MULTISPECIES VIRTUAL POPULATION ANALYSIS

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Introduction

Fisheries are the major driver for the changing in properties of both fished and unfished species, through direct and indirect effects. Direct effects can include reductions in population abundance, age and size structure, biodiversity, community composition and habitat destruction. Indirect effects, including incidental mortality, are transmitted through the ecosystem by trophic interactions and competition, and may result in increased or decreased abundance of prey or predator species, altering community composition. In recognition of the complex, interconnected nature of marine ecosystems, ecosystem approaches have been promoted as a way to improve fisheries assessment and management. There is a wide-range of multi-species and ecosystem modelling approaches. They range from extended single species models to multi-species minimum realistic models, food web models to whole ecosystem models with age and spatial structure. All models have their strengths and weaknesses: simplicity may entail missing key processes, whereas complexity requires more data, time and resources.

Multispecies Virtual Population Analysis

Multispecies virtual population analysis (MSVPA) is an approach to quantifying predator–prey interactions and estimating the rates of predation mortality for exploited fish populations. This approach was developed within International Council for the Exploration of the Sea (ICES) as a multispecies by extension of VPA or cohort analysis. MSVPA is a computation technique by which, one can calculate the amount of fish there must have been in the sea to account for the observed catches in fisheries and the observed stomach contents of predators. MSVPA provides useful insight into the role of predator-prey interactions by quantifying food consumption of major predators. Therefore, to perform MSVPA, detailed food-habit information is required. Thus, MSVPA requires input data as the natural mortality (non-predation), an estimate for fishing mortality in the last year (terminal F), abundance index for all groups, suitability estimates, weight-at-age, predator ration estimates and diet data.

The basic approach was derived from the model of Andersen and Ursin (1977) and subsequently described by Pope (1979), Helgason and Gislason (1979), and Gislason and Helgason (1985). Finally, this approach was reviewed by Sparre (1991) and Magnusson (1995). The main conclusions from applications to this system, summarized by Pope (1991), are that the rates of natural mortality are higher than typically assumed and are annually variable. The model is derived from the basic age-structured VPA approach with the addition of resolving natural mortality (M) into two components *i.e.* predation (M_2) and residual natural mortality (M_1), e.g. competition, disease, starvation and other natural causes. Predation mortality rates are calculated using the model that consists two primary terms, one for the total biomass of food consumed by the predator and other is suitability index that determines the predator's diet composition. In practice, the suitability coefficients can be calculated by incorporating diet information for all predator and prey age classes for at least 1 year in MSVPA time-series. Suitability coefficient measures the relative suitability of one species as prey for predators. These parameters must be estimated inside the model and this estimation requires data on the stomach contents of the predators in the model. MSVPA makes two key assumptions; one is constant ration size (*i.e.* independent of time for each species-age combination), hence fixed weights-at-age and other is prey selection which leads to a type II functional feeding response. Thus, suitability coefficients are constant in time and independent of prey abundance. In single species VPA, each cohort can be treated separately, the results being independent of the results of the other cohorts. The usual procedure for VPA is to work backwards in time, starting with the oldest age group and ending with the recruits. But, this procedure would not work for MSVPA. All cohorts of all species have to be dealt with simultaneously, as the value of the predation mortality depends on the abundances of predators and prey. Thus, MSVPA works on a "by-year basis" rather than on a by-cohort basis. MSVPA is a recursive algorithm and advantage of this model is the estimation the annual consumption of prey by predators.

Natural Mortality (M)

$M = M1 + M2$

Where, M1 is the residual mortality and *M2* is the predation mortality.

Predation Mortality Coefficient (M_2)

Predation mortality coefficient can be calculated using the model that consists two primary terms such as total biomass of food consumed by the predators and suitability coefficients of predators. Therefore, Predation mortality coefficient has been estimated by following formula:

$$M2_{p,a} = \sum_i \sum_j \frac{\bar{N}_{i,j}\ R_{i,j}\ S_{p,a,i,j}}{\sum_{p,a} \bar{N}_{p,a}\ W_{p,a}\ S_{p,a,i,j}}$$

$M_{2p,a}$ = Predation mortality of prey *'p'* at age *'a'*

$\bar{N}_{i,j}$ = Average abundance of predator *'i'* at age *'j'*

$R_{i,j}$ = Annual ration (total annual food consumption, kg) for the predator species

$S_{p,a,i,j}$ = Suitability coefficient for each predator - prey combination

$\bar{N}_{p,a}$ = Average abundance of prey *'p'* at age *'a'*

$W_{p,a}$ = Weight of the prey *'p'* at age *'a'*

Here Numerator reflects the diet composition of the predator relative to the available food. The denominator of equation represents the total suitable biomass available to the predator.

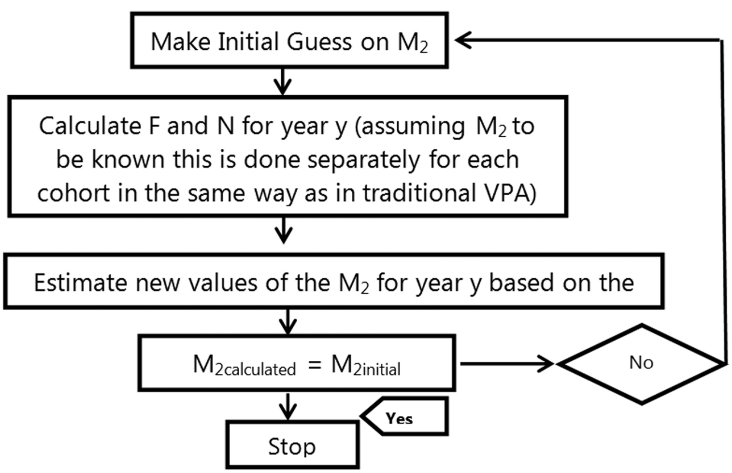
Computation of MSVPA

The computation of MSVPA is started by assuming that the suitability coefficients are known. If the 'N' is known, then 'M_2' can be calculated by using predation mortality coefficient equation. Other hand, once the 'M_2' is known; again 'N' can be calculated using single species VPA techniques. However, 'N' is not known, this problem can only be solved using iterative techniques**.**

Suitability Coefficient

The factor determining the availability of prey as food for predator is called a "(food) suitability coefficient". Suitability coefficient is the most important parameters estimated in a MSVPA model. It reflects predator preferences, vulnerability, and availability of prey, which is influenced by the spatial overlap of predators and prey. There are two assumptions for

Diagrammatic representation for calculation of MSVPA



calculation of suitability coefficient, it is independent with change time and also independent with prey abundance *i.e.* type II predator-prey feeding response. The suitability coefficients are estimated iteratively in the MSVPA model with the following equation by incorporating diet information for all predator and prey at age classes.

$$S_{p,a,i,j} = \frac{U_{p,a,i,j} / \bar{N}_{p,a} W_{p,a}}{\sum_p \sum_a U_{p,a,i,j} / \bar{N}_{p,a} W_{p,a}}$$

$U_{p,ja,i,j}$ = Observed food composition in the predator's stomach contents; *a* is the age of prey *p*; and *j* is the age of predator *i*

$\bar{N}_{p,a}$ = Average abundance of prey *p* at age *a*

$W_{p,a}$ = Weight of the prey *p* at age *a*

Input data for MSVPA

The following are the input data for MSPVA:

1. Stomach content data
2. Annual predator ration (kg)
3. Residual mortality coefficient (M_1)
4. Number of catch at age (C)
5. Terminal fishing mortality coefficient ($F_{terminal}$)

Outputdata for MSVPA

The following are the output for MSPVA:

1. Fishing mortality coefficient (F)
2. Stock numbers (N)
3. Suitability coefficient (S)
4. Predation mortality coefficient (M_2)

Advantages

MSVPA uses data inputs (e.g. fishery catch-at-age) that are similar to those used in single species fishery models. The model outputs of MSVPA are directly comparable with those of single-species approaches. MSVPA can be use in fishery management plans. If parameters are stable, MSVPA models can include trophic interactions in the development of management advice.

Limitation

1. It concerns over the type II of functional feeding response
2. MSVPA models typically include only exploited species, and all other components of the ecosystem (e.g. zooplankton, benthic secondary production, apex predators) are either omitted from the model or are includedas fixed inputs of biomass
3. If parameters vary from year to year, trophic MSVPA models may have little value for managers

Extended MSVPA

Extended MSVPA (MSVPA-X) is represented as an alternative to existing MSVPA approaches. It is an improvement over previous approaches by increasing the flexibility to model seasonal and interannual dynamics in the strength of prey – predator interactions. It includes an alternative functional feeding response with the implementation of type III feeding response. MSVPA-X uses index-tuned VPA methods for estimation of terminal fishing mortality (F_t). It also incorporates a more complex expression of predator feeding and consumption rates by more explicit formulation of prey size and type selection.

MSVPA assumes that food consumption is a constant proportion of body weight across seasons and years. In reality, food consumption rates in fish can vary strongly, particularly between seasons as a function of changing temperatures and metabolic demands. Therefore, a modified functional relationship between food availability and predator consumption rates is included in MSVPA-X. The total consumption for a predator 'i' age 'a' in year, '*y*', season,'*s*' can be calculated by following equation:

$$C_s^{ia} = 24E_s^{ia} * \overline{SC_{ias}} * D_s^{ia} * W_{ys}^{ia} * \overline{N_{iays}}$$

Where,

SC_{ias} = Stomach contents weight relative to predator body weight in a season

D^{ia}_{s} = Number of days in the season

w^{ia}_{ys} = Average weight at age for the predator species

N^{ia}_{ys} = Abundance of the predator age class

E^{ia}_{s} = Evacuation rate (hr^{-1})

Evacuation rate (E^{ia}_{s}) = $\alpha_{ia}\exp(\beta_{ia}.Temp_s)$

Where,

$Temp_s$ = Seasonal temperature (°C)

α_a & β_{ia} = Parameters based upon laboratory feeding experiments

Again, stomach contents across years for predator

$$\left(SC_y^{ia}\right) = \overline{SC_{ias}} + \left(log\frac{SB_{iays}}{SB_{ias}}\right).\overline{SC_{ias}}$$

Where,

$\overline{SC}_{ias}$ = Average stomach contents across years for predator *i,* age class *a*, in season '*s*'

SB = Average biomass available to the predator

Suitability in MSVPA-X

Suitability in MSVPA-X is calculated by defining selectivity equation rather than relying on back-calculating suitability in iteration method as MSVPA. Predation is based on "density risk" and "prey vulnerability". Density risk reflects the relative encounter rate of the predators and prey driven by spatial overlap. Prey vulnerability combined probabilities of attack, capture, and ingestion. Therefore, suitability equation components are represented by the product of spatial overlap, a type preference or electivity parameter, and size-selection parameter.

Suitability $S_{jb}^{ia} = O_j^{ia} A_j^{ia} B_{jb}^{ia}$

Where,

S^{ia}_{jb} = Suitability for a given prey species ' j' and age class 'b' for predator species 'I'

O^{ia}_{j} = Spatial overlap index

A^{ia}_{j} = Vulnerability

B^{ia}_{jb} = Size selection

Spatial Overlap Index

Spatial overlap index (O_{ij}) can be calculated by using following equation,

$$O_{ij} = \frac{\sum_{Z=1}^{m}\left(N_{jz}N_{iz}\right).m}{\sum_{z=1}^{m}N_{jz}\sum_{z=1}^{m}N_{iz}}$$

Where,

N. z is the abundance of each predator or prey in each of 'm' spatial cells. It ranges between 0 and 1. It represents horizontal overlap of the predator and prey.

Type Preferences

Type preference reflects selection for a particular species relative to all others based upon ease of capture, energy content, or other factors that result in a preferred prey type. For each prey type (or species), a preference rank is assigned for a given predator age class. If a prey species is not consumed by that predator age class, then it is given a rank of zero. It can be calculated by Proportionalized rank index (A^{ia}_j);

$$A_j^{ia} = \frac{m - r_j^{ia}}{\sum_{j=1}^{m} r_j^{ia}}$$

where,

m = Number of prey species and r^{ia}_j = Preference rank for each prey species

Size Selection

Size selection uses a flexible unimodal function (the incomplete beta integral) to describe size selection. The function can be fitted to data on the length distribution of fish prey in stomach data by maximum likelihood estimation. This assumes that the length distribution of prey in the diet reflects selection rather than availability.

Program Implementation for MSVPA

The MSVPA is implemented as a MS Windows application written in Visual Basic 6.0. The program includes interface screens for the entry and management of species data, model inputs, and both graphical and data outputs. All data and outputs are stored and managed within a relational database, created by the program termed a "project file". The project file is stored, where catch and other biological data for individual species are entered that can be included within MSVPA executions. The project file also allows development and storage of MSVPA-X runs.

Application of MSVPA

MSVPA has demonstrated that an increase in mesh size can result in lower long-term yields, an effect opposite to what is predicted if species interactions are ignored. Such insights into the dynamics of the system are useful and MSVPA may therefore have an important role in fisheries management.

Suggested Reading

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