of trophic webs of 2, 3 and 4 levels were constructed and exercised. These were used to examine effects of age class structure, reproductive time lag, and population regulation by starvation mortality and fecundity control. Competition between species and the effects of a top predator on competitors, with and without human exploitation, were studied.

Comment

The paper presents a good analysis of trophic relationships in fish food webs. Fishing and harvesting are only tangentially treated. A very large data set is necessary, which may make its application in this project doubtful.

Patariarche, M.H. 1977. Biological basis for management of lake whitefish in the Michigan waters of northern Michigan. Trans. Am. Fish. Soc. 106:295-308.

Applicable

Abstract

Stocks of lake whitefish (*Coregonus clupeaformis*) have supported an intensive commercial fishery in the Michigan waters of Lake Michigan for over a century. However, certain biological indicators suggested that recent upsurges in the catch reflect overfishing, and fish managers should institute measures to assure a stabilized population and fishery. A biological basis for establishing quotas is described in this paper, using information from 1968-73 commercial fisheries in statistical districts MM-1 and MM-3 and a modification of Ricker's dynamic pool model. Natural mortality rates computed for an unfished population of whitefish in the lower end of nearby Grand Taverse Bay were important components of the model.

Quota possibilities were based on the premise that the annual harvest should be confined to weight gained each year by the harvestable portion of the population. Six computations of equilibrium yields were made. A comparison of actual harvests and adjusted yields revealed an average annual overharvest of 28% during the period 1968-72 in the two statistical districts.

Total biomass for six age groups (I-VI) in three Michigan statistical districts of northern Lake Michigan was computed to be 6,600 tonnes in 1972. Approximately 2,695 tonnes (60%) of the total biomass in MM-1 and MM-3 were susceptible to exploitation. Adjusted 1972 yields based on both biomass calculations and the modified dynamic pool model differed by only 0.3%. A change in the minimum total length limit (from 432 to 482 mm) to build up a depleted stock also was discussed. Increased spawning stock, more spawning opportunities, and greater egg deposition should result from this regulation change.

Comment

The paper presents a possible method for determining equilibrium yield. However, calculations are based on numerous assumptions concerning growth and MSY, which might complicate its application.

Patten, B.C. 1969. Ecological systems analysis and fisheries science. Trans. Am. Fish. Soc. 98: 570-581.

Non-applicable

Abstract

Fish population dynamics cannot be separated operationally from ecosystem dynamics. Modeling and computer simulation are needed to adapt this truism for use in fisheries management. To exemplify the relevance of ecosystems to problems in fish production, a model food web is explored in detail. Dynamic characteristics are described, and sensitivity analysis is used to quantify direct and indirect interactions between components, two of which are groups of fish populations. Application to optimal control of a fishery is then considered.

Comment

This paper presents marine ecosystem models which are generally inapplicable to management situations. The presentation is primarily a theoretical discussion of holistic mechanisms in systems analysis and the roles of linear and non-linear systems procedures in ecosystem analysis.

Patten, B.C. 1975. A reservoir cove ecosystem model. Trans. Am. Fish. Soc. 104:596-619. Non-applicable

Abstract

A total ecosystem compartment model of a reservoir cove is described, with emphasis on the fish submodel. Nominal (unperturbed) annual cycles of selected compartments are presented, and results from three perturbation experiments (thermal pollution, eutrophication, piscivore invasion) are summarized. The ability of fishes to influence structure and function of the entire ecosystem (model) is demonstrated, and the role of top trophic levels in controlling the design of ecological communities is discussed. The status and prospects of total ecosystem modeling as a tool for fisheries science are considered.

Comment

The paper presents a good approach to ecosystem modeling, assuming the validity of donor-controlled flow. Cursory treatment of harvesting and lack of feedback make this model useless for this project.

Paulik, G.J., and W.H. Bayliff. 1967. A generalized computer program for the Ricker model of equilibrium yield per recruitment. <u>J. Fish. Res. Bd. Canada</u> 24:249-259. Applicable

<u>Abstract</u>

The Ricker method for predicting the yield per recruitment from a stock of fish under various conditions is superior to that of Beverton and Holt (1957) under most conditions because it permits greater flexibility of the input of growth and mortality data. Such useful devices as the isopleth diagram and the eumatic fishing curve, usually associated with the Beverton and Holt method, can be used also with the Ricker method. A computer program for the Ricker method is described, and its use is demonstrated with an example.

<u>Comment</u>

This paper represents an excellent overview of the Ricker yield-per-recruit model and will be useful in this project.

Pella, J.J., and P.K. Tomlinson. 1969. A generalized stock production model. Inter. Am. Trop. Tuna Comm. Bull. 13:419-496.

Applicable

Abstract

The problem investigated in this paper is the determination of the sustainable yield from fish stocks which can be anticipated under different effort information. The yield predictions from the model we discussed should be reasonably accurate provided the harvesting techniques are the same as those used to generate the data base from which the parameter estimates are made. A change in size selection by the fishery or in the time of the year when fishing occurs (e.g., compression of fishing seasons due to catch restrictions) could modify the stock production curve. Still in these cases the analysis of catch and effort information on the basis of the generalized production model should provide a bench mark from which refinements in yield estimates can be made on the basis of more detailed studies of the dynamics of the stock.

Comment

This paper presents a generalization of the Schaefer logistic surplus production model. This form represents the best application of the surplus production-type model (incorporating later alterations in form), but requires the estimation of five parameters instead of three. It will prove useful in this project.

Peterman, R.M. 1975. New techniques for policy evaluation in ecological systems: Methodology for a case study of Pacific salmon fisheries. J. Fish Res. Bd. Canada 32:2179-2188. Non-applicable

Abstract

The complexity of exploited ecological systems creates difficulties for the manager who must decide among alternative policy options. Some methods for overcoming these difficulties are presented, using examples from the salmon fishery of the Skeena River system in British Columbia. The described methods produced a "desk-top optimizer," a tool that permits decision-makers to perform fairly sophisticated "optimization" operations at their desks instead of having to rely on decision theorists or operations researchers. Also discussed are various system indices which should become part of the information used by managers. These indices include measures of resilience (ability to absorb the effects of unexpected events), costs of failures in management policies, and cost of uncertainty of various types.

Comments

The method presented for optimization of regulatory mechanisms represents a simple approach that can be used after population models are completed. However, the es technique is not as good as dynamic programming. It is explored further in a follow-up paper.

Peterman, R.M. 1977. Graphical evaluation of environmental management options: Examples from a forest-insect pest system. Ecol. Modelling 3:133-148. Applicable

Abstract

A graphical technique is demonstrated which, when combined with any resource simulation model, permits the resource manager to explore the effects of different management options. Also, this technique (nomogram or response surface) permits derivation of "optimal solutions" given particular objectives. Examples of the methodology are given for the spruce budworm -- forest system in eastern Canada. Effects of several kinds of uncertainties are discussed, including uncertainties in model assumptions, management precision, future objectives and system evolution. The graphical nature of nomograms helps managers and analysts to grasp more easily the complicated behavior of ecological systems models. Finally, the role of computer models in decision-making is discussed.

Comments

This paper presents a good and possibly useful optimization method which requires little computer work. It may be worth evaluating for future use.

Plourde, C.G. 1970. A simple model of replenishable natural resource exploitation. <u>Amer. Econ. Rev.</u> 60:518-522. — Applicable

<u>Abstract</u>

A simple economic model is proposed to determine optimal steady-state population levels and consumption levels of replenishable natural resources. The model is biological, based on the logistic growth equation, and incorporates a welfare utility function which depicts the economic dynamics of the exploitation of the resource. Optimal control theory is then applied to the resulting steady state to determine optimal usage levels.

<u>Comments</u>

The methods presented here are possibly applicable to the project as a simplified method of integrating biology and economics. Simplifying assumptions may limit its applicability.

Pope, J.G. 1971. An investigation of the accuracy of virtual population analysis. Inter. Comm. Northwest Atl. Fish. Res. Doc. 71/116 Ser. No. 2606:1-11.

Abstract

Comments

This paper is unavailable for review, but has been requested through interlibrary loans. It will be reviewed when received.

Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Inter. Comm. Northwest Atl. Fish. Bull. 9:65-74. **Applicable**

Abstract

Cohort analysis is a simplified, approximate form of Gulland's virtual population analysis. As such it may be used to obtain estimates of the instantaneous rate of fishing mortality and the population surviving for each age of a year class, given the catch-at-age data, and an estimate of the instantaneous rate of natural mortality and an estimate of the fishing mortality at the final age of exploitation. More importantly, the simplicity of cohort analysis makes it possible to investigate the errors generated in such estimates by the arbitrary choice of the rate of fishing mortality on the last age exploited and by the sampling errors of the catch-at-age data.

Comment

This paper presents an excellent explanation of the use of virtual population analysis and cohort analysis. It will be useful in this project.

Powers, J.E., R.T. Lackey, and J.R. Zuboy. 1975. Decision-making in recreational fisheries management. Trans. Am. Fish. Soc. 104:630-634.

Non-applicable

Abstract

A conceptual model of the decision-making process in fisheries management is presented in conjunction with applications of computer and systems analysis to this process. One of the most difficult problems to solve is selecting objectives to be used for management evaluation. An objective function based on some or all of the components of yield, species, size desirability, and environmental quality is needed. Systems analysis and computer technology in data processing and simulation may be used in many situations to evaluate decision alternatives as an aid in developing management strategies.

Comments

This paper is not useful to this project since it does not describe an analytical model. A method for analysis of the decision process may be helpful at a later date.

Rafail, S.Z. 1977. A simplification for the study of fish populations by capture data. Fish. Bull. 75:561-569.

Applicable for parameter estimation

Abstract

Expressions given by Rafail for estimating catchability are modified here to eliminate iteration, for better accuracy, and a large economy in calculations and time. The evaluation of catchability allows the estimation of other important parameters with the useful assumption of their variabilities according to seasons and recognized sections of a population.

Comments

The paper presents a method which appears useful for parameter estimation.

Regier, H.A., and H.F. Henderson. 1973. Towards a broad ecological model of fish communities and fisheries. Trans. Am. Fish. Soc. 102:56-72.

Applicable

Abstract

The paper brings together major inferences from: (1) classical limnology--lake and stream typology, the role of major abiotic variables; (2) fisheries limnology--Ryder's morphoedaphic index, Jenkins' reservoir findings, concepts of habitat niches; (3) studies of ecological structure of communities--succession, diversity, stability, variability, regulation; (4) recent developments concerning the effects of major cultural stresses on fish communities. A model is proposed to interrelate these and other concepts, and then relate them all to conventional fisheries practices and objectives. The model is directed at events and processes at the community level of organization and it is argued that much of fisheries theory and management practices of the future will perforce need to be directed at the community level.

Comment

This model should be further reviewed as an example of an ecosystem yield application, although its usefulness for this project is doubtful.

Ricker, W.E. 1945. A method of estimating minimum size limits for obtaining maximum yield. Copeia 1945:84-94.

Applicable for parameter estimation

Abstract

1. The "critical size" for a year-class of fish is defined as the size at which the average instantaneous rate of natural mortality begins to exceed the average instantaneous rate of increase in weight.

2. Assuming that what is true of the year-class as a whole is also true, on the average, of the fish individually, the critical size can be used as a basis for estimating the best minimum size at which fish should be taken, in order to achieve maximum production at the existing rate of fishing.

3. The best minimum size varies with the rate of fishing, being zero when the latter is very small, and approaching the critical size when fishing is very intensive.

4. Possible secondary effects of a change in fishing intensity, on the rate of growth of the fish, make it unwise to extrapolate too far from existing conditions: i.e., the critical size may change. However such extrapolation is a useful guide to the minimum size which will probably be desirable, following a moderate change in rate of fishing.

Comment

This paper may be useful in determining growth and mortality coefficients.

Ricker, W.E. 1958. Maximum sustained yields from fluctuating environments and mixed stocks. J. Fish. Res. Bd. Canada 15:991-1006.

Non-applicable

Abstract

Using numerical models, effects of environmental variability upon yield were tested for six single-age fish stocks characterized by different kinds and degrees of density-dependent reproduction potential. The two levels of variability examined had extremes of yield standing in the ratios 7:1 and 18:1, respectively. Close regulation of fishing to the optimum percentage for each year's stock improves the long-term average catch taken, the improvement being the greater, the more variable the environment. With the higher level of variability, improvement in average catch among five of the stocks ranged from 26% to 79% increase. However this increase in mean catch is achieved at the expense of increased variability in catch from year to year -- in fact, for some kinds of stock there must be complete cessation of fishing in some years in order to get the long-term maximum. The yield of stocks, in which reproduction per spawner declines at low levels of abundance, is particularly improved by a close adaptation of fishing effort to the supply of fish available.

When two or more populations of a species, characterized by different reproduction potentials, are fished in common, total potential catch is less than when each can be fished separately at its optimum level. If a common fishery cannot be avoided, the achievement of maximum average yield may find one of two originally-equal stocks as abundant or even more abundant than before the fishery began, while the other may persist only at a low level or even be exterminated completely.

Comment

This paper reports no useful new information concerning the Ricker yield-per-recruit model and will not be useful for this project. It does present a good comparison of Ricker and Beverton-Holt stock-recruitment relationships.

Ricker, W.E. 1973. Two mechanisms that make it impossible to maintain peak-period yields from stocks of Pacific salmon and other fishes. J. Fish. Res. Bd. Canada 30:1275-1286.

Applicable

Abstract

"Mechanism 1" has two aspects: catches taken at a given rate of exploitation are greater when rate of exploitation has been increasing than when it has been steady or decreasing; also, the yield taken from the progeny of a spawning of a given size is greater when rate of exploitation has been increasing than when it has been steady or decreasing. "Mechanism 2" is the fact that mixtures of stocks of unequal productivity, when harvested together, produce smaller recruitments than single stocks of the same original size and having the same optimum rate of exploitation. In addition, any fishery for a valuable species is likely to develop beyond the optimum rate of exploitation because there is no easily detectable symptom that the optimum is being passed. When this has happened, maximum sustainable yield (MSY) will not be achieved immediately if the optimum rate is imposed subsequent to a period of overexploitation; rather there will be a gradual approach to MSY that extends over several generations after the optimum rate is established. Both of the two mechanisms above, plus the likelihood of unrecognized overfishing, make for a catch maximum while fishing is still on the increase. For salmon this maximum is likely to be 30-60% greater than the sustainable yield. In addition, unavoidable difficulties of management make for even greater differences between the historical maximum and the mean equilibrium yield that can be achieved in practice. Good annual prediction of recruitment can improve this picture because rate of exploitation can then be adjusted to the quantity of fish available; however this procedure too is much less effective when mixtures of stocks are fished in common, because in general the recruitments to different stocks do not vary in exactly the same way. The phenomena described may also contribute to an historical early maximum of catch in fisheries for species such as cod, being independent of and additional to the maximum caused by "removal of accumulated stock."

Comments

The paper presents a useful methodology for comparing single stock and multiple stock applications of Ricker yield/recruit models. It discusses the reasons for optimal yield being below maximal yield in the context of population biology.

Riffenburgh, R.H. 1969. A stochastic model of inter-population dynamics in marine ecology. J. Fish. Res. Bd. Canada 26:2843-2880. Applicable

Abstract

A nonstationary Markov chain was developed to analyze and model the passage of energy through an ecological system composed of the Pacific sardine, the northern anchovy, their competitors, their predators, and their prey; then to carry the model forward through time projecting the biomasses of the relevant species if anchovy or hake fisheries, or both, have begun. The model seemed to agree adequately with observed data.

The hypothesis of some earlier work of the author that the abundances of populations could be completely controlled by fishing intensities was rejected. Although no measure was made of the robustness of the ecosystem, it was concluded to be relatively impervious to artificial pressures, although there was seen a measurable boundary beyond which the ecological interactions became unstable and the system collapsed.

Specifically, based on 1950-59 data, the sardine catch was projected to stabilize in the vicinity of 20 metric kilotons per year. Overfishing did not seem to have been a cause of the sardine "disappearance." To maximize sardine catch, the introduction of anchovy and hake fisheries with annual catches limited to certain percentages (depending on the maximizing criterion) of abundances would double or triple sardine catch and stabilize the fishing industry, but sardines could not be reinstated as the most abundant species as a result of selective fishing. To maximize the combined catch of the three fisheries, annual catches of 30% and 20% (for all criteria) of abundances of anchovy and hake, respectively, would yield nearly 1800 metric kilotons of fish, although most of it would be of less commercial interest than the sardine.

Comment

While this paper presents a very complex model of three interacting species, the application of the model requires a large numer of parameter values. This modeling approach (multiple population simulation model) may be applicable for interacting and/or competitive stocks (e.g., menhaden and bay anchovies) in Maryland, but the data base required for its utilization may be prohibitive.

Robson, D.S., and D.G. Chapman. 1961. Catch curves and mortality rates. Trans. Amer. Fish. Soc. 90:181-189.

Abstract

Comments

This paper is unavailable for review, but has been requested through interlibrary loans. It will be reviewed when received.

Rothschild, B.J., and J.W. Balsiger. 1971. A linear programming solution to salmon management. U.S. Fish. Wild. Serv. Fish. Bull. 69:117-139.

Non-applicable

Abstract

A linear-programming model was constructed to allocate the catch of salmon among the days of the salmon run. The objective of the model was to derive a management schedule for catching the salmon which would result in maximizing the value of the landings given certain constraints. These constraints ensured that cannery capacity was not exceeded, and that escapement of both male and female fish was "adequate." In addition to considering the allocation of the catch in the primal problem, the dual problem considered the shadow prices or marginal value of the various sizes of fish, eggs, and cannery capacity, thus enabling the manager to view his decisions in light of the marginal values of these entities. As an example, the model was applied to a run of sockeye salmon in the Bristol Bay system. In the particular example, which was chosen to replicate the 1960 run, the additional value of the catch owing to optimality amounted to an ex-vessel value of a few hundred thousand dollars. In addition it appeared that the required processing time could be reduced by several days. The optimum allocation was obtained through conformance to the linear-programming model. The cost of this conformance was not, however, determined.

Comment

This paper presents a linear programming optimization procedure for bioeconomic variables in a salmon management model. This procedure tests various management schemes allowing the determination of an optimal plan to maximize dock value of salmon. The approach is inappropriate to the project at this stage.

Rudd, W.G. 1975. Population modeling for pest management studies. Math. Biosci. 26:283-302. Applicable

Abstract

Modeling for crop insect pest management studies requires detailed attention to age- and stage-specific effects. Compartmental models with time delays produced by impulse response functions and proper attention to age density distribution functions provide for the needed generality and precision. Data required for such models include emergence and mortality functions, initial populations, and initial age density distribution functions.

Comment

This paper represents a good discussion of the use of discrete and continuous time lag in the population dynamics descriptions of a pest species. It may be applicable to harvested species as well.

Ryder, R.A., and H.F. Henderson. 1975. Estimate of potential fish yield for the Nasser Reservoir, Arab Republic of Egypt. J. Fish. Res. Bd. Canada 32:2137-2151.

Non-applicable

Abstract

Available biological and hydrographic information on Lake Nasser was examined to provide guidelines for future development of the fisheries. Not enough consistent data were available to allow precise estimates of fishing-stock interrelations; however, an approximation of potential yield was derived from subjective evaluation of limnological characteristics of the lake. Morphoedaphic factors were utilized to establish a numerical expectation of yield in relation to other tropical lakes and reservoirs. Two other models based on estimated zooplankton biomass and an assumed net gain in productivity in Lake Nasser at the expense of a yield loss to the Mediterranean fishery provided order-of-magnitude agreement. Potential yield estimates for Lake Nasser (including its southern portion, Lake Nubia, Sudan) were 23,000 metric tons (MT) of fish annually, providing the reservoir fills to its expected maximum (180m), or 12,000 MT if it remains at its 1973 level of about 160m. These estimates are considered sufficiently reliable to guide future development of the fishery.

There is little evidence to support the existence of stock overexploitation. *Tilapia nilotica*, however, the major species entering the fishery, has been subjected to potentially damaging fishing practices on its breeding grounds. These practices combined with water level drawdown, inadvertently timed to perturb *Tilapia* fry inhabiting the shallow nursery areas, may unduly stress a prime species largely responsible for the current success of the fishery.

Management recommendations for the Nasser-Nubia Reservoir include a regular program of monitoring both stocks and harvest, especially for *Tilapia*. Development emphasis should be placed on improving the logistics of the fishery rather than increasing the number of fishermen, at least until the lake area expands substantially.

Comment

The material presented here adds little to morphoedaphic index applications described in other papers which have been reviewed. It is also based on poor estimates of seasonal or annual trends in edaphic variables.

Saila, S.B., and K.W. Hess. 1975. Some applications of optimal control theory to fisheries management. Trans. Am. Fish. Soc. 104:620-629. Applicable

Abstract

A review is made of some optimization techniques applied to fisheries and related problems. Explanations of optimal control theory as applied to the Schaefer or logistic model and to the Beverton and Holt model are provided. An optimal policy for a fishery management model based on the Brody growth function is developed. The control variable in each of the above examples is the rate of fishing and the objective function is the maximum biomass yield. A method for estimating the parameters of the Brody growth function is illustrated for the albacore tuna.

Comment

This paper presents a good discussion of optimization techniques and their application to two major yield models. The methods may be useful if optimization techniques are employed after yield models are developed for Maryland stocks.

Schaaf, W.E., and G.R. Huntsman. 1972. Effects of fishing on the Atlantic menhaden stock: 1955-1969. Trans. Am. Fish. Soc. 101:290-297.

Applicable for parameter estimation

Abstract

To determine the effect of purse-seine fishing on the Atlantic menhaden (*Brevoortia tyrannus*) population, we analyzed data from 1955-69 on fishing activity and catches. Changes in fishing efficiency necessitated establishment of an abstract effort unit, the 1965 vessel-week. Catch per unit of effective effort in 1965 was one-fifth that of 1955. Our instantaneous natural mortality rate (M) estimate was 0.37. At the current recruitment age, 1.5 years, reducing F, instantaneous fishing mortality, to about 0.8 would slightly decrease the yield per recruit, but would increase the spawning stock and ultimately allow annual catches of 400,000-500,000 metric tons, the maximum sustained yield.

Comment

This methodology may be applicable to menhaden stocks, particularly in conjunction with other menhaden models concerning the effects of environmental variability on yield and recruitment. This paper also describes a method for the normalization of total effort when the fishery undergoes large changes due to technological advances.

Schaefer, M.B. 1954. Some aspects of the dynamics of population important to the management of the commercial marine fisheries. Inter.-Am. Trop. Tuna Comm. Bull. 1:25-56. Applicable

Abstract

A population of oceanic fish under exploitation by a fishery may be influenced by a great number of elements in the complex ecological system of which it forms a part. Of these, however, only one, predation by man, is capable of being controlled or modified to any significant degree by man's actions. Any management or control of the fishery, to the extent this may be possible at all, must, therefore, be effected through control of the activities of the fishermen. It seems important to elucidate some of the basic principles of the effect of fishing on a fish population and, conversely, the effect of the fish population on the amount of fishing, in order to understand in what circumstances and in what manner such control of the activities of the fishermen can influence the fish population and the yield obtained therefrom.

Comment

This paper presents the logistic surplus production model. Although severely limited by assumptions concerning stock dynamics, it is a very useful model, particularly in early management phases, because of its limited data requirements.

Schaefer, M.B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the Eastern Tropical Pacific Ocean. Inter.-Am. Trop. Tuna Comm. Bull. 2:245-285.

Applicable

Abstract

The mathematical model employed is essentially the same as that discussed by Schaefer (1954), with some modifications in notation. The theory is, however, also extended in application to provide estimates of all the essential constants from the catch data alone, without recourse to tagging data for estimating fishing mortality which was required in the earlier paper.

Comment

This paper provides little additional information concerning the Schaefer surplus production formulation. Its major advance is the determination of a method of calculating catchability (q) without utilizing additional data (e.g., tagging studies). This paper will be useful if surplus production models are applied in this project.

Schaefer, M.B. 1968. Methods of estimating effects of fishing on fish populations. Trans. Am. Fish. Soc. 97:231-241. Applicable

Abstract

The yield from an exploited fish population depends on the rate of harvesting (fishing mortality rate) and the magnitude of the standing stock. The latter is determined by rates of increase from recruitment and growth and rates of loss from both natural and fishing mortality. Since we lack information respecting the density-dependence of each of these rates, various simplifying assumptions are made in practice in developing mathematical models of exploited fish populations. Such models are described, with illustrations of their application to important commercial fisheries. Models of fisheries involving competing fish species, and the employment of computer simulation in studies of fishery-dynamics are also discussed.

Comment

This paper presents excellent reviews and comparisons of "dynamic pool" and "logistic" models. While it is not directly applicable to the project in the sense of providing a new yield model, it describes the relative merits, assumptions, and similarities of the two approaches.

Schnute, J. 1977. Improved estimates from the Schaefer production model: Theoretical considerations. J. Fish. Res. Bd. Canada 34:583-603. Applicable

Abstract

The Schaefer production model is converted to a form directly applicable to a data stream of annual fishing efforts and catches. The new version is also stochastic; that is, it allows for unpredictable influences on the fishery. A new method for estimating optimum effort and catch results from this analysis, as well as a way of measuring uncertainty in these estimates. Equations are given for predicting the next annual catch and assigning confidence limits to this prediction. Linear and non-linear regressions are proposed for this analysis, and the relationship between them is rigorously demonstrated. The linear method leads to estimation formulas simple enough to be applied on a programmable pocket calculator.

Comment

The paper presents a modified means of fitting a Schaefer model to existing effort and yield data, which provides better estimates of the variability associated with maximum sustainable yield. It may be useful in this study.

Sheldon, R.W., W.H. Sutcliffe, Jr., and M.A. Paranjape. 1977. Structure of pelagic food chain and relationship between plankton and fish production. J. Fish. Res. Bd. Canada 34:2344-2353.

Non-applicable

Abstract

Further observations on the standing stocks of pelagic organisms confirm the occurrence of approximately equal biomass over logarithmically equal size ranges. A simple theoretical framework is developed that shows that the structural elements of the pelagic ecosystem can be described in terms of the sizes of predator and prey and of the efficiencies of their interactions. In practice this means that if the standing stock at any size range is known, the production can be estimated. The theory is tested on three fisheries. For the Gulf of Maine and the North Sea, phytoplankton production is estimated from fishery production. For the area off Peru the fishery production is estimated from the plankton production.

Comment

The paper applies several theoretical models to pelagic fish communities. The applications do not deal specifically with the development of management of these fisheries, and do not appear to be particularly relevant to this study.

Shuter, B.J., and J.F. Koonce. 1977. A dynamic model of the Western Lake Erie walleye (Stizostedion vitreum vitreum) population. J. Fish. Res. Bd. Canada 34:1972-1982.

Non-applicable

Abstract

A simple population model of western Lake Erie walleye was constructed using empirical relationships linking growth to population density and recruitment to breeding stock size and the spring water temperature regime. Given a reasonable set of total survival for the period from 1947 to 1975, the model generated a pattern of behaviour similar, both qualitatively and quantitatively, to that exhibited by the real population. Two types of stochastic models, based on the initial population model, were used to derive optimal harvest strategies for the population. Optimal strategies were not sensitive to variations in catchability and natural mortality. Yields produced were highly sensitive to variations in both these factors. A refined and extended version of the model may serve as a useful tool in developing realistic management policies for this population.

Comment

The paper applies pre-existing yield models to a specific fishery based on a large amount of empirical data. It has little applicability to this study because the species modeled is not harvested in significant numbers in Maryland.

Silliman, R.P. 1969. Analog computer simulation and catch forecasting in commercially fished populations. Trans. Am. Fish. Soc. 98:560-569.

Applicable

Abstract

An analog computer was programmed and used to derive data on population dynamics of fish and whales. The types of mathematical models that were applied and the results of the studies, several of which have been published, are briefly reviewed.

Applications included two types of mathematical models--models of populations for studying and forecasting yields and models of competing populations. The yield models combined fishing and natural mortality rates with a Gompertz growth curve in a differential equation. When integrated by the computer, this equation produced survival curves for successive year classes, whose annual values were summed graphically. Recruitment was determined from a stock-recruitment curve. Yields for each season were calculated from stock weight by using known rate of exploitation and were compared with actual yields to test the validity of the models.

The technique has been demonstrated for Pacific sardine (Sardinops sagax), haddock (Melanogrammus aeglefinus), Atlantic cod (Gadus morhua), lake trout (Salvelinus namaycush), skipjack tuna (Euthynnus pelamis), bigeye tuna (Thunnus obesus), blue whale (Balaenoptera musculus), and fin whale (Balaenoptera physalus). Forecasts of sustainable catch have been made for the two species of tuna and for the fin whale.

The models of two competing populations use Volterra equations to generate biomass of one population as a function of biomass of the other. They have been applied to data of Pacific sardine -- northern anchovy (Engraulis mordax) and yellowfin tuna (Thunnus albacares) -- skipjack tuna.

Comment

The paper presents the application of a simple analog model to several marine species. While giving generally good results, it is unclear how yield is determined in the model. Also, its omission of environmental information makes a determination of its applicability to Maryland fisheries difficult. In light of its catch forecasting success, perhaps this type of simple yield-recruitment approach should be investigated further.

Shuter, B.J., and J.F. Koonce. 1977. A dynamic model of the Western Lake Erie walleye (Stizostedion vitreum vitreum) population. J. Fish. Res. Bd. Canada 34:1972-1982. Non-applicable

Abstract

A simple population model of western Lake Erie walleye was constructed using empirical relationships linking growth to population density and recruitment to breeding stock size and the spring water temperature regime. Given a reasonable set of total survival for the period from 1947 to 1975, the model generated a pattern of behaviour similar, both qualitatively and quantitatively, to that exhibited by the real population. Two types of stochastic models, based on the initial population model, were used to derive optimal harvest strategies for the population. Optimal strategies were not sensitive to variations in catchability and natural mortality. Yields produced were highly sensitive to variations in both these factors. A refined and extended version of the model may serve as a useful tool in developing realistic management policies for this population.

Comment

The paper applies pre-existing yield models to a specific fishery based on a large amount of empirical data. It has little applicability to this study because the species modeled is not harvested in significant numbers in Maryland.

Silvert, W. 1977. The economics of over-fishing. Trans. Am. Fish. Soc. 106:121-130. Applicable

Abstract

I analyze the problem of determining the optimal economic strategy for exploitation of a fish population when the stock has been driven to a low level and is threatened with extinction if over-exploitation continues. Two very simple models are investigated in detail and only very simple optimization techniques are used. Whether the optimal strategy, namely that which maximizes present value, is one that leads to conservation or extinction depends on economic factors which are partially determined by public policy, such as tax structure. In some economic situations the optimal strategy will always lead to extinction, and in these cases a policy of conservation requires direct government intervention through quotas and other restrictions; in other cases the choice between conservation and extinction can be affected by purely economic policies. I hope that this type of analysis will make it possible for societies to identify the most efficient methods of encouraging conservation while minimizing economic dislocation and direct governmental control.

Comment

The material here may have applicability to stocks which are over-exploited, if any such populations occur in Maryland. It also presents a good discussion of the economics of fisheries.

Silvert, W. 1978. The price of knowledge: Fisheries management as a research tool. J. Fish. Res. Bd. Canada 35:208-212.

Non-applicable

Abstract

One of the side effects of fisheries management is the discovery of new scientific information. Since this information has economic value, in that it can be used to improve future management of the fishery, the information that can be gained through a particular management strategy should not be ignored in evaluating that strategy. This paper shows, using a simple model, how the research component of fisheries management can be measured and used to plan an optimal strategy. The management objectives are taken to include avoidance of risk and maximization of yield. The results depend critically on the time horizon for management. Long-term management favors creative risk-taking and leads to optimal future exploitation, while management based on short-term considerations may freeze the fishery in a permanent pattern of suboptimal yields.

Comment

The arguments presented in this paper apply only to situations where the species of concern is already being managed according to some yield functions. It appears premature for this study.

Sinko, J.W., and W. Streifer. 1967. A new model for age-size structure of a population. Ecology 48:910-918.

Non-applicable

Abstract

An equation describing the dynamics of single species populations is derived. The model allows for variations in the physiological characteristics of animals of different ages and sizes. An analytical solution which holds under certain specific conditions is found. It is shown that Von Foerster's equation, the logistic equation and other prior models are special cases of the new model.

Comment

The discussion presented here is theoretical in nature. The complexity of the required inputs make it inapplicable for this study.

Sissenwine, M.P. 1974. Variability in recruitment and equilibrium catch of the Southern New England yellowtail flounder fishery. J. Cons. Int. Explor. Mer. 36:15-26. — Non-applicable

Abstract

The significance of biotic and abiotic regulation of the Southern New England yellowtail flounder fishery was investigated. Analysis of the published data provided no evidence of biotic regulation of the fishery. This analysis included the estimation of the annual equilibrium catch and recruitment to the fishery during the period 1944-1965.

The multiple correlation coefficients of regressions fitted between the natural log of the annual equilibrium catch and recruitment of the fishery with three- and four-year moving averages of atmospheric temperature at Block Island, Rhode Island (U.S.A.) ranged from 0·862 to 0·927. According to these regressions, the decline of the fishery during the late 1940s resulted from the adverse effect of a general warming trend in the region.

Comment

This paper adds no new information to the yellowtail simulation study done by the same author; thus it will not be included in this study.

Sissenwine, M.P. 1977. A compartmentalized simulation model of the Southern New England yellowtail flounder, *Limanda ferruginea*, fishery. *Fish. Bull.* 75:465-482. — Applicable

Abstract

A compartmentalized simulation of the Southern New England yellowtail flounder, *Limanda ferruginea*, fishery was developed. The population was divided into 10 age-groups, each of which was subdivided in 7 size categories. The model simulated discard mortality as well as natural mortality and fishing mortality. Fishing and discard mortality rates depended on the level of fishing and on gear and market selection factors. Both linear and density independent stock-recruitment functions were considered. Seasonal variations in growth and exploitation were incorporated into the model. The influence of fluctuation in temperature on recruitment and growth was also simulated. The model using a linear stock-recruitment function accounted for 85.5% of the variability in the yield of the fishery for 1943-65; with a density-independent stock-recruitment function. the model explained 83.2% of the variability in yield for the same period.

The linear stock-recruitment model was used to investigate the response of the fishery to alternative fishing strategies. Substantial increases in the past yield of the fishery were indicated by the model when fishing effort was concentrated during the second half of the year and when fishing effort and discard mortality were reduced.

Comment

This paper presents a very detailed and complex simulation model of an exploited fish stock. It may be of value in this study as an example of a single population simulation model.

Sissenwine, M.P., and A.M. Tibbetts. 1977. Simulating the effect of fishing on squid (Loligo and Illex) populations of the northeastern United States. Int. Comm. Northwest Atl. Fish. Sel. Pap. 2:71-84.

Applicable

Abstract

Models designed to simulate the effect of fishing on squid (Loligo and Illex) were developed. The instantaneous growth, fishing and natural mortality rates were varied on a monthly basis. Spawning was simulated over an extended period. Recruitment was described by the Beverton and Holt (1957) stock-recruitment function.

Based on these models, the exploitation rate (over the lifespan of the species, E_{MSY}) that will result in the maximum sustainable yield is 0.75 and 0.63 for Loligo and Illex respectively, if recruitment is independent of spawning stock size. If recruitment is moderately dependent on spawning stock size, the E_{MSY} is probably about 0.40 and 0.37 for Loligo and Illex, respectively. E_{MSY} is further reduced to about 0.15 for both species for a population with a stronger stock-recruitment relationship.

Comment

This paper represents one of the few applications of Beverton-Holt stock-recruitment relationships. While its predictive power is in doubt, it should be analyzed further and may be helpful in this project.

Sissenwine, M.P., B.E. Brown, and J. Brennan-Hoskins. 1979. Brief history and state of the art of fish production models and some applications to fisheries off the northeastern United States. pp. 25-48 In Climate and Fisheries. Center for Ocean Management Studies. Univ. of Rhode Island, Kingston, R.I.

Applicable

Abstract

Production models applicable to individual fish, cohorts of fish, and entire populations are reviewed. Hypotheses (often untested) describing the relationship between production and the biotic and abiotic environment are advanced. The paper supports the following generalizations:

(1) The effect of the physical environment on fish production is better understood by considering fisheries in an ecological context instead of the context of the traditional fish production models. On the other hand, fish production models can sometimes be modified to account for environmentally induced fluctuations empirically.

(2) Most of the variability in fish production results from presently unexplained variability in reproductive success. Variability in reproductive success probably reflects a plethora of complex biotic and abiotic interactions of early life stages of fish.

(3) Fish production models do not usually consider the effect of a fluctuating environment explicitly, but their application is usually tempered so that the conclusions based on these models are generally valid and useful.

Comment

This paper reviews the relationships between existing yield models and discusses their application to many Atlantic fisheries. It will be very valuable to this study as a source for the comparability of the many model types.

Smith, R.H., and R. Mead. 1975. A note on population growth in a variable environment. Oecologia 20:333-337. Non-applicable

Abstract

Some properties of diffusion approximations to models of population dynamics in a variable environment are noted and discussed. A counter-intuitive feature of these models is that a larger mean population can lead to instability, given a particular level of variation. The need to consider different types of stochastic variation is stressed. Migration is shown to be either stabilising or destabilising, depending on the balance of effects of different types of variation.

Comment

The paper explores the conseauences of incorporating stochastic processes into a logistic growth model. It presents little information that is directly applicable to this study as its application is primarily theoretical in nature.

Smith, T.D., and T. Polacheck. 1979. Analysis of a simple model for estimating historical population sizes. Fish. Bull. 76:771-779.

Non-applicable

Abstract

Estimates of historical abundance of animal populations are important in many management decisions. Historical estimates based on a simple model of population growth have been made for several populations of dolphin involved with the yellowfin tuna purse seine fishery. We used the data for the bridled dolphin, *Stenella attenuata*, to investigate the behavior of the model by which these historical estimates were calculated. For populations with low net reproductive rates, the effect of bias in the estimates of the input parameters on the estimated historical abundances was approximately linear and additive. When all the input parameters were independently estimated, the variances of the historical abundance estimates were dominated by the variance of the initial abundance estimates and the coefficient of variation of the historical estimate was less than the largest coefficient of variation of any parameter.

Comment

The procedures described in this paper appear to have limited applicability for finfish or shellfish fisheries.

Smith, V.L. 1969. On models of commercial fishing. *J. Polit. Econ.* 77:181-198. Non-applicable

Abstract

Models based on a formulation of an economic theory of fish production are developed. They are founded on three key economic and technological features: (1) a fishery resource is replenishable; (2) the resource and the activity of production from it form a stock-flow relationship; (3) the recovery or harvesting process is subject to various possible external effects, all of which represent external diseconomics to the firm. The author presents a generalization, explication and integration of previous works based on these characterizations to provide one example of a descriptive theory that transforms any specific pattern of assumptions about cost conditions, demand externalities, and biomass growth technology into a pattern of exploitation.

Comment

This paper stresses the economics of fisheries much more than the dynamics of the exploited stock. It appears inappropriate for inclusion in this phase of the study.

Southey, C. 1972. Policy prescriptions in bionomic models: The case of a fishery. J. Polit. Econ. 80:769-775. Applicable

Abstract

Analysis of fisheries and their efficient exploitation has [sic] been subject to successive refinements culminating in the recent work of Smith (1969). In the process of refinement a number of conclusions as to the effects of regulation have been modified. Nevertheless it would appear that at least in steady-state models there is some agreement to the effect that to achieve efficiency on a hitherto free-access fishery, total fishing "effect" must indubitably be reduced, and fish populations would probably increase and certainly not be reduced.

The authors demonstrate that contrary to the above, efficiency may involve a permanent increase in the total expenditure on factors employed in the fishery. This result is obtained without modification of the basic ingredients of the fishery model. We shall also show how the introduction of a somewhat different biological mechanism allows for a decrease in the population under regulation. Throughout our analysis, we abstract from problems of mesh size and crowding, concentrating exclusively on the effect of effort on population. We also confine our attention to a steady-state solution.

Comment

This paper presents a rather simplified integration of population dynamics and economic dynamics. It may be useful as a conceptual guide, but some unrealistic assumptions may limit its applicability.

Southward, G.M. 1968. A simulation of management strategies in the Pacific halibut fishery. Int. Pac. Halibut Comm. Rpt. 47:5-70. Applicable

Abstract

Simulation studies offer a means of investigating different strategies that might be applied to the management of the Pacific halibut resource. Since this study was concentrated on long range aspects, it was necessary to forego investigation of several interesting short-term questions that arose. However, simulation does provide a way of formulating hypotheses about relationships existing in the population such as density-dependent growth responses to fishing, and offers a means of determining the type and amount of field sampling necessary to study the relationship in the population itself.

In general it appears that each of the three management schemes would in the long run stabilize the stock of halibut at a level where the maximum sustainable yield would be obtained. However, Rule 1, the empirical analysis, seems to be the preferable scheme from the standpoint of small variance, in most of the situations studied, the exception being the situation where the recruitment is highly variable. In this case, Rule 2, the potential yield analysis, results in a lower standard deviation of the catch per unit effort.

Comment

This paper presents one of the most extensive single species management models found in the literature. The model consists of three functioning submodels -- biological, fishery (primarily economics), and management. The model, although exemplary in its thorough analysis, requires a very large data base. A single species data base of this type does not exist for any Maryland fishery; thus, the direct application of the model is inappropriate. In conjunction with new data collection programs, this type of modeling effort could be applicable to Maryland fisheries.

Sutcliffe, W.H., Jr., K. Drinkwater, and B.S. Muir. 1977. Correlations of fish catch and environmental factors in the Gulf of Maine. J. Fish. Res. Bd. Canada 34:19-30.

Applicable

Abstract

In an investigation of catches of 17 commercial marine species of fish and shellfish from the Gulf of Maine, 10 showed statistically significant correlations with sea temperatures at St. Andrews, N.B., or Boothbay Harbour, Maine. Most fish records contained at least 40 years of data. Descriptive equations are produced for four species based first on the correlation between catch and sea temperatures and second on the correlation between catch and sea temperature allowing for fishing effort. Inclusion of fishing effort, not surprisingly, improved the correlations for all of the species so examined. The equations permitted the "prediction" of later parts of the records from earlier parts.

Considering the fish species collectively, the Gulf of Maine system from 1940 to 1959 appeared to be in equilibrium with little fluctuation in the total commercial biomass. We interpret the large fluctuations in individual species abundance as resulting from a combination of fishing pressure and to a significant degree oceanic climate as represented by sea temperatures. The small fluctuations in the total biomass display the species variation, with their differing climatic "preferences," as well as possible predator (including man) -prey relationships. Environmentally imposed patterns underlie at least 50% of the fluctuations in catch of many species and the understanding of these fluctuations is basic to effective management.

Comment

This statistical model is similar in technique to others using morphoedaphic variables; however, this example is in a marine environment. It also includes application to benthic fisheries such as hard and softshell clams. The paper should be reviewed for application in this study.

Swartzman, G.L., and G.M. Van Dyne. 1972. An ecologically based simulation-optimization approach to natural resource planning. Ann. Rev. Ecol. Syst. 3:347-398. Applicable

Abstract

The paper presents a simulation model of a perturbed arid land ecosystem, with the natural ecosystem and sheep introductions modeled together in a complex fashion. Optimization methods are coupled to the model to aid in decision making concerning the maintenance of the natural ecosystem and the maximization of wool output.

Comment

The model presented in this paper represents a good application of optimization techniques and the combination of simulation and optimization problems. The data requirements for the model may make this approach unfeasible for Maryland fisheries, but it should be reviewed as a holistic approach to the management of renewable resources.

Talbot, G.B. 1954. Factors associated with fluctuations in abundance of Hudson River shad. Fish. Bull. 56:373-413.

Abstract

Comments

This paper is unavailable for review, but has been requested through interlibrary loan. It will be reviewed when received.

Tautz, A., P.A. Larkin, and W.E. Ricker. 1969. Some effects of simulated long-term environmental fluctuations on maximum sustained yield. J. Fish. Res. Bd. Canada 26:2715-2726.

Non-applicable

Abstract

For a variety of stock recruit systems, in which environment variability is simulated by random normal deviates used as multipliers or divisors, Ricker (J. Fish. Res. Bd. Canada 15:991-1006, 1958) and Larkin and Ricker (J. Fish. Res. Bd. Canada 21:1-7, 1964) demonstrated the benefits of complete stabilization of escapement as opposed to removal of a fixed proportion of the stock each year. The present paper is primarily concerned with the response of these same systems to a pattern of stochastic modification that is more regular in form, a pattern such as might be imagined to result from long-term trends in environmental conditions. The simulations indicate that the gains derived from complete stabilization of escapement are determined solely by the variance of the modifiers -- thus the pattern of modification, i.e., long- or short-term, is relevant only in terms of its influence on the variance. In addition, a check for maximum equilibrium catch using catch statistics is described.

Comment

In this model, random and cyclic events are included in such a way as to be biologically unrealistic (e.g., conformation to a sine wave). The paper does represent one of the few attempts to incorporate random environmental events into a production model, but it probably will not be useful in this project.

Timin, M.E., and B.D. Collier. 1971. A model incorporating energy utilization for the dynamics of single species populations. Theor. Pop. Biol. 2:237-251.

Non-applicable

Abstract

A model for the population dynamics of a single species of animals is developed. The model consists of three ordinary differential equations expressing the rates of change of the state variables, density of animals, mean biomass per animal and food density, and several algebraic equations. The model differs from previous models in that mean biomass is used as an index of the size-age structure of the population, energy utilization by the population is considered, and a dimensionless form is developed. Terms are included for food supply rates and harvest rates. The results of computer simulations are presented and the properties of the model, including its stability and sensitivity to varying the parameters and initial conditions are discussed.

Comment

The paper presents a good approach to modeling population dynamics, but the data requirements for its application to a specific species are so large that use of this model is impractical for this project.

Toews, D.R., and J.S. Griffith. 1979. Empirical estimates of potential fish yield for the Lake Bangweulu System, Zambia, Central Africa. Trans. Am. Fish. Soc. 108:241-252.

Non-applicable

Abstract

Estimates of potential fish yield derived for the Lake Bangweulu system by three independent methods varied from 10 to 35 kg/hectare. An estimate of 20 kg/hectare predicted by the regression of yield on morphoedaphic index (MEI) for 31 African lakes is in good agreement with the 1973-1974 estimated yield of 19 kg/hectare. Potential yield was 35 kg/hectare in the morphoedaphic model for 17 intensively exploited African lakes. Potential yield based on primary production covariates was 16 kg/hectare. Standing crop estimates indicated possible yields of 10 to 17 kg/hectare based on 100% and 60% sampling recovery, respectively, of fish from chemical treatment samples and a 50% annual exploitation rate.

Comment

This paper and method offer nothing new to the concept of morphoedaphic indices (MEI). The concept and methodology are clearly examined and explained in other papers which have been reviewed.

Tomlinson, J.W.C., and P.S. Brown. 1979. Decision analysis in fish hatchery management. Trans. Am. Fish. Soc. 108:121-129. Non-applicable

Abstract

Most hatchery management decision problems are "wicked," that is, they are multilevel and intellectually complex, involve interactions between different areas of analysis, and are often ill defined. Techniques of analysis commonly applied to management problems -- operations research, cost-benefit analysis, econometrics, Bayesian analysis -- are valuable, but limited. Basically, they are not decision-making techniques but assist participants to assess a situation, before undertaking the reconciliation process of arriving at decisions. In complex decision problems, participants often revert to "dodges and strategies" which attempt to minimize potential regrets of overall optimality. In order to limit the extent of ineffectual and varied suboptimizing procedures in hatchery management it is important to clarify decision procedures in the context of vertical and horizontal linkages on a system analytical basis.

Comment

This paper does not deal with fishery yield models, but rather reviews various techniques (e.g., Bayesian analysis) used in hatchery management. It will not be useful to this specific project, but may prove helpful in further management endeavors.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416. Non-applicable

Abstract

A positive relationship is demonstrated for 27 locations between commercial yields of penaeid shrimp per area intertidal vegetation and latitude which can be described by the formula

$$y = 158.7e^{-0.070(x)}$$

where y is kilograms/hectare and x is degrees latitude between 0° and 35°. The latitudinal gradient grossly parallels a gradient of heating-degree-days and is twice the slope of the probable rates of litterfall from estuarine macrophytes. On a regional basis, the yields inshore are directly related to the area of estuarine vegetation whereas they are not correlated with the area, average depth, or volume of estuarine water. A short example is given to illustrate the utility of this analysis for the selection of alternative land-use decisions.

Comment

This model is not useful to the project as it is specific to shrimp and not precise enough to denote small-scale differences in fishery yield.

Ulltang, Ø. 1976. Sources of errors in and limitations of virtual population analysis (cohort analysis). Int. Coun. Explor. Sea CM/H:40. Applicable

Abstract

The virtual population analysis or cohort analysis is extensively used in stock assessment both within ICES and other scientific bodies. It is an extremely useful technique for estimating past values of fishing mortalities and stock sizes. These part values may in several ways be utilized to get indications of the present state of the stock and the prospects for the coming years. Because of the extensive use of the method it is, however, important to know the limitations of it and the various sources of errors.

Comment

This paper represents a useful review of virtual population analysis and its limitations and assumptions. It will be useful in this project.

Usher, M.B. 1976. Extensions to models, used in renewable resource management, which incorporate an arbitrary structure. J. Environ. Manag. 4:123-140. Non-applicable

Abstract

Matrix models of populations can be easily formulated, simply computed, but have often been neglected in modeling renewable resources. Two extensions to the basic model are considered. First, what is the effect of error of estimation of the matrix parameters on the eigenvalue and eigenvector? This is investigated by two theoretical methods, one described for the first time, and by simulation of a matrix derived for a Blue whale population. Secondly, can more meaningful criteria be advanced for optimizing yield? A matrix model for a forest is extended so as not only to investigate number of trees in different size classes but also to give expressions for the volume increment and economic increment of the forest as a whole.

Comment

This paper presents theoretical insights into the utility of Leslie matrices for management models. It presents no direct application, but provides theoretical information concerning its applications. Its direct applicability to this project is questionable.

Van Winkle, W., B.W. Rust, C.P. Goodyear, S.R. Blum, and P. Thall. 1974. A striped bass population model and computer programs. Oak Ridge National Laboratory, Oak Ridge, Tenn. ORNL/TM-4578. 200 pp.

Applicable

Abstract

The population model consists of a system of difference equations involving age-dependent fecundity and survival. The model deals only with females. The fecundity for each age class is assumed to be a function of both the fraction of females sexually mature and the length of females as they enter each age class. Natural mortality for age classes 1 to 15 and over is assumed to be independent of population size. Fishing mortality is assumed to vary with the weight of fish available to the fishery according to the logistic relationship. The probability of survival for the y-o-y is estimated without and with density-dependent mechanisms. In the latter case, the entrainment period is considered separately from the remainder of the year. The probability of survival after the entrainment period from all causes of mortality other than impingement incorporates (a) cannibalism of y-o-y striped bass by older striped bass and (b) dependence of growth rate and, consequently, of mortality of y-o-y striped bass on availability of food.

Comment

This paper represents an application of the Leslie matrix to model the population dynamics of a striped bass population. It does not directly determine yield but it could possibly be adapted for management purposes. It should be included in this project for this reason.

Wallis, I.G. 1975. Modelling the impact of waste on a stable fish population. Water Res. 9:1025-1036.

Non-applicable

Abstract

A simple model is developed to express the effect of waste discharge on a stable fish population in a randomly varying environment. The conditions for the model to have a stable mean and variance are derived analytically. Simulation studies are used to compare exponential and logistic terms and three different frequency distributions of environmental disturbances. It is concluded that within the range of conditions likely to represent real populations, the predicted mean population is virtually the same for all of these possibilities. The study suggests that simple models, calibrated by field and laboratory determinations of the effect of waste, can give order of magnitude estimates of population changes resulting from waste discharge.

Comment

This paper discusses a model of the effects of organic waste pollutants on population dynamics. It appears to have little direct applicability to the project, but may prove useful in management practices which include habitat and water quality management.

Walter, G.G. 1973. Delay-differential equation models for fisheries. J. Fish. Res. Bd. Canada 30:939-945.

Applicable

Abstract

Two new "simple" fishery models based on delay-differential equations are introduced and compared to three currently used differential equation models. These new models can account for reproductive lag and allow oscillatory behavior of population biomass, but require only catch and effort data for their application. Equilibrium levels are calculated for both models and examples of various types of growth curves are given. Levels of fishing effort which maximize yield are calculated and found in one case to depend on the previous population and in the other to be constant.

Comment

This paper presents a method by which the time lag between spawning and recruitment can be incorporated into surplus production and yield models. The paper will be useful in this project.

Walter, G.G. 1976. Non-equilibrium regulation of fisheries. Int. Comm. Northwest. Atl. Fish. Sel. Pap. 1:129-140.

Applicable

Abstract

Many of the world's fisheries have until recently been in a virgin state or close to it. The exploitation has been marginal and has not severely affected the stock size. In the last twenty years these fisheries have come under increasing exploitation, which has often reduced the stock size and necessitated some sort of regulation of the catch.

There are many theories available to the fisheries biologist for this regulation. They usually give an estimate for the maximum yield that the fishery can produce on a continuing basis, i.e. the maximum sustained yield (MSY). It should be observed that this value is not the maximum possible catch in a given year but, particularly in a virgin fishery, is considerably less.

The newly exploited stock is usually difficult to manage. Few data are available and they are often unreliable. Moreover, the stock is not in equilibrium in the presence of fishing. This latter fact is often overlooked and is one of the reasons for the shrinking estimates of MSY that are sometimes encountered.

In this work we shall study the yield of a fishery under nonequilibrium conditions and compare strategies for bringing the stock size to that required for maximum sustained yield. We shall consider reduction to this optimum stock size from above as well as increase from below.

We introduce a procedure based on the equation of Schaefer which assumes the growth rate of the total stock biomass to be a function of the biomass itself and of fishing effort. Although no delayed effects are present in the equation, we shall see that there is considerable delay between the initiation of a regulation and the attainment of the desired equilibrium state.

Comment

This paper presents an excellent explanation of the consequences of the application of equilibrium surplus production formulations to non-equilibrium fisheries. A method is developed which is applicable to these situations and appears useable for Maryland fisheries.

Walter, G.G. 1978. A surplus yield model incorporating recruitment and applied to a stock of Atlantic mackerel (Scomber scombrus). J. Fish. Res. Bd. Canada 35:229-234. Applicable

Abstract

A modification of Schaefer's surplus yield model that takes into account variations in year-class strength is introduced. Expressions for long-term equilibrium yield under assumptions of both linear and density-dependent recruitment are derived and compared. Strategies for exploitation under nonequilibrium conditions are discussed and equations derived. The model is fitted to a stock of mackerel and projections for the stock biomass in 1980 under various levels of fishing mortality are made.

Comment

The method presented here is potentially useful for dominant year-class species such as striped bass or other species where recruitment relationships are known from historical data.

Walter, G., and W. Hogman. 1971. Mathematical models for estimating changes in fish populations with applications to Green Bay. Pages 170-184, In Proc. 14th Conf. Great Lakes Res. Great Lakes Research Division, University of Michigan.

Applicable

Abstract

A mathematical model for a multispecies exploited fishery is developed. The model consists of a system of first order differential equations similar to the single equation for one species of Schaefer. The coefficients of the equation are calculated from abundance and fishing intensity data by using multiple regression. That level of fishing intensity for each species which gives the maximum sustained yield is then calculated. The model is applied to the eight species fishery of northern Green Bay using data obtained over a period of 41 years.

Comment

This paper presents an excellent application of Schaefer-like yield formulations to multispecies fisheries in a semi-enclosed water body. It may be directly applicable to Maryland fisheries.

Walters, C.J. 1969. A generalized computer simulation model for fish population studies. Trans. Am. Fish. Soc. 98:505-512. Applicable

Abstract

A generalized computer model for fish population simulation and maximum yield determination is described. The model utilizes age-specific natural mortality rates, growth rates, relative fecundities, and any desired stock-recruitment relationship. Best harvest strategies are found by treating long-term yield as a response surface on the set of age- and year-specific fishing rates. The model is illustrated using data on arctic cod, stream brook trout, and on a hypothetical population with strong age-class dominance. Best predicted management strategies include periodic harvest when age at entry to the fishery cannot be controlled, but maximum yield is usually obtained with constant fishing rate.

Comment

This model offers little new information concerning the Beverton-Holt yield formulation, but it does incorporate age-specific recruitment, growth, and mortality rates and may be helpful in this project.

Walters, C.J., and J.E. Gross. 1972. Development of big game management plans through simulation modeling. J. Wildl. Manag. 36:119-128.

Non-applicable

Abstract

Current and future demands on wildlife resources require greater levels of stewardship from the wildlife manager. More complex demands and inevitable compromises will require more sophisticated management plans whose attributes are alternative paths of action and estimates of the consequences. The core of needed management plans is visualized as question banks and data-processing models. Simulation models permit pre-management experimentation in terms of what if games. Examples of what if games are discussed to illustrate critical population conditions, sensitive management parameters, alternative objectives, consequences of environmental catastrophes, and procedures for developing objective measures for management performance. This paper attempts to show how information generated from a complex of variables can be channeled into the decision-making process.

Comment

This paper presents the application of a Schaefer-like logistic model to white-tail deer in Texas. The specific application to a non-fish population adds little to the development of the surplus production concept of management. The model presented is not directly applicable to Maryland fisheries.

Welcomme, R.B. 1976. Some general and theoretical considerations on the fish yield of African rivers. J. Fish. Biol. 8:351-364. Applicable

Abstract

The factors regulating fish production from river systems remain poorly studied and understood. Rivers conform to physical and chemical laws which determine their morphology. From these laws relationships are calculated which estimate the total length and number of streams of different order on the African continent. Edaphic factors vary less than morphological ones and the chemical and physical conditions in the major river channels tend to resemble each other closely. The present catch from African rivers, evaluated from catch statistics, by country and by river system, resembles a theoretical figure derived from the basin area. However, these statistics are drawn only from major fisheries and there remain a very large number of smaller streams whose production does not enter into this calculation. A theoretical approach to this problem is proposed which gives an estimate of annual yield of 530,000 ton of fish at present levels of catch. Deviations from the theoretical yield in individual river systems arise from differences in both edaphic and morphological characteristics.

Comment

This paper may represent the most useful of the morphoedaphic index (MEI) approaches presented in numerous other papers. The approach described develops a MEI for river systems as opposed to lakes. The use of total dissolved solids is less reliable in river systems than lakes, and, thus, the primary statistical relationships are constructed between yield and drainage area, and yield and river length.

Winters, G.H. 1976. Recruitment mechanisms of southern Gulf of St. Lawrence Atlantic herring (Clupea harengus harengus). J. Fish. Res. Bd. Canada 33:1751-1763. Applicable

Abstract

Estimates of abundance of the southern Gulf of St. Lawrence herring complex by cohort analysis indicate that both biomass and population fecundity were reduced to low levels in the late 1950s following a widespread fungus disease in the mid-1950s. As a result of two strong year-classes in the late 1950s, however, abundance increased dramatically up to 1964 but has declined continuously since then due mainly to subsequent poor recruitment. Mackerel were also at low levels of abundance in the late 1950s and remained so until the mid-1960s when a series of strong year-classes produced a rapid increase in abundance to the extent that mackerel replaced herring as the dominant pelagic fish in the southern Gulf ecosystem. Changes in herring recruitment, growth, and maturation rates are investigated in relation to changes in herring biomass and total pelagic (herring + mackerel) biomass. Density-dependent changes in all three parameters have occurred in herring; mackerel also have interacted with the growth and recruitment of southern Gulf herring. This suggests that the carrying capacity of the southern Gulf for pelagic fish is limited and that competition and predation by mackerel intensifies [sic] the logistic response of herring. Thus, recruitment of southern Gulf herring in the period under consideration was largely controlled by the total pelagic biomass, acting mainly through herring up to the mid-1960s and through mackerel since then. The increase in mackerel abundance is attributed to a combination of favorable temperature regime and optimum spawning biomass. That being so, the probability of large year-classes of herring in the near future will depend heavily on the interaction between favorable survival conditions for mackerel and the effectiveness of ICNAF regulations to maintain mackerel biomass at maximum recruitment levels.

Comment

This paper describes an application of cohort analysis to an existing fishery and will prove useful to the project for species where adequate data have previously been collected.

Winters, G.H. 1978. Production, mortality, and sustainable yield of Northwest Atlantic harp seals (*Pagophilus groenlandicus*). *J. Fish. Res. Bd. Canada* 35:1249-1261. Applicable

Abstract

From recent and historical data the natural mortality rate of adult harp seals (*Pagophilus groenlandicus*) is estimated to be 0.10 which is within the range of previous estimates (0.08 - 0.11). New estimates of bedlamer and 0-group natural mortality rates were not significantly different from those of adult seals. Pup production estimates from survival indices agreed well with those from sequential population analyses and indicated a decline from about 350,000 animals in the early 1950s to about 310,000 animals in the early 1970s. Over the same period the 1+ population size declined from 2.5 to 1.1 million animals but has been increasing at the rate of 3% per year since the introduction of quotas in 1972. The relative contribution of the "Front" production of total ("Front" plus Gulf) production during the past decade has fluctuated from 49 to 87%, the average of 64% being very similar to the 61% obtained previously. These fluctuations suggest some interchange between "Front" and Gulf adults and it is concluded that homing in the breeding areas is a facultative rather than obligatory aspect of seal behavior. Thus the heavier exploitation of the "Front" production is probably sufficiently diffused into the total population to avoid serious effects on "Front" production. The maximum sustainable yield of Northwest Atlantic seals harvested according to recent patterns is estimated to be 290,000 animals (80% pups) from a 1+ population size of 1.8 million animals producing 460,000 pups annually. The sustainable yield at present levels of pup production (335,000 animals) is calculated to be 220,000 animals which is substantially above the present TAC of 180,000 animals and coincides with present harvesting strategies designed to enable the seal hunt to increase slowly towards the MSY level.

Comment

The paper represents the combination of cohort analysis for the determination of parameters and yield and a Schaefer model for determinations of surplus yield; while the application described (i.e., to seals) is inappropriate to the project, the utility of the combination of these two methods should be reviewed.

APPENDIX B

An annotated bibliography of stock management submodels

and methods of parameter estimation

Age Structure Submodels

Kimura, D.K. 1977. Statistical assessment of age-length key. J. Fish. Res. Bd. Canada 34:317-324.

Abstract

Since 1934 when Fridricksson originated the age-length key, it has been widely used by fisheries biologists to estimate age distributions of populations. In recent years, there has been a general recognition that often the key has little value, or even worse, gives biased results. The analysis presented here indicates why the age-length key is so susceptible to bias. More importantly, a criterion is presented for determining whether the age-length key should be used in a particular situation. If the key is to be used, results from examples indicate that random age subsamples (i.e., the number of specimens aged from each length category proportional to the number in each length category) are superior to fixed age subsamples (i.e., a constant number of specimens aged from each length category). Generally, small increases in the age sample will likely increase the accuracy of an age-distribution determination more effectively than relatively large increases in the length sample.

Comment

This paper discusses the bias introduced to estimated age distribution through the use of an age-length key and suggests a test for the determination of the key's applicability to specific investigations. Due to the bias generally involved with the use of age-length keys, their use is not suggested for this project.

Kumar, K.D., and S.M. Adams. 1978. Estimation of age structure of fish populations from length-frequency data. Pages 256-281 In W. Van Winkle (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Administration, and Electric Power Research Institute.

Abstract

A probability model is presented to determine the age structure of a fish population from length-frequency data. It is shown that when the age-length key is available, maximum-likelihood estimates of the age structure can be obtained. When the key is not available, approximate estimates of the age structure can be obtained. The model is used for determination of the age structure of populations of channel catfish and white crappie. Practical applications of the model to impact assessment are discussed.

Comment

This paper presents a good review of the methods for the determination of population age structure from length-frequency data. The assumptions of the normality of length data and the prior existence of an age-length key may make this procedure less desirable for use for Maryland stocks, but even without the age-length key, first approximations are possible. The approach will prove useful for stocks where a stable age distribution does not exist.

McNew, R.W., and R.C. Summerfelt. 1978. Evaluation of a maximum-likelihood estimator for analysis of length-frequency distributions. Trans. Am. Fish. Soc. 107:730-736.

Abstract

The maximum-likelihood estimation procedure described by Hasselblad is a statistical method applicable to estimates of population parameters in a mixture of normal distributions of component age-groups. The method was used to estimate mean length-at-age and percentage composition of the component age-groups in 10 collections of largemouth bass (Micropterus salmoides) for which age was determined by the scale method. Compared to fish aged by the scale method, the error of the estimates of mean length-at-age averaged 3.2%. About one-third of the 31 frequency distributions, and six of seven distributions with more than 100 fish, deviated significantly from that of a normal distribution; many distributions exhibited skewness and kurtosis. However, the general failure of the samples to fit characteristics of the normal curve did not greatly influence accuracy in estimating mean length. The average error of the estimates of percentage composition by age was 28%; the magnitude of this error was related to the degree of asymmetry and a large standard deviation of length. The latter was apparently related to a prolonged and disjunct spawning season which produced multimodal distributions within each age-group.

Comment

This paper presents an established method of determining age structure from length-frequency data. The assumption of normality in the distribution of the length data was tested for reservoir bass and found to not significantly affect the projected age composition. This assumption should be tested on any Maryland species on which this procedure might be utilized in this project.

Westrheim, S.J., and W.E. Ricker. 1978. Bias in using an age-length key to estimate age-frequency distributions. J. Fish. Res. Bd. Canada 35:184-189.

Abstract

Consider two representative samples of fish taken in different years from the same fish population, this being a population in which

year-class strength varies. For the "parental" sample the length and age of the fish are determined and are used to construct an "age-length key," the fractions of the fish in each (short) length interval that are of each age. For the "filial" sample only the length is measured, and the parental age-length key is used to compute the corresponding age distribution. Trials show that the age-length key will reproduce the age-frequency distribution of the filial sample without systematic bias only if there is no overlap in length between successive ages. Where there is much overlap, the age-length key will compute from the filial length-frequency distribution approximately the parental age distribution. Additional bias arises if the rate of growth of a year-class is affected by its abundance, or if the survival rate in the population changes. The length of the fish present in any given part of a population's range can vary with environmental factors such as depth of the water; nevertheless, a sample taken in any part of that range can be used to compute age from the length distribution of a sample taken at the same time in any other part of the range, without systematic bias. But this of course is not likely to be true of samples taken from different populations of the species.

Comment

The paper does not present a submodel but only discusses the bias introduced through the use of age-length keys. This procedure appears to be particularly biased in cases where variation in year-class strength affects growth rates. Age-length keys do not appear to be a useful tool in this project.

Allometric Submodels

Dame, R.F. 1972. Comparison of various allometric relationships in intertidal and subtidal American oysters. Fish. Bull. 70:1121-1126.

Abstract

The allometric relationships for the possible combinations of whole weight, dry body weight, soft body weight, shell weight, height, and length were computed for intertidal and subtidal South Carolina oysters. All relationships between intertidal and subtidal oysters involving dry body weight were significantly different. The percent moisture in the tissues was 81.1% for subtidal oysters and 83.4% for intertidal oysters and did not vary with size. Height appears to be the most useful parameter for predicting other biomass parameters from field data.

Comment

This paper presents the allometric coefficients for several variables (e.g., shell weight, height, dry body weight, soft body weight) for intertidal and subtidal oysters. The procedure is straightforward and can be used in some cases to estimate biomass for simulation models.

Pienaar, L.V., and J.A. Thomson. 1969. Allometric weight-length regression model. J. Fish. Res. Bd. Canada 26:123-131.

Abstract

Two methods of fitting the allometric weight-length relationship are described; one involving the common logarithmic transformation of variables in a multiplicative model, and the other assuming an additive nonlinear model and general nonlinear estimation procedures. Differences in the assumptions involved in the two methods are emphasized and the practical significance of the different methods is demonstrated with the aid of a sample problem. A number of procedures are suggested to compensate for possibly unjustified assumptions.

Comment

This paper presents several statistical procedures for the estimation of allometric coefficients. The information presented allows determination of the procedure to be used under certain circumstances. The allometric equation would probably not prove useful in this project unless biomass data were non-existent.

Catchability Submodels

Paloheimo, J.E. 1961. Studies on estimation of mortalities: I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Bd. Canada 18:645-662.

Abstract

A method, described by Beverton (1954) and Beverton and Holt (1956 and 1957), giving estimates of the natural mortality rate, M, and the catchability coefficient, q, from catch at age and effort data, is examined. This method requires 4 to 5 iterations to arrive at the estimates. We have derived approximate solutions for q and M in a closed form. This makes the laborious iterations unnecessary, and gives virtually the same values as arrived at by iterations.

The effectiveness of the iterative Beverton and Holt method is evaluated by calculating q and M in 30 hypothetical examples. A new and simple (linear formula) method for estimating q and M is derived. Application of the new method to these 30 examples resulted in a 48% reduction of the standard deviation of q and a 45% reduction in that of M. The new method is in part the same as one suggested by Gulland, Beverton, and Holt (Beverton et al., MS, 1958; Holt, MS, 1959) to arrive at initial values in their short-cut (iterative) method of estimating the mortality rates. We show that these initial values are actually better estimates than the final values arrived at by the iteration.

Neither the Beverton and Holt method nor the linear formula gives necessarily unbiased estimates; the bias depends on the types of variability in the data.

To arrive at non-biased, least squares estimates would require ancillary information not normally available on the distributions of the three variates: catch at age, effort, and catchability coefficient.

Comment

This paper presents a method of estimating natural mortality and catchability which simplifies an earlier Beverton-Holt method. The simplification requires primarily effort data and could be useful for Maryland stocks.

Rafail, S.Z. 1977. A simplification for the study of fish populations by capture data. Fish. Bull. 75:561-569.

Abstract

Expressions given by Rafail for estimating catchability are modified here to eliminate iteration, for better accuracy, and a large economy in calculations and time. The evaluation of catchability allows the estimation of other important parameters with the useful assumption of their variabilities according to seasons and recognized sections of a population.

Comment

This paper presents a method for the estimation of catchability given catch per unit effort and a series of effort data. The procedure for the calculation of the true value is complicated and requires data not likely to exist for Maryland fisheries. The estimation procedure may prove useful for this project.

Effort Submodels (Commercial)

Nicholson, W.R. 1971. Changes in catch and effort in the Atlantic menhaden purse-seine fishery, 1940-1968. Fish. Bull. 69:765-781.

Abstract

The catch, number of vessel weeks, and catch per vessel week in the Atlantic menhaden fishery increased during the 1950's. During this period fishing methods improved and the efficiency of vessels increased. Improvements included use of airplanes for spotting schools, aluminum purse boats, nylon nets, power blocks, and fish pumps for catching and

handling fish, and larger and faster carrier vessels that could range farther from port. The catch and catch per vessel week began declining north of Chesapeake Bay in the early 1960's. By 1966, fish north of Chesapeake Bay had become so scarce that plants either closed or operated far below their capacity. In Chesapeake Bay the number of vessel weeks increased, and the catch and catch per vessel week decreased through the early and mid 1960's. Variations in catch, effort, and catch per unit of effort showed no trends in the South Atlantic. The annual mean number of purse-seine sets per day varied in different areas and ranged from about 2.0 to 4.5. The annual mean catch per set ranged from about 11 to 25 metric tons.

Comment

The paper presents a method for the calculation of total effort and a "normalizing" function for a fishery where technical improvement has increased effort and catchability at the same time. This approach should be applied to all long-term simulations using historical data for Maryland stocks.

Schaaf, W.E., and G.R. Huntsman. 1972. Effects of fishing on the Atlantic menhaden stock 1955-1969. Trans. Am. Fish. Soc. 101:290-297.

Abstract

To determine the effect of purse-seine fishing on the Atlantic menhaden (Brevoortia tyrannus) population, we analyzed data from 1955-1969 on fishing activity and catches. Changes in fishing efficiency necessitated establishment of an abstract effort unit, the 1965 vessel-week. Catch per unit of effective effort in 1965 was one-fifth that of 1955. Our instantaneous natural mortality rate (M) estimate was 0.37. At the current recruitment age, 1.5 years, reducing F, instantaneous fishing mortality, to about 0.8 would slightly decrease the yield per recruit, but would increase the spawning stock and ultimately allow annual catches of 400,000-500,000 metric tons, the maximum sustained yield.

Comment

This paper presents a useful and easily applied method for "normalizing" fishing effort which is dependent on relative catchability. This method could be important for all Maryland fisheries in which effort and stock size were significantly altered over the past decade.

Effort Submodels (Recreational)

Malvestuto, S.P., W.D. Davies, and W.L. Sheldon. 1978. An evaluation of the roving creel survey with nonuniform probability sampling. Trans. Am. Fish. Soc. 107:255-262.

Abstract

A roving creel survey with nonuniform probability sampling was conducted on West Point Reservoir, Georgia, for 24 months. The sampling design is described in detail. The assumption that catch per unit effort (CPE) for incompleted fishing trips is an unbiased estimator of CPE for completed trips is tested and verified. Coefficients of variation for monthly estimates of catch and effort are used to measure the precision of the sampling design. Precision was relatively high during the summer (April-October), but decreased markedly during the winter (November-March). This change is largely independent of sample size within the range of 5-10 sample days per month leading to the conclusion that sampling effort could be reduced 50% without impairing the precision of the survey. The method appears capable of detecting changes in the quality of fishing small enough for management purposes. The paper is intended to provide guidelines for the implementation, evaluation, and modification of statistically based creel survey programs.

Comment

This paper presents a complete sampling design and analysis procedure for the determination of recreational fishing effort. The present recreational fishing survey being conducted in Maryland will make the use of this procedure unnecessary, but further studies of this type should consider the methodology explained in this paper as well as the companion paper by the same authors.

Malvestuto, S.P., W.D. Davies, and W.L. Sheldon. 1979. Predicting the precision of creel survey estimates of fishery effort by use of climatic variables. Trans. Am. Fish. Soc. 108:43-45.

Abstract

A multiple regression equation was developed which explained 83% of the variation in the precision (CV_E) of monthly creel survey estimates of fishing effort on West Point Reservoir, Georgia-Alabama, over a 24-month period. The equation is CV_E = 34.678 - 1.154(TEM) + 9.274(SD_T) + 84.942 (RAIN) - 38.854(SD_R), where TEM = mean daily air temperature for a particular month; RAIN = mean daily rainfall for that particular month; and SD_T and SD_R = the standard deviations of daily air temperature and rainfall for that same month, respectively. The constants in the regression equation may be specific to West Point Reservoir, but the climatic variables are certainly of general importance. The model reflects the environmental basis for the variation associated with creel survey estimates of fishing effort, and provides a means of optimally allocating sampling effort prior to implementation of a survey.

Comment

This presentation is completely site specific, but the generality of climactic variables affecting the precision of survey estimates of recreational effort should be investigated in light of the present Maryland survey.

Robson, D.S. 1961. On the statistical theory of a roving creel census of fishermen. Biometrics 17:415-437.

Abstract

In order to estimate the day's total catch from a fishery an enumerator roves through the fishing area interviewing fishermen as he encounters them to determine the number n of fish caught and the time t expended. The interviewer is assumed to (i) start his trip at a randomly chosen point along a well defined route which completely covers the fishery, (ii) choose his initial direction at random from the two alternatives, and (iii) travel at a constant rate of c circuits per day. If the catch rate n/t at time of interview is an unbiased estimator of a fisherman's catch rate for his completed trip and if the fishermen's movements relative to the interviewer's path never exceed the interviewer's rate c, then rn/ct, summed over all interviews, is an unbiased estimator of the day's total catch. The unit of time is one day, r is the number of times the fisherman was interviewed, and n/t is the catch rate at the r'th interview.

Unbiasedness of n/t implies that the waiting times to first catch and from first to second catch are identically distributed chance variables, and that all waiting times between successive catches have the same expected value. If waiting times are independent, then unbiasedness implies that fishing is a Poisson process.

Comment

This paper presents a complete sampling design and analysis scheme for determining recreational fishing effort. The Coastal Zone Management Unit is presently involved in a complete recreational effort survey which will make the use of this presentation unnecessary.

Fecundity Submodels

Brousseau, D.J. 1978a. Population dynamics of the soft-shell clam, *Mya arenaria*. Mar. Biol. 50:63-71.

Abstract

A life table was constructed for *Mya arenaria* from Gloucester, Massachusetts, USA, based on schedules of age-specific fecundity and mortality determined under natural conditions. Mortality rates decrease with size and age in this species, with the period of maximum mortality occurring during the summer months. Mortality rates during the fall and winter were considerably lower, perhaps due to the inactivity of natural predators. The survivorship curve for *M. arenaria*

approximates the Type 3 curve of Deevey (1947). Mean life expectancy is low in recently-settled clams, peaks when the individual reaches 30.0 to 34.9 mm (1 year of age), and remains fairly high for most of the remainder of life. The intrinsic rate of natural increase (r_{max}) is very high: 4.74. This enormous rate of potential increase is offset by high rates of larval mortality in the plankton. Unlike the reproductive values of most animals studied, those in M. arenaria peak late in life, well after the known age of first reproduction. This is probably the result of increased fecundity with age. The implications of this work in the area of resource management are discussed.

Comment

This paper presents the use of life tables to determine the intrinsic rate of natural increase (r). Size-specific natality and mortality were converted to age-specific rates using the von Bertalanffy age-size relationship. This procedure will be of little use for this project.

Brousseau, D.J. 1978b. Spawning cycle, fecundity, and recruitment in a population of soft-shell clam, Mya arenaria, from Cape Ann, Massachusetts. Fish. Bull. 76:155-166.

Abstract

A population of Mya arenaria in the Annisquam River system, Gloucester, Mass., was studied for 3 years to determine spawning frequency, fecundity, and recruitment rates under natural conditions. This population was observed to spawn twice each year, in March-April and June-July. Temperature appeared to be a more critical factor in the timing of gonad maturation than in triggering the release of gametes. Female body sizes and oocyte production were positively correlated (1973, $r = 0.95$; 1974, $r = 0.90$). Regression lines were compared by analysis of covariance. Slopes of the lines did not differ significantly between years or between spawning cycles within years ($P \geq 0.05$). Elevations of the lines differed significantly from one another ($P \leq 0.05$) indicating annual and seasonal variability in fecundity. Sex ratios of M. arenaria 25-95 mm shell length did not differ significantly from 1:1 over the 3-year study period. In smaller individuals, male and female gonads were indistinguishable. No evidence of hermaphroditism or protandry was observed. Recruitment rates of juveniles fluctuated widely between spawning cycles as well as between years.

Comment

This paper presents a very simple statistical linear relationship between female shell length and oocyte number. This approach could easily be employed for Maryland stocks if fecundity was determined a necessary component of a simulation model.

Tsai, C., and G.R. Gibson., Jr. 1971. Fecundity of the yellow perch, Perca flavescens Mitchill, in the Patuxent River, Maryland. Ches. Sci. 12:270-274.

Abstract

The fecundity of 114 female yellow perch was studied during the 1969 spawning run (20 through 25 March) in the Patuxent River, Maryland. The fecundity was proportional to the total weight and gutted weight, respectively, as expressed by the regression equations $Y = 150.55730X - 1,424.0878$ ($r = 0.88$) for the former, and $Y = 217.65656X - 2,387.9915$ ($r = 0.87$) for the latter (Y, fecundity; X, either total weight or gutted weight). It was nearly proportional to the quadruplicate of fork length as expressed by the regression equation, $\log Y = 3.7179 \log X - 1.50917$ ($r = 0.90$). This quadruplicate phenomenon was due in part to the heavier proportionate increase in body weight and the visceral space available for egg development as the fish length increased.

Comment

This paper presents simple regressions of fecundity, total weight, gutted weight, and fork length for yellow perch. The approach and/or actual numbers may prove useful if yellow perch yield is evaluated with a simulation model.

Growth Submodels

Allen, K.R. 1966. A method of fitting growth curves of the von Bertalanffy type to observed data. J. Fish. Res. Bd. Canada 23:163-179.

Abstract

A method is described for obtaining the best least-squares estimates of the parameters L_∞, k, and t_0 when von Bertalanffy curves of the type

$$L = L_\infty \left(1 - e^{-k[t-t_0]}\right)$$

are fitted to observed data. This method imposes no restrictions on the number or size of the samples or on the time intervals between them. It also provides estimates of the limits of error of the parameters. The amount of computation is fairly large, but a method of systematizing it is described which makes manual computation practicable for moderate-sized sets of data. The method has been used to develop a computer program which seems to have advantages over some existing methods.

A numerical example is worked out in full to illustrate application of the method.

Comment

This paper presents an excellent method for the computation of von Bertalanffy growth parameters by a least-squares technique regardless of sample size. Equations are presented to determine the error of the growth parameter estimates. This method can be easily applied without the use of a computer.

Bayley, P.B. 1977. A method for finding the limits of application of the von Bertalanffy growth model and statistical estimates of the parameters. J. Fish. Res. Bd. Canada 34:1079-1084.

Abstract

The following expression is derived expressing the instantaneous growth rate (G) in terms of length (L), the power of the weight-length relationship (b), and the Bertalanffy growth parameters (K and $L\infty$):

$$G = bK(L\infty / L - 1) .$$

Since this is valid for a length (or age) range in which growth conforms to the Bertalanffy model, a plot of G vs 1/L should be linear with the intercept on the G axis being -bK and on the 1/L axis being $1/L\infty$. Since the variables can be measured independently, deviations of points from the regression can be tested and the limits of validity of the model ascertained. In addition, confidence limits of K and $L\infty$ can be estimated. Two examples compare results with those using previous methods.

Comment

This paper presents an extension of the von Bertalanffy growth equation where the parameters which determine K can be measured independently. It can be easily applied, and an estimate of the variance associated with the growth parameter (K) is presented. It could be applied to Maryland species especially where growth records available are for unequal time periods.

Brousseau, D.J. 1978. Population dynamics of the soft-shell clam, *Mya arenaria*. Mar. Biol. 50:63-71.

Abstract

A life table was constructed for *Mya arenaria* from Gloucester, Massachusetts, USA, based on schedules of age-specific fecundity and mortality determined under natural conditions. Mortality rates decrease with size and age in this species, with the period of maximum mortality occurring during the summer months. Mortality rates during the fall and winter were considerably lower, perhaps due to the inactivity of natural predators. The survivorship curve for *M. arenaria* approximates the Type 3 curve of Deevey (1947). Mean life expectancy is low in recently-settled clams, peaks when the individual reaches 30.0 to 34.9 mm (1 year of age), and remains fairly high for most of the remainder of life. The intrinsic rate of natural increase (r_{max}) is very high: 4.74. This enormous rate of potential increase is offset by high rates of larval mortality in the plankton. Unlike the reproductive values of most animals studied, those in M. arenaria peak late in life, well after the known age of first reproduction. This is probably the result of increased fecundity with age. The implications of this work in the area of resource management are discussed.

Comment

This paper presents the use of life tables to determine the intrinsic rate of natural increase (r). Size-specific natality and mortality were converted to age-specific rates using the von Bertalanffy age-size relationship. This procedure will be of little use for this project.

Brousseau, D.J. 1979. Analysis of growth rate in Mya arenaria using the von Bertalanffy equation. Mar. Biol. 51:221-227.

Abstract

Field studies were conducted in Gloucester, Massachusetts, USA, to determine linear shell growth rates for Mya arenaria. These rates were then compared with those reported for the same species from other locations. Most shell deposition occurred from March through November of each year. Winter interruptions in growth were not as marked in the small clams as in the larger ones (>60.0 mm). Annual variations in growth were slight during the period 1973-1974. Growth of mature clams (>35.0 mm) slowed during the spawning season. No significant sexual dimorphism in mean annual growth rates was detected. Winter rings were shown to be a reliable method for determining age in clams from Gloucester. Age-size relationships, based on two independent measures of annual growth, winter rings and tagging experiments, were computed using the von Bertalanffy growth equation. No well-defined latitudinal patterns in growth could be established for M. arenaria.

Comment

This paper presents the application of the von Bertalanffy growth function to several populations of soft-shell clams. The estimates presented may be helpful in determining if growth rates assessed for Maryland populations are realistic. No new methods are presented.

Chadwick, E.M.P., T.R. Porter, and P. Downton. 1978. Analysis of growth of Atlantic salmon (Salmo salar) in a small Newfoundland river. J. Fish. Res. Bd. Canada 35:60-68.

Abstract

Growth and sea survival rates decreased with increasing smolt age, with survival being 12, 6, and 3% for 3+, 4+, and 5+ smolt, respectively.

All spawning fish were grilse, which suggests that older smolt became large salmon and were thus more vulnerable to the commercial fishery. A density-dependent relationship was observed for 3+ smolt in their 1st year of growth, but not for older smolt; younger smolt probably spend their juvenile life in a more productive but space-limiting part of the river. Variation between river-system environments may be responsible for the opposing results of studies on Atlantic salmon (Salmo salar) life history.

Comment

This paper explains a method for the determination of instantaneous growth rates from back-calculated lengths (as determined by a regression of fork length on scale radius). The presentation provides little new information, but may prove useful for species which do not spend their entire life span in Maryland waters.

Cloern, J.E., and F.H. Nichols. 1978. A von Bertalanffy growth model with a seasonally varying coefficient. J. Fish. Res. Bd. Canada 35:1479-1482.

Abstract

The von Bertalanffy model of body growth is inappropriate for organisms whose growth is restricted to a seasonal period because it assumes that growth rate is invariant with time. Incorporation of a time-varying coefficient significantly improves the capability of the von Bertalanffy equation to describe changing body size of both the bivalve mollusc, Macoma balthica, in San Francisco Bay and the flathead sole, Hippoglossoides elassodon, in Washington state. This simple modification of the von Bertalanffy model should offer improved predictions of body growth for a variety of other aquatic animals.

Comment

This paper presents a simple extension of the von Bertalanffy growth equation incorporating seasonal variation into the growth coefficient, K. It is easily applied to any yield model incorporating von Bertalanffy growth. It could be useful in determining growth functions for Maryland species where growth data are available over several years.

Dame, R.F. 1975. Day degree growth models for intertidal oysters. Contr. Mar. Sci. 19:107-112.

Abstract

Linear and polynomial day degree models are shown to be capable of predicting oyster growth in terms of height or weight. Polynomial models predict growth more accurately than linear models, but are less meaningful biologically. A general linear model for predicting oyster growth in terms of weight is developed for the North Inlet, South Carolina area.

Comment

This paper presents very simple linear and quadratic growth equations for oysters based on initial size and day-degrees (mean temperature multiplied by number of days in period). Growth is easily determined and may prove useful for non-motile species.

DeAngelis, D.L., and C.C. Contant. 1979. Growth rates and size distributions of first-year smallmouth bass populations: Some conclusions from experiments and a model. Trans. Am. Fish. Soc. 108:137-141.

Abstract

Growth rates of populations of first-year smallmouth bass (*Micropterus dolomieui* Lacépède) were studied during the first few weeks of life at temperatures ranging from 15.2 to 32.5°C. In all cases, the average length of fish in each group increased linearly with time, t, in a range from 10 to 30 mm. The variances about these mean lengths increased approximately as t^2. A partial differential equation model can be useful in expressing the dynamics of populations in which size distributions are taken into consideration. Applied to our experiment, this type of model shows that both of the observed length-versus-time phenomena are expected if the rates of increase of length of fish are independent of length and that these rates for individual fish are normally distributed about some mean rate of growth. The variance of individual growth rates needed to produce the observed length-versus-time data can be calculated from the model.

Comment

The paper presents a complex growth function (length) which accounts for mean individual growth and variance during early larval stages. While the model appears to be applicable to Maryland species and accounts for variability, the lack of the inclusion of growth rates at later stages may complicate its general use.

Gallucci, V.F., and T.J. Quinn. 1979. Reparameterizing, fitting, and testing a simple growth model. Trans. Am. Fish. Soc. 108:14-25.

Abstract

If the von Bertalanffy growth model is used to statistically compare the properties of growth in two spatial regions by examination of the estimates of the growth parameter k and the asymptotic length parameter L_∞, a possible compound null hypothesis H_o, is H_o: $k_1 = k_2$ and $L_{\infty 1} = L_{\infty 2}$ for regions 1 and 2. Since the results of this two-parameter test may be difficult to interpret, an alternative procedure is suggested. In addition, the interpretation of the test must be based upon the nature of the data as well as upon the parameter estimates.

A regression fit of the model to real but "inappropriate" data may yield a very "good" statistical fit but unrealistic estimates. The use of a third parameter (for example, t_0, the time when length is zero) is necessary to uniquely specify a solution; its inclusion always enhances the statistical fit. Because of the interdependence between parameters k and L_∞, we reparameterize the von Bertalanffy model with a new parameter $\omega = k \cdot L_\infty$. The parameter corresponds to the growth rate near t_0 and is suitable for comparisons because of its statistical robustness. In general, the standard Ford-Walford method of estimating the model's parameters is now obsolete and should be replaced with widely available nonlinear regression programs. Such programs generally estimate a variety of statistical criteria that facilitate a quantitative comparison of the growth parameters in H_0 above.

Comment

The paper presents a reparameterization of the von Bertalanffy parameters incorporating t_0 (the time when length is zero) and combining k (growth rate) and L_∞ (maximal length). The method proposed is easily implemented and statistically robust for all yield models including von Bertalanffy growth formulations.

Kitchell, J.F., D.J. Stewart, and D. Weininger. 1977. Application of a bioenergetics model to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). J. Fish. Res. Bd. Canada 34:1922-1935.

Abstract

A simple energy budget equation is developed to yield a bioenergetics model designed to simulate fish growth. Parameters for the model are estimated from the literature for application to yellow perch (Perca flavescens) and walleye (Stizostedion vitreum vitreum). Simulations are presented that demonstrate model output as functions of body size, activity level, ration level, food quality, and environmental temperature. Sensitivity analyses identify the importance of food consumption, activity, and excretion as biological processes represented in the parameters. On the basis of temperature conditions in selected lakes and specified feeding levels, simulations are presented to quantify the importance of year-to-year variation of temperature in determining growth. In heterothermal systems, temperature selection by periods can have a significant effect on growth. For walleye on fixed rations, annual growth can vary from zero to twofold increments due entirely to differences in summer temperatures. Variations in food quality have lesser effects.

Comment

This simulation model represents growth bioenergetically. Its application to yellow perch in Maryland could prove useful in the production of a simulation yield model for the Maryland stock. Its primary flaw is its need for large amounts of site-specific data concerning consumption, metabolism, excretion, and egestion.

This submodel requires the estimation of 17 parameters representing these bodily functions.

Knight, W. 1969. A formulation of the von Bertalanffy growth curve when the growth rate is roughly constant. J. Fish. Res. Bd. Canada 26:3069-3072.

Abstract

The author contends that the parameters of any growth curve should be a direct description of the graphical appearance of the data. For growth that is even approximately linear this is not true of the von Bertalanffy curve in its usual form (von Bertalanffy, Human Biol. 10: 181-213, 1938). On the above grounds, an alternate form of the von Bertalanffy curve for use in such instances is proposed.

Comment

This paper presents a linearization of the von Bertalanffy growth equation which adds a correction factor corresponding to the degree of nonlinearity of the growth data. This approach adds little to the conceptualization of a general growth submodel but does allow a more exact fit to existing growth data.

Pratt, D.M., and D.A. Campbell. 1956. Environmental factors affecting growth in Venus mercenaria. Limnol. Oceanogr. 1:2-17.

Abstract

The results of a five years' study of variations in quahog growth rates in Narragansett Bay are summarized. Linear increments are inversely proportional to initial length over the size range 35-70mm (greatest dimension), whereas volumetric increments in this range are approximately constant. Growth in some parts of the Bay is three times as fast as in others. Most of the year's growth occurs before mid-July, and growth rates showed no significant variation from year to year. Annual increments in Narragansett Bay are considerably greater than at Prince Edward Island, and they appear to fall in the same general range as those reported for New Jersey and the south side of Cape Cod.

The effects of various environmental factors on growth have been investigated over a three-year period. Growth was not appreciably influenced by existing differences in current speed, dissolved oxygen content, or salinity of the bottom water. Temperature imposes an upper limit to the potential rate of growth, which is negligible below 10°C and rises with increasing temperature at least to 23°C. Comparisons of growth rates with phytoplankton concentrations suggest that small diatoms, either living or as detritus, are an important source

of quahog nutrition in these waters. Growth is retarded in sediments with a high silt-clay content. This effect is discussed in relation to the concomitant reduction in sediment permeability, the possible accumulation of inhibitory substances, and the necessity for more frequent clearing of the animals' filtering apparatus.

Comment

The paper presents a simple linear regression showing the effects of temperature, sediment grain size, and phytoplankton concentration on the growth rates of quahog clams. Its only foreseeable use for Maryland fishery is to accent the need to account for environmental variation in growth simulations, particularly for sedentary invertebrates.

Richards, F.J. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10:290-300.

Abstract

The application of an extended form of von Bertalanffy's growth function to plant data is considered; the equation has considerable flexibility, but is used only to supply an empirical fit. In order to aid the biological analysis of such growth data as are capable of representation by the function, general rate parameters are deduced which are related in a simple manner to its constants.

Comment

This paper presents a generalized von Bertalanffy growth relationship and an excellent discussion of all the mathematical formulations of growth (monomolecular, autocatalytic, and Gompertz). While the presentation is primarily theoretical in nature, it removes many of the restrictive assumptions of von Bertalanffy growth. It could prove useful (but application may be difficult) for Maryland species.

Taylor, C.C. 1962. Growth equations with metabolic parameters. J. Cons., Cons. Int. Explor. Mer. 27:270-286.

Abstract

Growth in weight is the difference between anabolic and catabolic processes. These are taken as proportional to length to the power of a and b. Equations giving the length at any time, and also relating length to the power of b-a at successive times are deduced. If b-a=1 these reduce to the Bertalanffy equation and the Ford-Walford plot. Other values of a and b may produce parabolic growth, or an inflection in curve of growth in length. Possible values of a and b based physiological data are discussed, as are changes in the other growth parameters with environmental factors, including food and temperature.

The methods are applied to data of several species, including char, sturgeon, and sardine.

Comment

This paper presents extensions of the von Bertalanffy equation to situations where length and weight are not related by a cubic exponent. The approach is primarily theoretical (related to metabolic rates) and the exponential value of the basic von Bertalanffy growth equation is the difference between the exponential relationship of surface area to length and the relationship of weight to length. This approach does not appear to be useful or easily applied to Maryland fisheries.

Ursin, E. 1967. A mathematical model of some aspects of fish growth, respiration, and mortality. J. Fish. Res. Bd. Canada 24:2355-2393.

Abstract

A simple metabolic model describing growth as the difference between what enters the body and what leaves it, is elaborated assuming that synthetic building-up processes (the anabolism) are consuming energy supplied by processes of decomposition of the break-down (the catabolism). This leads to partitioning total catabolism into two components, one being a function of the rate of synthesis, another keeping the body functioning independently of synthesis. The rate of synthesis is described as a function of food taken, of the efficiencies of digestion and energy conversion, and of the absorbing surface of the intestine. Catabolic processes are supposed to be functions of the oxygen concentration in the water, the absorbing surface of the gills, and the rate of oxygen transport. Both kinds of processes are made functions of temperature in the way enzymatic processes usually are. Assuming that molecular interactions accidentally go wrong makes natural mortality, like growth, a function of the rates of anabolic and catabolic processes and body size.

Application of the model to data of length-at-age, food and oxygen consumption, weight loss, gill area, and natural mortality indicates that at least some of the main hypotheses cannot be rejected on available evidence.

Comment

This paper presents excellent submodels of growth and natural mortality based on the bioenergetics of anabolism and catabolism. Unfortunately, it cannot be practically employed for Maryland fisheries due to the large number of parameters and amount of data necessary for the determination of growth or natural mortality (81 parameters to determine the estimated growth and natural mortality). These submodels are theoretically complete but practically unusable.

Ware, D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. J. Fish. Res. Bd. Canada 32:2503-2512.

Abstract

A set of density-dependent growth and survivorship equations is derived from evidence that the instantaneous death rate in the sea is inversely proportional to particle size. The survivorship equation reproduces several well-known phenomena observed in fish populations. It predicts: 1) that winter and spring spawning species ought to produce larger eggs than summer spawners, 2) that it is advantageous for species that spawn in batches to produce progressively smaller eggs in spring and summer, and 3) that the death rate of a cohort of fish should decrease continuously as the survivors grow and approach the critical size.

The biological basis for the observed variation in the size of pelagic fish eggs and larvae is thought to be due primarily to trophic relations within the pelagic community. It is suggested from what is known of the relative abundance and foraging capabilities of different sized particles, that the survival rates of larval and juvenile fish should increase as they grow and occupy a progressively higher position in the food chain.

Comment

This paper presents a method of determining natural mortality rates of larval fish from growth rates. The procedure requires many parameters which are poorly defined biologically and appear to be difficult to measure in situ. While this assessment of mortality and growth appears biologically reasonable, its application would not be practical.

Yamaguchi, M. 1975. Estimating growth parameters from growth rate data. Oecologia 20:321-332.

Abstract

The time interval over which growth rates are measured modified the observed growth rates in non-linear growth curves. Growth rates obtained from a sigmoid curve such as the logistic growth equation may appear as if they were derived from the non-sigmoid von Bertalanffy growth equation when the small stage is not represented in the hypothetical growth observation. The inflection point of a sigmoid curve may be underestimated in non-instantaneous growth rate data when they are plotted on a graph against the initial sizes. This problem is significant for marine macro-benthos, whose growth is likely to be sigmoid and initiates mostly at microscopic sizes, when the popular von Bertalanffy growth equation is fitted to the observed growth rate data. Even when the von Bertalanffy growth equation appears to represent the observed growth rates adequately,

extrapolation of the equation toward the smaller stage may require an independent investigation.

Comment

This paper presents a method of determining growth parameters from changes in individual size through time. It can be easily applied and may be useful in evaluating the growth of oysters and clams.

Mortality Submodels (Fishing)

Brown, B.E., J.A. Brennan, and J.E. Palmer. 1979. Linear programming simulations of the effects of bycatch of mixed species fisheries off the northeastern coast of the United States. Fish. Bull. 76:851-860.

Abstract

We evaluated the results of using historic bycatch (incidental catch) ratios in adjusting fishing regulations by linear programming techniques. We used both 1971 and 1973 bycatch ratios separately to assess the sensitivity of the results to the reported changes in bycatch ratios in estimating the total 1975 catch of countries fishing in the northwest Atlantic. For 4 of the 11 countries for which data were examined, the difference between the percentage of a country's species total allowable catches (i.e., those catches allowed a country by regulation) using the 1971 and 1973 bycatch ratios, was at least 20%. Only four countries were predicted to catch at least 80% of their species total allowable catches. The predicted total catches of all countries and all species was only 60% of the total species quotas. The simulated directed fisheries constituted only 70% of the total catch using 1971 bycatch ratios and only 73% using 1973 bycatch ratios. Examination of the reported 1975 catches indicated that the total allowable catches for herring were most frequently limiting a country's catch. Except for USSR, the differences between reported and simulated catches were less than 50 metric tons, with the difference less than 10 metric tons for 6 of the 11 countries. There was little difference in reported versus simulated catches between the schemes using the 1971 and 1973 bycatch ratios.

Comment

This paper presents a statistical method of incorporating bycatch mortality rates into fishing mortality rates. Their use of bycatch-catch figures makes this procedure difficult to employ for Maryland fisheries due to the probability that bycatch data for Maryland fisheries do not exist.

Francis, R.C. 1974. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock production model. J. Fish. Res. Bd. Canada 31:1539-1542.

Abstract

The often-used approximation that, for a stock of fish under exploitation, the instantaneous fishing mortality rate equals the instantaneous natural mortality rate at the point of the maximum sustainable yield is examined with respect to its mathematical roots and practical utility. Examples from two diverse fisheries are utilized.

Comment

This paper does not present a submodel but simply discusses the relationship of natural and fishing mortality at MSY for populations operating under the assumption of logistic growth. It will not provide a useful submodel for this project.

Van Winkle, W., D.L. DeAngelis, and S.R. Blum. 1978. A density-dependent function for fishing mortality rate and a method for determining elements of a Leslie matrix with density-dependent parameters. Trans. Am. Fish. Soc. 107:395-401.

Abstract

A density-dependent function for the instantaneous fishing mortality rate is presented. It is shown that this function may be readily incorporated into the age-specific probability of survival in a Leslie-matrix population model.

A method is presented for indirectly determining the probability of survival for age-class 0 of a fish population using a density-dependent Leslie matrix. The method involves the two constraints that the population be at equilibrium and that the index of absolute population size in the density-dependent function be assigned a value. In addition, given the probability of survival for age-class 0, it is shown that the probability of survival through a selected life stage within age-class 0 can be indirectly determined. Three problems in modeling a fish population using a Leslie model are discussed in light of the difficulties involved in modeling density dependence due to insufficient information and lack of understanding concerning density-dependent phenomena.

Comment

This paper presents a methodology for decomposing instantaneous fishing mortality into density-dependent and independent terms. While this decomposition is well based, information on the estimation of the density-independent and dependent weighing factors is not included in the presentation except in the special cases where F_{DI} or F_{DD} is equal to zero. This formulation is too theoretical for application to Maryland species.

Young, W.D. 1975. An analysis of the effect of seasonal variability of harvest on the estimate of exploitation rate. Trans. Am. Fish. Soc. 105:45-47.

Abstract

Five functional forms for the seasonal distribution of force of fishing mortality were used in determining expectations of death from fishing. Expectation of death from fishing calculated from E/F = A/Z was compared to the actual expectation of death from fishing determined by numerical integration. Bias results in the formula-calculated expectation of death from fishing if the force of fishing mortality is not a constant fraction of the force of total mortality. Bias is greater when the force of fishing mortality is more asymmetrical. Bias is positive when greater force of fishing mortality occurs early in the year; negative bias occurs when force of fishing mortality is greater later in the year. The magnitude of bias, for a given functional form of force of fishing mortality, is a function of the relative size of force of fishing mortality to force of total mortality.

Comment

This paper presents the addition of seasonal variation to fishing mortality rates in a very theoretical framework. It assumed prior knowledge of the functional form of fishing mortality and simply investigates the consequences of altering that form. It appears to be a better practice to subdivide the time scale into periods of apparently equal fishing pressure than to employ this form of seasonal variation.

Mortality Submodels (Natural)

Brousseau, D.J. 1978. Population dynamics of the soft-shell clam, *Mya arenaria*. Mar. Biol. 50:63-71.

Abstract

A life table was constructed for *Mya arenaria* from Gloucester, Massachusetts, USA, based on schedules of age-specific fecundity and mortality determined under natural conditions. Mortality rates decrease with size and age in this species, with the period of maximum mortality occurring during the summer months. Mortality rates during the fall and winter were considerably lower, perhaps due to the inactivity of natural predators. The survivorship curve for *M. arenaria* approximates the Type 3 curve of Deevey (1947). Mean life expectancy is low in recently-settled clams, peaks when the individual reaches 30.0 to 34.9 mm (1 year

of age), and remains fairly high for most of the remainder of life. The intrinsic rate of natural increase (r_{max}) is very high: 4.74. This enormous rate of potential increase is offset by high rates of larval mortality in the plankton. Unlike the reproductive values of most animals studied, those in M. arenaria peak late in life, well after the known age of first reproduction. This is probably the result of increased fecundity with age. The implications of this work in the area of resource management are discussed.

Comment

This paper presents the use of life tables to determine the intrinsic rate of natural increase (r). Size-specific natality and mortality were converted to age-specific rates using the von Bertalanffy age-size relationship. This procedure will be of little use for this project.

Butler, S.A., and L.L. McDonald. 1979. A simulation study of a catch-effort model for estimating mortality rates. Trans. Am. Fish. Soc. 108:353-357.

Abstract

The properties of the estimators of the instantaneous natural mortality rate, M, and the instantaneous exploitation rate, q, are investigated for a multiple regression model of catch-effort data developed independently by D.G. Chapman and J.E. Paloheimo. It is assumed that the units of effort are coded such that the values of effort fall in an interval (a,b). Values of M and q are then considered which will give realistic probabilities of mortality over two to 10 time periods. It is shown in a simulation study that the approximation used to arrive at the regression model is accurate. However, when sampling error is taken into consideration, the estimators of M and q do not simultaneously have acceptable properties in the ranges anticipated in practice.

Comment

This paper presents an accepted methodology for computing instantaneous natural and fishing mortalities using catch/unit effort and total effort data. A statistical and simulation analysis of this submodel shows the variables to be covariant and a good estimate of one provides a meaningless estimate of the other. The procedures presented here are not directly applicable.

Marten, G.G. 1978. Calculating mortality rates and optimum yields from length samples. J. Fish. Res. Bd. Canada 35:197-201.

Abstract

An equation is derived for yield per recruit of a fishery (or other exploited animal population) as a function of fishing intensity

and age of first capture. The equation has the advantage that it does not require explicit estimates of natural mortality or individual growth rate parameters. Linear length growth is assumed until maximum size is reached, and mortality parameters are expressed relative to growth rate. Mortality parameters are estimated from average length samples of separate populations experiencing different fishing efforts in the same fishery. The equation may be used to compare existing fishing efforts and age of first capture with optimal values. Samples of the catfish, Bagrus docmac, from Lake Victoria (East Africa) are used to illustrate the method.

Comment

This paper presents a methodology for the determination of total mortality and natural mortality from population length parameters (length at time zero, asymptotic length, and mean length). The assumptions of equal growth and natural mortality used to determine natural mortality from mean lengths in two populations under different fishing pressure are weak, but the method may provide useful estimates for Maryland species where no other data exist.

Paloheimo, J.E. 1961. Studies on estimation of mortalities: I. Comparison of a method described by Beverton and Holt and a new linear formula. J. Fish. Res. Bd. Canada 18:645-662.

Abstract

A method, described by Beverton (1954) and Beverton and Holt (1956 and 1957), giving estimates of the natural mortality rate, M, and the catchability coefficient, q, from catch at age and effort data, is examined. This method requires 4 to 5 iterations to arrive at the estimates. We have derived approximate solutions for q and M in a closed form. This makes the laborious iterations unnecessary, and gives virtually the same values as arrived at by iterations.

The effectiveness of the iterative Beverton and Holt method is evaluated by calculating q and M in 30 hypothetical examples. A new and simple (linear formula) method for estimating q and M is derived. Application of the new method to these 30 examples resulted in a 48% reduction of the standard deviation of q and a 45% reduction in that of M. The new method is in part the same as one suggested by Gulland, Beverton, and Holt (Beverton et al., MS, 1958; Holt, MS, 1959) to arrive at initial values in their short-cut (iterative) method of estimating the mortality rates. We show that these initial values are actually better estimates than the final values arrived at by the iteration.

Neither the Beverton and Holt method nor the linear formula give necessarily unbiased estimates; the bias depends on the types of variability in the data.

To arrive at non-biased, least-squares estimates would require ancillary information not normally available on the distributions of the three variates: catch at age, effort, and catchability coefficient.

Comment

This paper presents a method of estimating natural mortality and catchability which simplifies an earlier Beverton-Holt method. The simplification requires primarily effort data and could be useful for Maryland stocks.

Polgar, T.T. 1978. Striped bass icthyoplankton abundance, mortality, and production estimation for the Potomac River population. Pages 109-125 In W. Van Winkle (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Administration and Electric Power Research Institute.

Abstract

Methods are developed for estimating, from field survey data, the mortality rate and production for each successive ichthyoplanktonic stage. The abundance estimators used in the computation of these quantities are also derived. An age-dependent, ichthyoplankton population model is developed assuming either a uniform age distribution or an exponential age distribution within each stage. Striped bass egg and larval data from a 1974 ichthyoplankton survey in the Potomac River are used in model computations. The various model estimates are evaluated qualitatively, and the usefulness and limitations of the models are discussed.

Comment

This paper and subsequent work by the author provide a framework to determine natural mortality rates for fish populations exhibiting variable yearclasses. This approach will prove to be very helpful in this project.

Robson, D.S., and D.G. Chapman. 1961. Catch, curve and mortality rates. Trans. Am. Fish. Soc. 90:181-189.

Abstract

The assumptions necessary to obtain a valid estimate of survival rate from a single catch curve are discussed. An example of the best estimate of survival rate and its variance is worked out for the case that age is known exactly for the entire sample. A test for validity of the model is illustrated. Methods of estimating the survival rate are also given when some age groups are combined, when an age-length key is used, and when only a segment of the catch curve is usable. A table is provided to facilitate the estimation in this last case.

Comment

The paper presents a simplistic method for determining natural mortality rates from catch curves and age distributions. The determination requires several assumptions which may not be reasonable for Maryland species (i.e., constant survival rate, constant yearclass strength) but may prove useful in some cases.

Ursin, E. 1967. A mathematical model of some aspects of fish growth, respiration, and mortality. J. Fish. Res. Bd. Canada 24:2355-2393.

Abstract

A simple metabolic model desribing growth as the difference between what enters the body and what leaves it, is elaborated assuming that synthetic building-up processes (the anabolism) are consuming energy supplied by processes of decomposition of the break-down (the catabolism). This leads to partitioning total catabolism into two components, one being a function of the rate of synthesis, another keeping the body functioning independently of synthesis. The rate of synthesis is described as a function of food taken, of the efficiencies of digestion and energy conversion, and of the absorbing surface of the intestine. Catabolic processes are suggested to be functions of the oxygen concentration in the water, the absorbing surface of the gills, and the rate of oxygen transport. Both kinds of processes are made functions of temperature in the way enzymatic processes usually are. Assuming that molecular interactions accidentally go wrong makes natural mortality, like growth, a function of the rates of anabolic and catabolic processes and body size.

Application of the model to data of length-at-age, food and oxygen consumption, weight loss, gill area, and natural mortality indicates that at least some of the main hypotheses cannot be rejected on available evidence.

Comment

This paper presents excellent submodels of growth and natural mortality based on the bioenergetics of anabolism and catabolism. Unfortunately, it cannot be practically employed for Maryland fisheries due to the large number of parameters and amount of data necessary for the determination of growth or natural mortality (81 parameters to estimate growth and natural mortality). These submodels are theoretically complete but practically unusable.

Van Sickle, J. 1977. Mortality rates from size distributions. Oecologia 27:311-318.

Abstract

A population model explicitly describing the dynamics of an arbitrary population size distribution is presented. One consequence of the model is an equation for the exact shape of the size distribution of a stationary or steady-state population. The shape is expressed as a function of size-specific mortality and growth rates. From the equation, various mortality estimation formulas can be derived, two of which are discussed in detail. One of the methods permits estimation of size-specific mortality rates without the assumption of a theoretical growth model.

Comment

This paper presents a useful and easily employed estimate of natural mortality rates using only a knowledge of recruitment and size-frequency distributions. The procedure may be useful for the determination of natural mortality rates for oysters and clams.

Ware, D.M. 1975. Relation between egg size, growth, and natural mortality of larval fish. J. Fish. Res. Bd. Canada 32:2503-2512.

Abstract

A set of density-dependent growth and survivorship equations is derived from evidence that the instantaneous death rate in the sea is inversely proportional to particle size. The survivorship equation reproduces several well-known phenomena observed in fish populations. It predicts: 1) that winter and spring spawning species ought to produce larger eggs than summer spawners, 2) that it is advantageous for species that spawn in batches to produce progressively smaller eggs in spring and summer, and 3) that the death rate of a cohort of fish should decrease continuously as the survivors grow and approach the critical size.

The biological basis for the observed variation in the size of pelagic fish eggs and larvae is thought to be due primarily to trophic relations within the pelagic community. It is suggested from what is known of the relative abundance and foraging capabilities of different sized particles, that the survival rates of larval and juvenile fish should increase as they grow and occupy a progressively higher position in the food chain.

Comment

This paper presents a method of determining natural mortality rates of larval fish from growth rates. The procedure requires many parameters which are poorly defined biologically and appear to be difficult to measure in situ. While this assessment of mortality and growth appears biologically reasonable, its application would not be practical.

Mortality Submodels (Total)

Ssentongo, G.W., and P.A. Larkin. 1973. Some simple methods of estimating mortality rates of exploited fish populations. J. Fish. Res. Bd. Canada 30:695-698.

Abstract

Some simple equations are derived from mortality functions that enable estimation of the total mortality coefficient from the mean age and the age of first capture, or the mean length and the length of first capture, of fish in a catch.

Comment

This paper presents a methodology by which an estimate of total mortality rate can be determined from mean age and age of first capture of mean length and length of first capture. Since it does not partition total mortality (Z) into natural (M) and fishing (F) mortality rates, the procedure is of little use to this project. Subsequent works have expanded this procedure by partitioning total mortality into its component parts.

Vaughan, D.S., and S.B. Saila. 1976. A method for determining mortality rates using the Leslie matrix. Trans. Am. Fish. Soc. 105:380-383.

Abstract

The Leslie matrix algorithm has been utilized to estimate mortality of a year class assuming an equilibrium population for a species. Under this assumption an estimate of the mortality for the 0^{th} year class of the Atlantic bluefin tuna (*Thunnus thynnus thynnus*) has been made indicating about five survivors from 10 million eggs in the first year of life. The mortality rates for later year classes were derived from empirical data.

Comment

This paper presents a procedure for the calculation of total mortality rates using age-specific fecundity and assuming an equilibrium population level. This assumption realistically makes the use of this procedure impractical for Maryland fisheries, but in some situations the method may prove useful.

Parameter Estimation (Specific Yield Models)

Fox, W.W., Jr. 1971. Random variability and parameter estimation for the generalized production model. Fish. Bull. 69:569-580.

Abstract

Three alternative statistical models are proposed for estimating the parameters of the generalized production model by the method of least squares. A stochastic representation of the generalized production model is constructed and simulation (or the Monte Carlo Method) is employed to infer the effects of random variability on the variation in catch. The use of residuals examination for selecting the appropriate statistical model for least-squares estimation of the generalized production model parameters is demonstrated for the yellowfin tuna fishery in the eastern tropical Pacific Ocean. In both the simulation and actual fishery, statistical Model 3 --- assuming catch residual variance is proportional to the catch squared --- best fulfills the assumptions of least-squares theory and should, therefore, provide the best least-squares parameter estimates.

Comment -- Applicable model - Surplus production models

This paper presents four easily utilizable methods of estimating Schaefer, Pella-Tomlinson, and Fox surplus production model parameters employing least-squares criteria. Two of these approaches do not meet several of the assumptions concerning parameter residuals and residual variance.

Fox, W.W., Jr. 1975. Fitting the generalized stock production model by least-squares and equilibrium approximation. Fish. Bull. 73:23-37.

Abstract

A least-squares method for fitting the generalized stock production to fishery catch and fishing effort data which utilizes the equilibrium approximation approach is described. A weighting procedure for providing improved estimates of equilibrium fishing effort and an estimator of the catchability coefficient are developed. A computer program PRODFIT for performing the calculations is presented. The utility and performance of PRODFIT is illustrated with data from a simulated pandalid shrimp population.

Comment -- Applicable model - Surplus production models

This paper adds parameter estimation methods of equilibrium approximation to the least-squares criteria presented in an earlier paper. This approach can be easily used for deriving the surplus production model parameters α and β. Estimation procedures to determine q, catchability, are also presented in an easily employable form. PRODFIT, a computer program, is presented, which determines these parameters.

Rivard, D., and L.J. Bledsoe. 1978. Parameter estimation for the Pella-Tomlinson stock production model under non-equilibrium conditions. Fish. Bull. 76:523-534.

Abstract

To estimate the parameters of the Pella-Tomlinson model, as restructured by Fletcher, we suggest a derivative-free version of the Levenberg-Marquardt algorithm, along with an algorithm that locates starting values for the iterative procedure. The iterative method of Levenberg-Marquardt was applied to two versions of the restructured model: five parameters were estimated in the first version and three in the second, the latter preventing degeneracy of the model to exponential form. We discuss in particular the causes of the degeneracies associated with previous applications of the model. Such faults lie, inherently, with the mathematical indeterminacy of the system equations themselves, so that all nonlinear estimation methods will tend to be inefficient in the absence of external constraints. The effectiveness of the Levenberg-Marquardt method was evaluated by Monte-Carlo simulation. As examples, we analyzed catch-effort data from the yellowfin tuna fishery of the eastern Pacific and catch-effort data from the Pacific halibut fishery (Area 2 of the International Pacific Halibut Commission).

Comment -- Applicable model - Pella-Tomlinson surplus production model (as altered by Fletcher)

This paper presents a methodology for estimating the five parameters necessary to fit the Pella-Tomlinson yield equation in non-equilibrium conditions using a Levenberg-Marquardt algorithm. The authors present a procedure for estimating the variability of these parameters as well. These estimates are easily determined and in most instances accurate for the Pella-Tomlinson yield determination.

Walter, G.G. 1975. Graphical methods for estimating parameters in simple models of fisheries. J. Fish. Res. Bd. Canada 32:2163-2168.

Abstract

A graphical method for calculating the coefficients for a Schaefer model of a fishery is introduced. It involves plotting catch per effort vs effort data and then correcting the values for disequilibrium of the fishery. A hypothetical and a realistic example are presented.

Comment -- Applicable models - Grahm and Schaefer surplus production models

This paper presents a simple methodology for the determination of the parameters of the Schaefer surplus production model. These estimates are corrected according to the disequilibrium conditions of the fishery. An estimate of catchability is also determined. These estimates are easily obtained, and the data necessary for the estimates are minimal.

Recruitment Submodels

Allen, K.R. 1968. Simplification of a method of computing recruitment rates. J. Fish. Res. Bd. Canada 25:2701-2702.

Abstract

A simplification of a method for computing the proportion of new recruits in each year-class in each year's catch from annual age composition is presented.

Comment

This simplification is easily applicable to Maryland stocks for which annual age compositions and fishing rates are known. The method could provide important input information for non-equilibrium surplus production models and simulation models.

Christensen, S.W., D.L. DeAngelis, and A.G. Clark. 1978. Development of a stock-progeny model for assessing power plant effects on fish populations. Pages 195-225 In W. Van Winkel (ed.), Assessing the Effects of Power-Plant-induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Adminstration and Electric Power Research Institute.

Abstract

A multi-age-class model, based on simple but general biological principles, is developed to assess the impact of power plants on fish populations. The model is then parameterized in order to produce a variety of stock-progeny relationships, assuming that the stock is always at stable age distribution. The predicted response of the fish stock to power plant cropping of young-of-the-year fish is investigated for each of these stock-progeny relationships. In general, the sensitivity of the equilibrium stock size to cropping is positively related to the slope of the stock-progeny curve at the equilibrium point and, to a lesser extent, negatively related to the slope of the curve at the origin. In addition, the timing of power-plant-induced mortality in relation to the timing of compensation is important. The maximum amount of power-plant-induced mortality that can be tolerated by the stock can be calculated from the slope of the curve at the origin. Application of the model to specific cases will likely need to utilize time-series simulations in addition to the steady-state approach investigated here.

Comment

This paper presents a workable submodel for density-dependent recruitment, but requires numerous parameters which will probably not be available for Maryland species.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Bd. Canada 11:559-623.

Abstract

Plotting net reproduction (reproductive potential of the adults obtained) against the density of stock which produced them, for a number of fish and invertebrate populations, gives a domed curve whose apex lies above the line representing replacement reproduction. At stock densities beyond the apex, reproduction declines either gradually or abruptly. This decline gives a population a tendency to oscillate in numbers; however, the oscillations are damped, not permanent, unless reproduction decreases quite rapidly and there is not too much mixing of generations in the breeding population. Removal of part of the adult stock reduces the amplitude of oscillations that may be in progress and, up to a point, increases reproduction.

Comment

This paper presents one of the most extensive treatments of recruitment models. Most of the treatments are directed towards salmon and are thus of little direct value for Maryland fisheries. The paper primarily presents hypotheses with numerous examples, but with little or no mathematical formulation. Regardless, this family of recruitment curves will prove helpful in this project.

Yearclass Strength Submodels

Stevens, D.E. 1977. Striped bass (Morone saxatilis) year class strength in relation to river flow in the Sacramento-San Joaquin estuary, California. Trans. Am. Fish. Soc. 106:34-42.

Abstract

Striped bass, Morone saxatilis, abundance indices were developed from two analyses of sportfishing party boat catch statistics for the Sacramento-San Joaquin Estuary. These analyses cover the periods 1938-1954 and 1958-1972. The abundance indices provided evidence that the size of the fishable population fluctuated by a factor of 3.7 during the latter period and that river flows in the first summer of life affected recruitment during both periods.

Comment

This paper presents a simple statistical relationship between freshwater discharge and young striped bass survival. It will probably not be useful for determining yearclass strengths in Maryland striped bass stocks.

Walter, G., and W.J. Hoagman. 1975. A method for estimating year class strength from abundance data with application to the fishery of Green Bay, Lake Michigan. Trans. Am. Fish. Soc. 104:245-255.

Abstract

A method of calculating indices of annual year class strength from abundance data only is introduced. It involves a mathematical technique based on difference equations. The method is applied to data for six commercially harvested species of Green Bay, Lake Michigan. Estimated year class strengths are then compared with relative abundance indices of the parental spawning populations. Only for smelt and perch was there a significant correlation between the two. The same species were also the only ones for which the exponential relation of Ricker between spawners and year class strengths could be established.

Comment

This paper presents a relatively complex submodel which predicts yearclass strength from the biomass of exploitable stock, the biomass of newly recruited exploitable stock, the hatching biomass, and pre- and post-recruitment survival rates. It may prove useful for Maryland species which exhibit variable yearclasses, but the data necessary for its use probably do not exist.

APPENDIX C

An annotated bibliography of methods of data acquisition

for stock management models

Age Structure

White, M.L., and M.E. Chittenden. 1977. Age determination, reproduction and population dynamics of the Atlantic croaker, Micropogonias undulatus. Fish. Bull. 75:109-123.

Abstract

A validated scale method of age determination is described for the Atlantic croaker, Micropogonias undulatus. Two age-classes were usually observed, but only one was abundant. Mean total lengths were 155-165mm at age I and 270-280mm at age II based on three methods of growth estimation. Fish matured near the end of their first year of life when they were about 140-170mm total length. Spawning occurred from at least September through March, but there was a distinct peak about October. Somatic weight-length relationships varied monthly, and changes appeared to be associated with maturation and spawning. Somatic weight reached a maximum in June, and the minimum was observed in March. Maximum somatic weight loss (24%) occurred in March, but no data were obtained from December through February. In estuaries, age 0 croaker apparently occupied soft-substrate habitats and older fish occurred near oyster reefs. Life spans were only 1 or 2 yr, and the total annual mortality rate was 96%. The above life history pattern appears similar for croaker found throughout the Carolinian Province. Contrasts are presented to illustrate differences in the life histories and population dynamics of croaker found north and south of Cape Hatteras, N.C. A parallel is drawn with apparently similar changes in the American shad, Alosa sapidissima, and the suggestion is made that changes in the population dynamics of species that traverse the Cape Hatteras area may represent a general phenomenon.

Growth

DuPaul, W.D., and J.D. McEachran. 1973. Age and growth of the butterfish, Peprilus triacanthus, in the lower York River. Ches. Sci. 14:205-207.

Abstract

Age, rate of growth and the length-weight relationship of the butterfish, Peprilus triacanthus, were determined. The age of specimens collected in September, 1969 from the lower York River, Virginia, was determined by counting rings in the otoliths. Four age groups were represented in the sample: young-of-the-year fish (91-95mm), year-old fish (98-139mm), two-year-old fish (142-187mm), and three-year-old fish (174-200mm). The length-weight relationship for all specimens is: $\log W = -5.1852 + 3.2646 \log L$.

Eldridge, P.J., W. Waltz, R.C. Gracy, and H.H. Hunt. 1976. Growth and mortality rates of hatchery seed clams, Mercenaria mercenaria, in protected trays in waters of South Carolina. Proc. Nat. Shellfish. Assoc. 66:13-20.

Abstract

Seed hard clams, Mercenaria mercenaria, were planted in trays at densities of 290, 580, and 869/m^2 in three widely separated intertidal areas in South Carolina. Survival of clams was similar at each site although clams at Clark Sound experienced a lower survival rate. Growth of clams planted at Clark Sound and Albergottie Creek was significantly higher than those at Bull Bay. Growth occurred throughout the year with the best growth experienced in summer and fall.

Feder, H.M., and A.J. Paul. 1974. Age, growth and size-weight relationships of the soft-shell clam, Mya arenaria, in Prince William Sound, Alaska. Proc. Nat. Shellfish. Assoc. 64:45-52.

Abstract

Soft-shell clams, Mya arenaria, from Simpson Bay, William Sound, Alaska, were examined. A single sample of 178 specimens was used to determine the growth history of twelve year-classes by the annular method. In Prince William Sound soft-shell clams reach a harvestable size of 50 mm long in 6 or 7 years. Length-weight relationships are considered. Dry meat weight (solids) averaged 18.8%.

Knudsen, E.E., and W.H. Herke. 1978. Growth rate of marked juvenile Atlantic croakers, Micropogon undulatus, and length of stay in a coastal marsh nursery in southwest Louisiana. Trans. Am. Fish. Soc. 107:12-20.

Abstract

To estimate the growth rate of the Atlantic croaker 113,670 juveniles were marked and released between 23 January and 23 March 1975. The experiment was divided into five tests; in each, the fish were marked with a different fluorescent pigment. Recapture efforts produced 100 usable returns. Individual croakers appear to have had an average maximum stay of 1.8 months in the nursery. Growth rate was estimated by the regression of length of recaptured juveniles on time; estimates ranged from 0.51 to 0.99mm/day, all of which were considerably higher than most estimates in the literature. There was a trend of increasing growth rate through the five tests. Length frequencies of 159,381 croakers taken in a trap at the study area outlet could not be interpreted in a reliable manner for growth rate estimates. Future attempts to estimate young-of-the-year croaker growth rates should use methods other than length frequency.

Ney, J.J., and L.L. Smith. 1975. First-year growth of the yellow perch, Perca flavescens, in the Red Lakes, Minnesota. Trans. Am. Fish. Soc. 104:718-725.

Abstract

First-year growth of the yellow perch, Perca flavescens (Mitchill), was determined from 28,241 young-of-the-year fish collected in the Red Lakes during the summer (1 July-20 August) in 15 seasons and on back calculations from I-annulus fish of the same year classes. Sexes did not differ in growth rate. Geographic variations in first-season growth occurred in 2 years but were not reflected at I-annulus. A consistent seasonal growth pattern in all years was linear through the summer sampling period. Growth rate after 20 August gradually declined and became nearly asymptotic by the end of the season. Growth during midsummer varied widely in different seasons, but length at I-annulus was relatively uniform (71-79mm) for most years as the result of apparent growth compensation. Negative correlations of length on 1 July with midsummer rate of growth and, consequently, with I-annulus length were noted. Although high summer water temperature appeared to exert a positive influence on growth, it did not obscure the compensatory phenomenon. Growth compensation is probably not affected by predation, but may be related to interaction of perch size and food availability.

Shelton, W.L., W.D. Davies, T.A. King, and T.J. Timmons. 1979. Variation in the growth of the initial year class of largemouth bass in the West Point Reservoir, Alabama and Georgia. Trans. Am. Fish. Soc. 108:142-149.

Abstract

West Point Reservoir, Alabama and Georgia, first reached full pool in spring 1975. Growth within the initial year class of largemouth bass (Micropterus salmoides) was highly variable. During the first summer of impoundment, length frequencies of the 1975 year class were characterized by a single mode. However, there was an obvious condition difference among individuals within the population. Generally, fish longer than 17cm total length were in relatively good condition and those 8-17cm long were in relatively poor condition. By fall (September to October), one segment of the population had grown rapidly but the other segment had grown little and a bimodal length-frequency distribution was evident. A shortage of available prey for the smaller fish was considered to be the cause of the growth disparity.

St. Pierre, R.A., and J. Davis. 1972. Age, growth, and mortality of the white perch, Morone americana, in the James and York rivers, Virginia. Ches. Sci. 13:272-281.

Abstract

More than 800 white perch, Morone americana, were collected from each of two major tributaries of southern Chesapeake Bay to compare

age structures, growth, and mortality rates. The James River is characterized by heavy domestic and industrial pollution in several tributaries and segments, whereas the York River is only slightly polluted.

Maximum ages determined by scale analysis were 7 and 10 years for males and females in both rivers. Yearling perch in the York River appeared to have a significantly greater mean length than those from the James but this difference is largely due to sampling bias. Both sexes of white perch from the James River were significantly larger than perch from the York River at ages II and III. However, mean lengths of white perch from age groups IV and older were not significantly different between rivers for either sex. In both rivers females were significantly longer (to age V) and heavier (all ages) than males of comparable age. Yearly growth increments were greatest early in life. All year classes of white perch followed a similar growth pattern during their first year in both estuaries. However, for later years of life earlier year classes apparently had a greater mean length than those from more recent years at comparable ages. Males were more abundant than females for the first 3 years of life in both rivers; however, females were present in significantly greater numbers in all older age groups. Analysis of relative age frequency suggested dominant year classes in 1964 and 1965 in the James River, and a weak year class in 1968. No dominant year classes were apparent from the York River collections.

Mortality rates were calculated from age frequency distributions. Total annual mortality in the James River was about 69% for males after age IV and for females after age VI. In the York River, males at age III and older die at a rate of 59%, whereas females older than age V have an annual mortality of 57%.

Schwartz, F.J., and R. Jachowski. 1965. The age, growth, and length-weight relationship of the Patuxent River, Maryland ictalurid white catfish, *Ictalurus catus*. *Ches. Sci.* 6:226-237.

Abstract

The age and growth of 470 white catfish captured in 1963 from the Patuxent River near Trueman Point, Maryland, was [sic] examined. Annual growth increments varied 25-45mm. Oldest river specimens were 12 years. The largest known Maryland specimen from a freshwater millpond was 14 years old. Length back calculations at each age were possible by the curved vertebral-fish length relationship formula $Y = 63.21 + 89.64X + .01X^2$. The length-weight relationship for the same specimens was best exemplified by the log formula $\log Y = 1.9791 + .1689 \log X$. In each case Patuxent specimens were shorter lived, shorter, and weighed less than those from other parts of its natural or introduced range.

Winget, R.R., C.E. Epifanio, T. Runnels, and P. Austin. 1976. Effects of diet and temperature on growth and mortality of the blue crab, *Callinectes sapidus*, maintained in a recirculating culture system. *Proc. Natl. Shellfish. Assoc.* 66:29-33.

Abstract

Blue crab growth parameters were measured over a sixty-day period in a recirculating culture system, with each crab in physical isolation. Dependent variables were molt interval, increase in carapace width per molt, percent molt and mortality. No consistent growth differences were detected in animals fed diets ranging from 26 to 75% protein content. A temperature of 30°C generally increased molt frequency and percent of animals molting compared to a temperature of 20°C. Increased temperature appears to depress cuticle expansion and to decrease mortality.

Migration

Lund, W.A., and G.C. Maltezos. 1970. Movements and migrations of the bluefish, Pomatomus saltatrix, tagged in waters of New York and Southern New England. Trans. Am. Fish. Soc. 99:719-725.

Abstract

Bluefish were tagged in and near Long Island Sound between 1964 and 1969. Tag returns support the belief that there is a discrete northern race of bluefish as more than 75% of the returns from fish at large more than one season return to the general area of Long Island Sound. Small bluefish move southward along the coast during late fall while adults, fish over approximately 45 cm total length, have an inshore-offshore migration.

Bluefish first arrive in the area when the water temperatures reach 12 to 15°C which is usually during May. The fish follow the warmer water by entering the inner bays of Long Island or going to the western end of Long Island Sound. Large numbers of bluefish arrive in the general area during late July and August after spawning in offshore waters. The fall migration takes place when the water temperature drops to approximately 13 to 15°C.

Nicholson, W.R. 1971. Coastal movements of Atlantic menhaden as inferred from changes in age and length distributions. Trans. Am. Fish. Soc. 100:708-716.

Abstract

Length frequency distributions of Atlantic menhaden, Brevoortia tyrannus, plotted by age, month, and latitude, support the hypothesis of an annual north-south movement. The majority of Atlantic menhaden, wintering in offshore waters south of Cape Hatteras, North Carolina, move northward in early spring. By about mid-June menhaden are distributed in coastal waters from Florida to Maine, their age and size increasing from south to north. A slow northward movement of fish north of False Cape, Virginia, continues throughout the summer. A southward movement, beginning in early September north of Cape Cod, Massachusetts, and involving all fish north of False Cape by November, culminates in

January when the majority of the population is again south of Cape Hatteras.

Nicholson, W.R. 1978. Movements and population structure of Atlantic menhaden indicated by tag returns. Estuaries 1:141-150.

Abstract

Over 968,000 adult Atlantic menhaden, Brevoortia tyrannus, were tagged from 1967 to 1969 and over 85,000 juvenile menhaden were tagged from 1969 to 1973. Recoveries of these tagged fish through 1975 provide direct evidence that Atlantic menhaden consist of a single population that overwinters in offshore waters off the southeastern coast of the United States, moves northward in spring and stratifies along the coast by age and size during summer, and moves southward in late autumn.

Mortality (Natural or Fishing)

Coates, P.G., A.B. Howe, and A.E. Peterson. 1970. Analysis of winter flounder tagging off Massachusetts, 1960-1965. Mass. Dept. Nat. Res., Div. Mar. Fish. 47 pp.

Abstract

From 1960 to 1965, 12,151 winter flounder, Pseudopleuronectes americanus (Walbaum), were tagged with Petersen tags at 21 locations off Massachusetts. Returns through 1967 totaled 4,105 or 33.8% with considerable variation between areas. The ratio of females to males at tagging was 2.3. Movement was apparently related to water temperature and was greatest south of Cape Cod. Intermingling of breeding adults was more evident south of Cape Cod than north of the Cape. Little mixing was evident between Georges Bank and inshore areas. Returns during successive spawning seasons indicated some homing movement. Growth rate varied with area and females grew larger than males in all areas. Survival and mortality rates calculated from annual returns show that flounder inshore south of Cape Cod were exploited at a higher rate than those offshore. Returns showed negligible foreign exploitation. Standing crop was greater south and east of Cape Cod than on Georges Bank. Patterns of movement and other information suggest the existence of three groups of winter flounder off Massachusetts. Massachusetts trawling regulations and effects of increases in winter flounder exploitation are discussed.

Dryfoos, R.L., R.P. Cheek, and R.L. Kroger. 1973. Preliminary analysis of Atlantic menhaden, Brevoortia tyrannus, migration, population structure, survival and exploitation rates, and availability as indicated from tag returns. Fish. Bull. 71:719-734.

Abstract

Over 1 million adult Atlantic menhaden, Brevoortia tyrannus, were tagged from Long Island Sound to Florida between 1966 and 1969. Tag recoveries indicate these fish migrated northward in spring and early summer and southward in fall. As the fish grew older and larger, they also migrated farther northward each spring. Calculation of rates of interchange between fishing areas indicated that 21% of the recoveries from fish released in Chesapeake Bay in 1967 and 1968 accounted for 72% of the catch of tagged fish 1 year later in New York and New Jersey.

Preliminary estimates of population parameters were made from tag-recovery and catch data. Survival rates determined yearly from rate of recoveries, however, varied due to fluctuations in availability. Annual survival rates averaging 0.23 were calculated with Robson-Chapman catch curve analysis and age composition of catch methods. From tag recoveries, exploitation rate was extimated to be 50%, instantaneous fishing mortality rate (F) was 0.95, and instantaneous natural mortality (M) was 0.52. Tag returns also indicated that significant fluctuations in availability of Atlantic menhaden occurred in Chesapeake Bay.

Henry, K.A. 1978. Estimating natural and fishing mortalities of chinook salmon, Oncorhynchus tshawytscha, based on recoveries of marked fish. Fish. Bull. 76:45-57.

Abstract

In this paper the method of calculating estimates of fishing mortality (F) and natural mortality (M) occurring in the ocean for 1961 and 1962 brood Columbia River hatchery fall chinook salmon, Oncorhynchus tshawytscha, based on assumed values of the proportion of fish that mature annually (m) and on recoveries of marked fish is demonstrated.

The advantages of this method over the method of assuming fixed natural mortality rates and back calculating estimates is discussed. It was possible to develop estimates of 1962 Spring Creek data up to the fourth year of life and to compare these estimates with values for the 1961 brood whereas no estimates had been possible with the back calculation method. Thus, estimates of M_1 are slightly higher for the 1962 brood. A major difference between the two methods is that natural mortality was assumed to be constant for the back calculation method whereas estimates of natural mortality were obtained separately each year using assumed proportions maturing. Thus, for the 1962 brood of general marked fish, a $M = 0.60$ was used in the back calculation method while estimates of $M_1 = 5.814$, $M_2 = 0.510$, $M_3 = 0.653$, and $M_4 = 0.727$ were obtained by assuming varying proportions maturing.

A series of graphs are developed that permit a quick analysis of any combination of proportions of fish maturing, fishing mortality, and natural mortality and which clearly depict the relationship between these various factors.

Howe, A.B., P.G. Coates, and D.E. Pierce. 1976. Winter flounder estuarine year class abundance, mortality, and recruitment. Trans. Am. Fish. Soc. 105:647-657.

Abstract

Mark-recovery methodology, accounting for mortality, enabled annual estimates of estuarine winter flounder (Pseudopleuronectes americanus) abundance at summer's end. Recruitment from the estuarine system to an inshore-offshore otter trawl fishery occurred incompletely (73%) over three age groups (II-IV). The release of tagged pre-recruits in two consecutive years and subsequent return data, adjusted for non-reporting of tag recoveries, yielded the following 1970 post-recruit, instantaneous mortality parameters: total = 0.3570, fishing = 0.2445, natural = 0.1125. A comparison of total recruitment from southeastern Massachusetts flounder groups, derived from a population estimate and instantaneous total mortality rate, with recruitment from the Waquoit Bay-Eel Pond system indicated that the latter constituted less than one percent of the total required to maintain equilibrium catch.

King, T.A., W.D. Davies, and W.L. Shelton. 1979. Fishing and natural mortality: Effects on the initial year class of largemouth bass in West Point Reservoir, Alabama and Georgia. Trans. Am. Fish. Soc. 108:150-155.

Abstract

Rates of growth, fishing mortality, and natural mortality of the initial (1975) year class of largemouth bass (Micropterus salmoides) in 10.481-hectare West Point Reservoir were estimated over a 2-year period by rotenone sampling, electrofishing, and tagging studies. The estimate of an initial standing stock of 1,617 largemouth bass or 28.3 kg/hectare in August 1975 was reduced to 1.5 largemouth bass or 1.6 kg/hectare by August 1977. Instantaneous annual rates of growth, fishing mortality, and natural mortality were 2.19, 1.17, and 2.78, respectively, in the first year, and 0.65, 0.92, and 2.11 in the second. Total yield from the 1975 year class was 21.4 kg/hectare, of which 95% was harvested during the first year of impoundment, through August 1976. Natural and fishing mortality reduced the standing crop of 1975 largemouth bass by 88.2% (58.6% natural, 29.6% fishing) in the first year and 86.2% (69.1% natural, 17.1% fishing) in the second. The abundant initial year class of bass was responsible for creating a fishing "boom." Population structure change brought about by high natural mortality and fishing mortality resulted in a "bust" in largemouth bass fishing after 2 years of impoundment.

Lough, R.G. 1974. A re-evaluation of the combined effects of temperature and salinity on survival and growth of Mytilus edulis larvae using response surface techniques. Proc. Natl. Shellfish. Assoc. 64:73-76.

Abstract

Response surface techniques were used to critically examine the combined effects of temperature and salinity on late larval survival and growth of Mytilus edulis using experimental data reported in the literature. The range of conditions estimated for maximum survival was found to be significantly different than those for maximum growth. Temperature exerted a strong effect on both larval survival and growth, while a temperature-salinity interaction effect was not significant.

Matlock, G.C., R.A. Marcello, and K. Strawn. 1975. Standard length-total length relationships of Gulf menhaden, *Brevoortia patronus* Goode, Bay anchovy, *Anchoa mitchelli* (Valenciennes), and Atlantic croaker, *Micropogon undulatus* (Linnaeus), from Galveston Bay. *Trans. Am. Fish. Soc.* 104:408-409.

Abstract

Regression equations were developed between standard length (SL) and total length (TL) for *Brevoortia patronus*, *Anchoa mitchilli*, and *Micropogon undulatus* taken from Galveston Bay, Texas. The standard length-total length conversion equation for *B. patronus* was TL = 0.62044 + 1.25323 SL, and for *A. mitchilli* it was TL = 0.22391 + 1.26753 SL (for fish 28-95 mm SL); TL = 9.70548 + 1.17538 SL (for fish 102-159 mm SL); and TL = 19.88505 + 1.10952 SL (for fish 168-255 mm SL).

Oliver, J.D., G.F. Holeton, and K.E. Chua. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores and environmental temperature. *Trans. Am. Fish. Soc.* 108:130-136.

Abstract

Hatchery-reared, 0 + age smallmouth (*Micropterus dolomieui*) of 55-107 mm total length were "wintered" from September 1975 to May 1976. Temperature regimes were modelled on those of the natural environment and final temperatures were 2, 4, and 6°C. Final wintering temperature did not noticeably influence mortality rates. Long fish survived the period of low temperature better than did shorter ones. Body ratios of dry weight/wet weight, lipid weight/dry weight, and ignitable weight/dry weight all decreased during wintering, and the data indicated that there may be critical percentages of dry weight/wet weight and ignitable weight/dry weight below which these fish will die.

Otwell, W.S., and J.V. Merriner. 1975. Survival and growth of juvenile striped bass, *Morone saxatilis*, in a factorial experiment with temperature, salinity, and age. *Trans. Am. Fish. Soc.* 104:560-566.

Abstract

A 3n factorial experiment to evaluate the effects of an abrupt transfer of striped bass, *Morone saxatilis*, from a closed system rearing facility into a variety of experimental temperature and salinity combinations demonstrated a considerable hardiness of juvenile fish. Striped bass less than two months old had over 80% survival during seven days subsequent to acute introduction from the rearing facility into temperatures of 18°C or 24°C and salinities of 4 ppt or 12 ppt. Relative growth in these treatments was monitored, and the results suggest a degree of flexibility for stocking programs into estuaries.

Youngs, W.D., and D.S. Robson. 1975. Estimating survival rates from tag returns: Model tests and sample size determination. J. Fish. Res. Bd. Canada 32:2365-2371.

Abstract

This paper brings to the attention of fishery biologists a method of estimating survival and exploitation rates when a series of tag recaptures from angler-killed fish is available; this model is appropriate only for recaptures that are removed from the population. Tests for the appropriateness of the model and methods for determining sample size are presented. The test for the model is imperative since estimates of survival would be meaningless if data do not conform to model.

Stock Assessment

Austin, H.M., and C.R. Hickey. 1978. Predicting abundance of striped bass, *Morone saxatilis*, in New York from modal lengths. Fish. Bull. 76:467-473.

Abstract

The abundance of cohorts for any given year class of striped bass, *Morone saxatilis*, prior to their leaving Chesapeake Bay is inversely related to the modal length of fish in that year class 2 years later in New York waters. The modal length of bass in their third year migrating into the New York area is a reliable index of the abundance of that year class. When back extrapolated modal lengths at the end of the second year of life are considered for the dominant year classes in the New York fishery (ages III-VI), a high degree of inverse correlation is found between age II and modal length and reported landings suggesting that this is an effective method of predicting the abundance of the stock for the fishery.

Berggren, T.J., and J.T. Lieberman. 1978. Relative contribution of Hudson, Chesapeake, and Roanoke striped bass, *Morone saxatilis*, stocks to the Atlantic coast fishery. Fish. Bull. 76:335-345.

Abstract

Morphological characters were used in discriminant analysis to quantitatively estimate the relative contribution of striped bass, *Morone saxatilis*, stocks from various estuaries to the striped bass fishery along the Atlantic coast. Representative samples of the spawning stocks of the Hudson River, Chesapeake Bay system, and Roanoke River were collected and counts and measurements were taken on each

specimen. Discriminant functions based on five morphological characters correctly classified approximately 75% of the specimens. The effectiveness of three types of estimates based on these functions in accurately estimating stock proportions was investigated in a simulation study. Results of the simulation study indicated which type of estimate was least biased. A sampling design using geographical and temporal strata was then employed to sample the Atlantic coastal fishery from Cape Hatteras, N.C., to Maine. Observations for the morphological characters were taken on collected fish and the resulting data entered into discriminant functions obtained from spawning-stock collections. The specimens were classified by area of origin and the three types of estimates of relative contribution of the Hudson, Chesapeake, and Roanoke stocks were obtained. Results indicated that the Chesapeake stock was the major contributor to the Atlantic coastal striped bass fishery and the Hudson and Roanoke stocks were minor contributors.

Buck, D.H., and C.F. Thoits. 1965. An evaluation of Petersen estimation procedures employing seines in 1-acre ponds. J. Wildl. Manage. 29:598-621.

Abstract

Seines were used to make Petersen estimates of various size and age components of single-species fish populations in 15 1-acre ponds at the former McGraw Hydrobiological Laboratory near Dundee, Illinois. All estimates were checked by draining censuses. Each of the five species of fish involved was by itself in three of the ponds. Combinations of fin-clip marks permitted a maximum of seven separate estimates for each of the several size or age-groups of each species; together these constituted a total of 274 individual estimates. Analyses applied to the estimates and census data indicated that significant bias occurred most often in the bluegill (Lepomis macrochirus) estimates (70 percent of 37), least commonly among yellow perch (Perca flavescens) estimates (13 percent of 63), intermediately in smallmouth bass (Micropterus dolomieui) and largemouth bass (Micropterus salmoides) estimates (16 percent of 45 and 18 percent of 61, respectively), and brown bullhead (Ictalurus nebulosus) estimates (25 percent of 56). Although errors of estimate were lowest for perch, 54 percent of separate estimates showed errors greater than 10 percent; in bluegills, where errors of estimate were highest, 78 percent showed errors greater than 10 percent. Only among yellow perch were marked fish commonly recaptured in proportions less than their true abundance in the population. This resulted in more overestimations than underestimations for perch. In all other species, underestimations exceeded overestimations because of the recapture of disproportionately large numbers of marked fish. These data were believed to indicate that marking did not influence catchability. The cause of bias possibly differed with different species and was never completely assignable; however, bias may have been caused (1) by the greater susceptibility to capture of certain segments of populations, and (2) by the existence of certain groups of fishes living in areas of high vulnerability to which they returned when marked and released. The variable quality of the estimates based on data collected by seining demonstrates that such estimates may be unreliable.

Kimura, D.K. 1976. Estimating the total number of marked fish present in a catch. Trans. Am. Fish. Soc. 105:664-668.

Abstract

The simple ratio of the total number of marked fish present in a catch is described and the variance estimates discussed. A maximum likelihood estimate of the total number of marks present in a catch is derived which combines both marks found in samples and marks voluntarily returned from the non-sampled portion of the catch. The use of this estimate is illustrated with data from the salmon sport fishery in Puget Sound.

Kjelson, M.A. 1978. Estimating the size of juvenile fish populations in southeastern coastal-plain estuaries. Pages 71-89 In W. Van Winkle (ed.), Assessing the Impact of Power-Plant-Induced Mortality on Fish Populations. Sponsored by Oak Ridge National Laboratory, Energy Research and Development Administration, and Electric Power Research Institute.

Abstract

Understanding the ecological significance of man's activities upon fishery resources requires information on the size of affected fish stocks. The objective of this paper is to provide information to evaluate and plan sampling programs designed to obtain accurate and precise estimates of fish abundance. Nursery habitats, as marsh-tidal creeks and submerged grass beds, offer the optimal conditions for estimating natural mortality rates for young-of-the-year fish in Atlantic and Gulf of Mexico coast estuaries. The area-density method of abundance estimation using quantitative gears is more feasible than either mark-recapture or direct-count techniques. The blockage method provides the most accurate estimates, while encircling devices enable highly mobile species found in open water to be captured. Drop nets and lift nets allow samples to be taken in obstructed sites, but trawls and seines are the most economical gears. Replicate samples are necessary to improve the precision of density required to improve the accuracy of density estimates. Coefficients of variation for replicate trawl samples range from 50 to 150%, while catch efficiencies for both trawls and seines for many juvenile fishes range from approximately 30 to 70%.

Loesch, J.G., and D.S. Haven. 1973. Estimates of hard clam abundance from hydraulic escalator samples by the Leslie method. Ches. Sci. 14:215-216.

Abstract

The feasibility of predicting hard clam abundance in a sample area from subsamples collected with a hydraulic escalator was investigated. Seven experimental plots, each about 1/2 acre in size, were sampled and then completely harvested. The error for the difference between estimated abundance and total catch varied from 0 to 7.6 percent.

Messiah, S.N. 1975. Delineating spring and autumn herring populations in the southern Gulf of St. Lawrence by discriminant function analysis. J. Fish. Res. Bd. Canada 32:471-477.

Abstract

A discriminant function based on three variables, pectoral and dorsal fin rays and gill rakers, was calculated for Atlantic herring (*Clupea harengus harengus*) taken from spring- and autumn-spawning concentrations in the southern Gulf of St. Lawrence and tested for general applicability by classifying other herring of known origin. The function was then used to classify herring sampled from feeding concentrations. Results showed that feeding herring (pre- and post-spawning) comprised a mixture of spring and autumn herring populations averaging 51.8 and 48.2%, respectively.

The observed heterogeneity of feeding concentrations, in contrast to homogeneity of spawning concentrations, confirmed the hypothesis that spring and autumn herring populations mix during feeding, though they separate at the onset of spawning. Discriminant function analysis is most useful for separating herring spawning groups during their feeding season when overlap of maturation stages prevents separation by maturation stage alone.

Rhodes, R.J., W.J. Keith, P.J. Eldridge, and V.G. Burrell. 1977. An empirical evaluation of the Leslie-DeLury method applied to estimating hard clam, *Mercenaria mercenaria*, abundances in the Santee River estuary, South Carolina. Proc. Natl. Shellfish. Assoc. 67:44-52.

Abstract

This paper estimates the abundance of hard clams, *Mercenaria mercenaria*, in the Santee River estuary based upon catch and effort data generated by hydraulic escalator clam harvesters between 1974 and 1976. Using the Leslie method, catch per unit of standardized effort at each time interval was regressed on the cumulative catch. The resulting regression equations had regression coefficients (estimates of catchability) of .0006, .0014, and .0006 for the South Santee River, North Santee River, and North Santee Bay, respectively. There were an estimated 6.4 million, 5.0 million, and 10.7 million clams in the legal harvesting areas of the South Santee River, North Santee River, and North Santee Bay, respectively. The density of clams in the preferred fishing areas varied between $18/m^2$ and $24/m^2$.

In this analysis, the Leslie-DeLury method had two major limitations: first, the lack of effort estimates for specific locations, and second, significant gear competition. It is suggested this method should be considered only for supplementing designed, direct sampling.

APPENDIX D

A bibliography for life history data

on selected Maryland species

1. Schwartz, F.J., and R. Jachowski. 1965. The age, growth, and length-weight relationship of the Patuxent River, Maryland ictalurid white catfish, Ictalurus catus. Ches. Sci. 6(4):226-237.

2. Tsai, C., and G.R. Gibson, Jr. 1971. Fecundity of the yellow perch, Perca flavescens Mitchill, in the Patuxent River, Maryland. Ches. Sci. 12(4):270-284.

3. St. Pierre, R.A., and J. Davis. 1972. Age, growth, and mortality of the white perch, Morone americana, in the James and York Rivers, Virginia. Ches. Sci. 13(4):272-281.

4. Norcross, J.J., S.L. Richardson, W.H. Massmann, and E.B. Joseph. 1974. Development of young bluefish (Pomatomus saltatrix) and distribution of eggs and young in Virginian coastal waters. Trans. Amer. Fish. Soc. 103(4):477-497.

5. White, M.L., and M.E. Chittenden, Jr. 1977. Age determination, reproduction, and population dynamics of the Atlantic croaker, Micropogonias undulatus. Fish. Bull. 75(1):109-123.

6. Winget, R.R., C.E. Epifanio,T. Runnels, and P. Austin. 1976. Effects of diet and temperature on growth and mortality of the blue crab, Callinectes sapidus, maintained in a recirculating culture system. Proc. Natl. Shellfish. Assoc. 66:29-33.

7. Sandifer, P.A. 1975. The role of pelagic larvae in recruitment to populations of adult decapod crustaceans in the York River estuary and adjacent lower Chesapeake Bay, Virginia. Estuarine and Coastal Mar. Sci. 3:269-279.

8. Whetstone, J.M., and A.G. Eversole. 1978. Predation on hard clams, Mercenaria mercenaria, by mud crabs, Panopeus herbstii. Proc. Natl. Shellfish. Assoc. 68:42-48.

9. Pratt, D.M., and D.A. Campbell. 1956. Environmental factors affecting growth in Venus mercenaria. Limnol. and Oceanog. 1:2-17.

10. Roosenburg, W. 1976. Can the oyster industry learn from livestock breeders? Proc. Natl. Shellfish. Assoc. 66:95-99.

11. Muncy, R.J. 1962. Life history of the yellow perch, Perca flavescens, in estuarine waters of Severn River, a tributary of Chesapeake Bay, Maryland. Ches. Sci. 3:143-159.

12. Nelson, W.R., M.C. Ingham, and W.E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden. Fish. Bull. 75(1):23-44.

13. Forney, J.L. 1971. Development of dominant year classes in a yellow perch population. Trans. Amer. Fish. Soc. 100(4):739-749.

14. Pacheco, A.L. 1962. Movements of spot, Leiostomus xanthurus, in the lower Chesapeake Bay. Ches. Sci. 3:256-257.

15. Pfitzenmeyer, H.T. 1962. Periods of spawning and setting of the soft-shelled clam, Mya arenaria, at Solomons, Maryland. Ches. Sci. 3:114-120.

16. Krantz, G.E., and J.V. Chamberlin. 1978. Blue crab predation on cultchless oyster spat. Proc. Natl. Shellfish. Assoc. 68:38-41.

17. Knudsen, E.E., and W.H. Herke. 1978. Growth rate of marked juvenile Atlantic croakers, Micropogon undulatus, and length of stay in a coastal marsh nursery in southwest Louisiana. Trans. Amer. Fish. Soc. 107(1):12-20.

18. Richards, C.E. 1965. Availability patterns of marine fishes caught by charter boats operating off Virginia's eastern shore, 1955-1962. Ches. Sci. 6(2):96-108.

19. Otwell, W.S., and J.V. Merriner. 1975. Survival and growth of juvenile striped bass, Morone saxatilis, in a factorial experiment with temperature, salinity, and age. Trans. Amer. Fish. Soc. 104(3):560-566.

20. Kissil, G.W. 1974. Spawning of the anadromous alewife, Alosa pseudoharengus, in Bride Lake, Connecticut. Trans. Amer. Fish. Soc. 103(2):312-317.

21. Kaneko, T., R.R. Colwell, and F. Hamons. 1975. Bacteriological studies of Wicomico River soft-shell clam (Mya arenaria) mortalities. Ches. Sci. 16(1):3-13.

22. Nicholson, W.R. 1978. Movements and population structure of Atlantic menhaden indicated by tag returns. Estuaries 1(3):141-150.

23. Neves, R.J., and L. Depres. 1979. The oceanic migration of American shad, Alosa sapidissima, along the Atlantic coast. Fish. Bull. 77(1):199-212.

24. Nicholson, W.R. 1971. Coastal movements of Atlantic menhaden as inferred from changes in age and length distributions. Trans. Amer. Fish. Soc. 100(4):708-716.

25. Nelson, W.R., and C.H. Walburg. 1977. Population dynamics of yellow perch (Perca flavescens), sauger (Stizostedion canadense), and walleye (S. vitreum vitreum) in four main stem Missouri River reservoirs. J. Fish. Res. Bd. Canada 34:1748-1763.

26. Ney, J.J., and L.L. Smith, Jr. 1975. First-year growth of the yellow perch, Perca flavescens, in the Red Lakes, Minnesota. Trans. Amer. Fish. Soc. 104(4):718-725.

27. Cooper, R.A. 1961. Early life history and spawning migration of the alewife, Alosa pseudoharengus. M.S. Thesis, Univ. of Rhode Island, Kingston, R.I.

28. Kendall, A.W., Jr., and L.A. Walford. 1979. Sources and distributions of bluefish, Pomatomus saltatrix, larvae and juveniles off the east coast of the United States. Fish. Bull. 77(1):213-227.

29. Markle, D.F. 1976. The seasonality of availability and movements of fishes in the channel of the York River, Virginia. Ches. Sci. 17(1):50-55.

30. Kendall, A.W., Jr., and J.W. Reintjes. 1975. Geographic and hydrographic distribution of Atlantic menhaden eggs and larvae along the middle Atlantic coast from R.V. Dolphin cruises, 1965-66. Fish. Bull. 73(2):317-335.

31. MacKenzie, C.L., Jr. 1977. Predation on hard clam (Mercenaria mercenaria) populations. Trans. Amer. Fish. Soc. 106(6):530-537.

32. Howe, A.B., P.G. Coates, and D.E. Pierce. 1976. Winter flounder estuarine year-class abundance, mortality, and recruitment. Trans. Amer. Fish. Soc. 105(6):647-657.

33. Havey, K.A. 1961. Restoration of anadromous alewives at Long Pond, Maine. Trans. Amer. Fish. Soc. 90(3):281-286.

34. Feder, H.M., and A.J. Paul. 1974. Age, growth, and size-weight relationships of the soft-shell clam, Mya arenaria, in Prince William Sound, Alaska. Proc. Natl. Shellfish. Assoc. 64:45-52.

35. Frame, D.W. 1974. Feeding habits of young winter flounder (Pseudopleuronectes americanus): prey availability and diversity. Trans. Amer. Fish. Soc. 103(2):261-269.

36. Eldridge, P.J., W. Waltz, R.C. Gracy, and H.H. Hunt. 1976. Growth and mortality rates of hatchery seed clams, Mercenaria mercenaria, in protected trays in waters of South Carolina. Proc. Natl. Shellfish. Assoc. 66:13-20.

37. Dietrich, C.S., Jr. 1979. Fecundity of the Atlantic menhaden, Brevoortia tyrannus. Fish. Bull. 77(1):308-311.

38. Davis, J., J.V. Merriner, W.J. Hogman, R.A. St. Pierre, and W.L. Wilson. 1971. Annual Progress Report, Anadromous Fish Project. Proj. No. Virginia AFC 7-1. Virginia Inst. of Mar. Sci., Gloucester Pt., Va. 100 pp.

39. Brousseau, D.J. 1978. Spawning cycle, fecundity, and recruitment in a population of soft-shell clam, Mya arenaria, from Cape Ann, Massachusetts. Fish. Bull. 76(1):155-166.

40. Berggren, T.J., and J.T. Lieberman. 1978. Relative contribution of Hudson, Chesapeake, and Roanoke striped bass, Morone saxatilis, stocks to the Atlantic coast fishery. Fish. Bull. 76(2):335-345.

41. Brazo, D.C., P.I. Tack, and C.R. Liston. 1975. Age, growth, and fecundity of yellow perch, Perca flavescens, in Lake Michigan near Ludington, Michigan. Trans. Amer. Fish. Soc. 104(4):726-730.

42. Brousseau, D.J. 1978. Population dynamics of the soft-shell clam, Mya arenaria. Mar. Biol. 50:63-71

43. Andrews, J.D., and J.L. Wood. 1967. Oyster mortality studies in Virginia. VI. History and distribution of Minchinia nelsoni, a pathogen of oysters, in Virginia. Ches. Sci. 8(1):1-13.

44. Leggett, W.C. 1977. Ocean migration rates of American shad (Alosa sapidissima). J. Fish. Res. Bd. Canada 34:1422-1426.

45. Dryfoos, R.L., R.P. Cheek, and R.L. Kroger. 1973. Preliminary analyses of Atlantic menhaden, Brevoortia tyrannus, migrations, population structure, survival and exploitation rates, and availability as indicated from tag returns. Fish. Bull. 71(3):719-734.

46. Cargo, D.G. 1958. The migration of adult female blue crabs, Callinectes sapidus Rathbun, in Chincoteague Bay and adjacent waters. J. Mar. Res. 16(3):180-191.

47. Henry, K.A. 1971. Atlantic menhaden (Brevoortia tyrannus) resource and fishery-analysis of decline. U.S. Dept. of Commerce, Seattle, WA. NOAA Technical Report NMFS SSRF-642. 32 pp.

48. Richkus, W.A. 1975. Migratory behavior and growth of juvenile anadromous alewives, Alosa pseudoharengus, in a Rhode Island drainage. Trans. Amer. Fish. Soc. 104(3):483-493.

49. Developmental Sciences, Inc. 1979. Maryland's Chesapeake Bay commercial fisheries. Prepared for Energy and Coastal Zone Admin. MDNR by Developmental Sciences, Inc., Sagamore, Mass. Edited by M.M. Bundy and J.B. Williams. 119 pp.

50. Marasco, R.J. 1972. The Chesapeake Bay fisheries: An economic profile. Agricultural Experiment Station, Univ. of Md., College Park, Md. MP No. 802. 203 pp.

51. Powell, A.B. 1979. Personal communication. National Marine Fisheries Service, Beaufort, North Carolina.

52. Jones, P.W., F.D. Martin, and J.D. Hardy, Jr. 1978. Development of Fishes of the Mid-Atlantic Bight, Vol. I. Biological Services Program, Fish and Wildlife Service, U.S. Dept. of the Interior. 366 pp.

53. Hardy, J.D., Jr. 1978a. Development of Fishes of the Mid-Atlantic Bight, Vol. II. Biological Services Program, Fish and Wildlife Service, U.S. Dept. of the Interior. 458 pp.

54. Hardy, J.D., Jr. 1978b. Development of Fishes of the Mid-Atlantic Bight, Vol. III. Biological Services Program, Fish and Wildlife Service, U.S. Dept. of the Interior. 394 pp.

55. Johnson, G.D. 1978. Development of Fishes of the Mid-Atlantic Bight, Vol. IV. Biological Services Program, Fish and Wildlife Service, U.S. Dept. of the Interior. 314 pp.

56. Martin, F.D., and G.E. Drewry. 1978. Development of Fishes of the Mid-Atlantic Bight, Vol. VI. Biological Services Program, Fish and Wildlife Service, U.S. Dept. of the Interior. 416 pp.

57. Smith, H.M. 1907. The Fishes of North Carolina, Vol. II. North Carolina Geological and Economic Survey, Raleigh, N.C. 453 pp.

58. Lippson, A.J., M.S. Haire, A.F. Holland, F. Jacobs, J. Jensen, R.L. Moran-Johnson, T.T. Polgar, and W.A. Richkus. 1979. Environmental Atlas of the Potomac Estuary. Prepared for Md. Dept. of Natural Resources, Power Plant Siting Program by Martin Marietta Corporation, Environmental Center. 280 pp.

59. Hildebrand, S.F., and W.C. Shroeder. 1928. Fishes of the Chesapeake Bay. U.S. Bur. Fish. Bull. Volume 53, Part 1. 388 pp.

60. Galtsoff, P.S. 1964. The American yster, Crassostrea virginica Gmelin. Fish. Bull. 64:1-480.

61. Setzler, E.M., W.R. Boynton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Mountford, P. Frere, L. Tucker, and J.A. Mihursky. 1979. Synopsis of biological data on striped bass, Morone saxatilis (Walbaum). Cont. No. 802 (draft). Center for Environmental and Estuarine Studies, Univ. of Md. 209 pp.

62. Dawson, C.E. 1958. A study of the biology and life history of the spot, Leiostomus xanthurus Lacepede, with special reference to South Carolina. Contr. Bears Bluff Lab., Wadmalaw Island 28:1-48.

63. Lewis, R.M., and R.R. Bonner, Jr. 1966. Fecundity of striped bass, Roccus saxatilis (Walbaum). Trans. Amer. Fish. Soc. 95:328-331.

64. Jackson, H.W., and R.E. Tiller. 1952. Preliminary observations on spawning potential in striped bass (Roccus saxatilis). Md. Dept. Res. and Ed. Publ. No. 93. 16 pp.

65. Clark, J.R., and S.E. Smith. 1969. Migratory fish of the Hudson estuary. In G.J. Lauer (ed.), Hudson River Ecology. N.Y. Dept. of Envir. Conserv. 473 pp.

66. Van Engel, W.A. 1958. The blue crab and its fishery in Chesapeake Bay. Comm. Fish Review 20(6):6-17.

67. Carriker, M.R. 1961. Interrelation of functional morphology, behavior, and autecology in early stages of the bivalve, Mercenaria mercenaria. J. E. Mitchell Soc. 77(2):168-241.

68. Meritt, D.W. 1977. Oyster spat set on natural cultch in the Maryland portion of the Chesapeake Bay (1939-1975). Horn Point Environmental Laboratories, Cambridge, Maryland. UMCEES Special Report No. 7. 30 pp.

69. Young, L.G. 1972. The survivorship of Crassostrea virginica (Gmelin) larvae of Clambank Creek, South Carolina. M.S. Thesis, Univ. of South Carolina, Columbia, S.C. 48 pp.

70. Loesch, J.G., and W.A. Lund, Jr. 1977. A contribution to the life history of the blueback herring, Alosa aestivalis. Trans. Amer. Fish. Soc. 106(6):583-589.

71. Johnson, H.B., D.W. Crocker, B.F. Holland, J.W. Gilliken, D.L. Taylor, and M.W. Street. 1978. Biology and management of mid-Atlantic anadromous fishes under extended jurisdiction. Annual Report, Anadromous Fish Project, 1978. North Carolina Dept. Nat. Res. and Comm. Dev., and Va. Inst. Mar. Sci., Gloucester Point, Va. 175 pp.

72. Maurer, D., L. Watling, and R. Keck. 1971. The Delaware oyster industry: A reality? Trans. Amer. Fish. Soc. 100(1):100-111.

73. Sulkin, S.D. 1973. Blue crab study in Chesapeake Bay, Maryland. Natural Resources Institute, Univ. of Md., Ches. Biol. Lab., Solomons, Md. Ref. No. 73-94. 82 pp.

74. Lippson, R.L. 1971. Blue crab study in Chesapeake Bay, Maryland. Natural Resources Institute, Univ. of Md., Ches. Biol. Lab., Solomons, Md. Ref. No. 71-9. 18 pp.

75. Carter, N., and H. Speir. 1979. Personal communication. Tidewater Fisheries, Tidewater Administration, Md. Department of Natural Resources.

76. Hibbert, C.J. 1977. Growth and survivorship in a tidal-flat population of the bivalve, Mercenaria mercenaria, from Southhampton water. Mar. Biol. 44:71-76.

77. Wells, H.W. 1957. Abundance of the hard clam, Mercenaria mercenaria, in relation to environmental factors. Ecology 38:123-128.

78. Hibbert, C.J. 1977. Energy relations of the bivalve, Mercenaria mercenaria, on an intertidal mudflat. Mar. Biol. 44:77-84.

79. Talbot, G.B. 1954. Factors associated with fluctuation in abundance of Hudson River shad. Fish. Bull. 56:373-413.

80. Woodin, S.A. 1976. Adult-larval interactions in dense infaunal assemblages: Patterns of abundance. J. Mar. Res. 34:25-41.

81. Krantz, G. 1979. Personal communication. Horn Point Environmental Laboratory, University of Maryland.

82. Merriner, J.V. 1976. Anadromous fishes of the Potomac estuary. In W. Mason and K. Flynn (eds.) The Potomac Estuary: Trends and Options. Interstate Commission on the Potomac River Basin and Maryland Power Plant Siting Program. 140 pp.

83. Nelson, W. 1979. Personal communication. Beaufort Laboratory, National Marine Fisheries Service.

84. Scarlett, P. 1979. Personal communication. New Jersey Division of Fish, Shellfish and Wildlife.

85. Massman, W.H. 1963. Age and size composition of weakfish, Cynoscion regalis, from pound nets in Chesapeake Bay, Virginia, 1954-1958. Ches. Sci. 4:43-51.

86. Perlmutter, A.W., W.S. Miller, and J.C. Poole. 1956. The weakfish, Cynoscion regalis, in New York waters. N.Y. Fish and Game J. 3:1-43.

87. Merritt, D.W. 1977. Oyster spat on natural cultch in the Maryland portion of the Chesapeake Bay (1939-1975). Center for Environmental and Estuarine Studies, University of Maryland, Solomons, Md. CEES Species Report No. 7.

88. Mansueti, R.J. 1961. Movements, reproduction, and mortality of the white perch, Roccus americanus, in the Patuxent estuary, Maryland. Ches. Sci. 2:142-205.

89. Coates, P.G., A.B. Howe, and A.E. Peterson. 1970. Analysis of winter flounder tagging off Massachusetts, 1960-1965. Div. of Mar. Fish., Dept. of Natural Resources of Massachusetts.

90. Brousseau, D.J. 1979. Analysis of growth rate in Mya arenaria using the von Bertalanffy equation. Mar. Biol. 51:221-227.

91. Darnell, R.M. 1959. Studies of the life history of the blue crab (Callinectes sapidus Rathbun) in Louisiana waters. Trans. Amer. Fish. Soc. 88:294-304.

92. Chittenden, M.E., Jr. 1975. Dynamics of American shad, Alosa sapidissima, runs in the Delaware River. Fish. Bull. 73(3):487-494.

93. Dame, R.F. 1971. The ecological energies of growth, respiration, and assimilation in the intertidal American oyster, Crassostrea virginica (Gmelin). Ph.D. Thesis. Univ. of South Carolina, Columbia, S.C. 81 pp.

94. Boone, J.G. 1979. Personal communication. Maryland Department of Natural Resources, Annapolis, Maryland.

95. Early, S. 1979. Personal communication. Maryland Department of Natural Resources, Annapolis, Maryland.

APPENDIX E

A KEYWORD AND SPECIES INDEX TO APPENDICES A-D