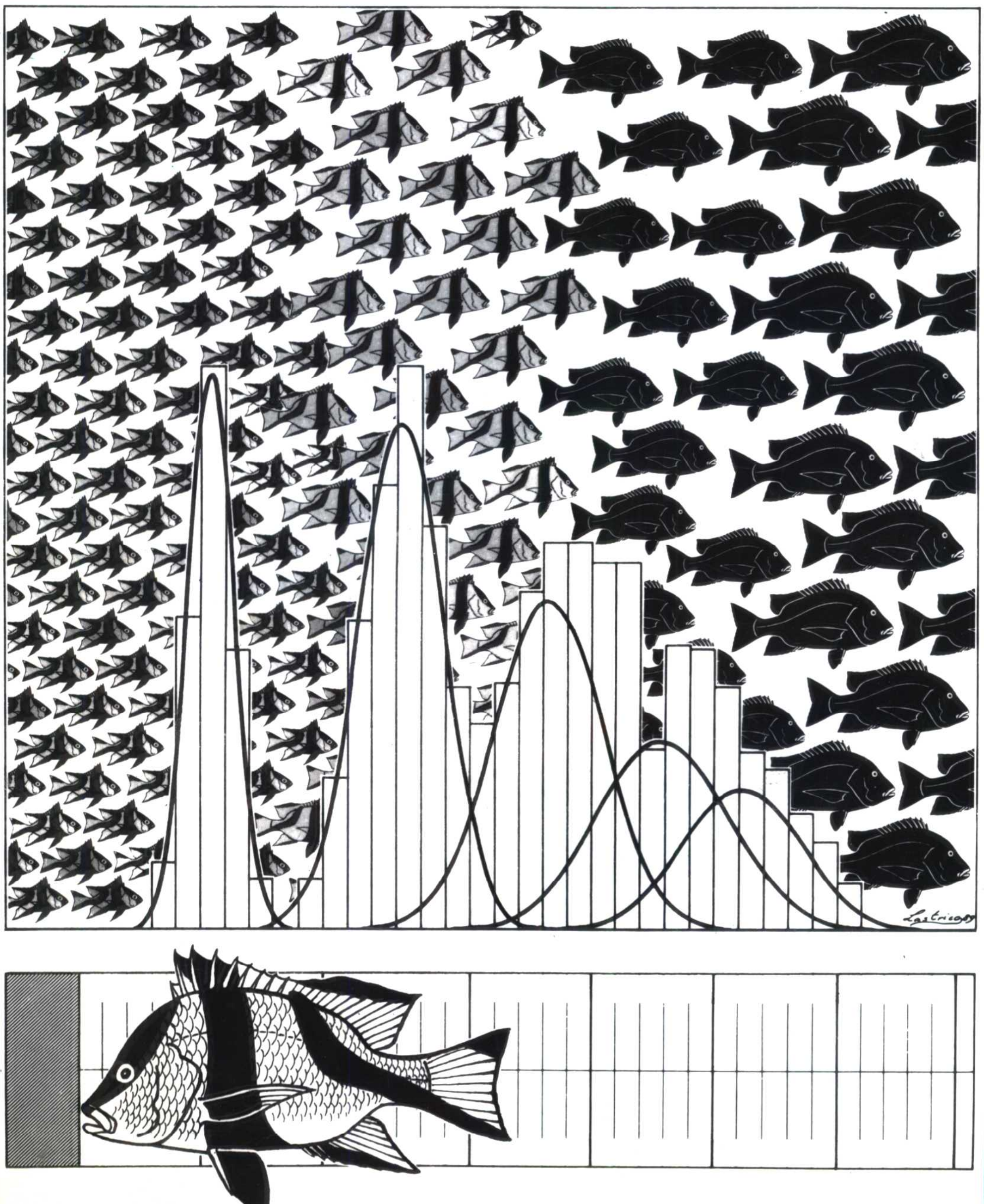
Introduction to tropical fish stock assessment Part 1 - Manual

FAO FISHERIES TECHNICAL PAPER
306/1



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Introduction to tropical fish stock assessment Part 1 - Manual

by
Per Sparre
Marine Resources Service
Fishery Resources and Environment Division
FAO Fisheries Department
Rome, Italy

Erik Ursin
Consultant
GCP/INT/392/DEN
Gislinge, Denmark

Siebren C. Venema
Project Manager
GCP/INT/392/DEN
Rome, Italy

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M-43
ISBN 92-5-102850-8

PREPARATION OF THIS DOCUMENT

The first edition of this manual was prepared by the FAO/DANIDA project "Training in fish stock assessment and fisheries research planning" (GCP/INT/392/DEN) for use in a series of regional and national training courses on fish stock assessment organized by the project from 1983 to early 1989.

In 1984 the author Per Sparre, then employed by the Danish Institute of Fisheries and Marine Research, Charlottenlund, Denmark, was asked to write this manual on the basis of lecture notes and case studies prepared by the following team of lecturers engaged in the courses:

Mr. Peder Agger of Roskilde University, Denmark, Dr. Ole Bagge, Dr. Jan Beyer, Mr. JØrgen MØller Christensen, Mr. Poul Degnbol, Mr. Henrik Gislason, Mr. Eskild Kirkegaard, Mr. Hans Lassen, Mr. Niels A. Nielsen, Mr. Per Sparre and Dr. Erik Ursin of the Danish Institute for Fisheries and Marine Research, Dr. Daniel Pauly of the International Center for Living Aquatic Resources Management and Mr. Siebren C. Venema of FAO.

The first edition was printed in July 1985 in Manila, Philippines, and distributed by the project through the Network of Tropical Fisheries Scientists of ICLARM and training courses.

The demand for copies of the manual turned out to be high and in 1986 an FAO/DANIDA project evaluation team strongly recommended it to be edited, reprinted and distributed widely.

In the mean time the project has organized three follow-up courses, where participants were assisted in preparing a scientific paper based on their own data sets, respectively in Hirtshals, Denmark (1986), Manila, the Philippines (1987) and Cochin, India (1987). These courses exposed the need for an expansion of the manual to cover assessments of migratory stocks and gear selectivity and the modification of other subjects.

Further a large number of useful comments and suggestions were received from various users of the first edition in particular the participants and local staff of the courses organized between 1985 and 1989, Dr. E.L. Olsen of the University of Papua New Guinea, Dr. S. Garcia, Chief of the Marine Resources Service, FAO and many others.

Dr. Keith Brander (Fisheries Laboratory, Lowestoft, UK) and Mr. Niek van Zalinge (FAO, Rome) were engaged by the project to review the manual, including some of the additions and they also came up with many useful suggestions and corrections.

Early 1989 it was decided to make a more thorough review of the manual and to publish it as a FAO Fisheries Technical Paper. Dr. Erik Ursin (consultant) and Siebren C. Venema (project manager) of the FAO/DANIDA project, undertook this revision in close cooperation with Per Sparre (now Fishery Resources Officer, Marine Resources Service, FAO, Rome). The figures, of which the originals were all drawn by Per Sparre, were partly revised and redrawn by Mr. Oliviero Lidonnici and a new cover was designed by Per Sparre and Paolo Lastrico (FAO). The references were reviewed by Ms. Gloria Soave and Siebren Venema and last, but not least, the text was completely retyped and rearranged by Ms. Jane Ugilt (Denmark).

Due to time constraints the text has not been reviewed by an English mother tongue editor, and we hope that you will forgive us for the occasional odd wording. Translations into French (already partly completed on the basis of the first edition by the International Center for Ocean Development, Canada), Spanish and Portuguese, are scheduled to appear in the course of 1990 or early 1991.

Sparre, P.; Ursin, E.; Venema, S.C.
Introduction to tropical fish stock assessment.
Part 1. Manual.
FAO Fisheries Technical Paper. No. 306.1. Rome, FAO.
1989. 337p.

ABSTRACT

A selection of methods on fish stock assessment is described in detail, with examples of calculations. Special emphasis is placed on methods applicable to tropical fisheries, i.e. those based on the analysis of length-frequencies. After a short introduction to statistics, it covers the estimation of growth parameters and mortality rates, virtual population methods (including length and age based methods), gear selectivity, the yield per recruit model of Beverton and Holt, the estimation of maximum sustainable yield using surplus production models, multispecies and multifleet problems, the assessment of migratory stocks, a discussion on the stock/recruitment relationship and the execution of demersal trawl surveys. The link between this manual and the Length Frequency Stock Assessment (LFSA) package of microcomputer programs is explained. The manual is completed with an extensive list of references (including material for further reading), a list of symbols used, a subject index and a number of exercises with solutions.

Distribution:

DANIDA
Participants at FAO/DANIDA courses
on Fish Stock Assessment
Members of the Network of Tropical
Fisheries Scientists
Institutes specialised in Tropical
Fish Stock Assessment
Institutes of Fisheries Education
Interested National and International Organizations
Marine and Inland Selectors
FAO Regional Fishery Officers
FAO Fisheries Department
GCP/INT/392/DEN

LIST OF SYMBOLS USED

A: Mathematical notation (general)

*	multiplication sign
/	division
ln	natural logarithm (base e = 2.7182818)
log	10 based logarithm
exp	exponential function, $\exp(x) = e^x$
$\sum_{i=1}^{i=n} X(i)$	sum of all values of X(i), for i from 1 to n; the sum X(1)+X(2)+...+X(n)
$\surd$ or $\sqrt{\ }$	square root
∞	infinity
Δx	delta x, a small increment of the variable x
$\max_j \{ X(j) \}$	maximum value among the elements in the set { X(j) } = { X(1),X(2),...X(j),...)
$\bar{x}$	mean value of x
x(i,j)	i,j indices of x (usually printed as $x_{i,j}$)
π	pi = 3.14159
a < b	a smaller than b
a > b	a greater than b
a => b	a greater than or equal to b

B. Statistical notation

		First introduced Section
linear regression y = a + bx		2.4
a	intercept	-
b	slope	-
x	independent variable	-
y	dependent variable	-
r	correlation coefficient	-
a'	intercept of functional regression	2.5
b'	slope of functional regression	-
n	number of observations	2.1
$\bar{x}$	mean value of x	2.1
s^2	variance	
s	standard deviation	2.1
$s/\bar{x}$	relative standard deviation or coefficient of variation	2.1
$s/\sqrt{n}$	standard error	2.1
t(f)	fractile of Student's t-distribution	2.3
f	degrees of freedom	2.3
ϵ	(epsilon) maximum relative error	2.7

C. Symbols used in formulas for fish stock assessment

Symbol	Description	Section
a	swept area (effective path swept by a trawl)	13.5
ASP	available sum of peaks (ELEFAN)	3.5
b	constant in length-weight relationship $W = qL^b$	2.6
B	biomass	5.3
Bv	virgin (unexploited) biomass	8.3, 9.1
B/R	biomass per recruit	8.2
C	catch in numbers (VPA)	5.0
C(t,∞)	cumulated catch	4.4
C	amplitude (0-1) (ELEFAN)	3.5
CPUE	catch per unit of effort	4.3
D	number of natural deaths (VPA)	5.0
D50%	deselection, length at which 50% is not caught	6.2
dL	interval size of length	3.4
E	fishing effort	7.1
E	exploitation rate (F/Z)	8.4
ESP	explained sum of peaks (ELEFAN)	3.5
f	fishing effort (also as F)	9.0
F	fishing mortality coefficient or instantaneous rate (per time unit)	4.2
Fm	maximum fishing mortality	5.3
F-array	array of F at age, fishing pattern	5.1
I	separation index	3.5
K	curvature parameter	3.1
L	length	general
L1-L2	length class	-
L_∞ or L∞	L infinity, asymptotic length (mean length of very old fish)	3.1
L'	some length for which all fish of that length and larger are under full exploitation (lower limit of corresponding length interval)	4.5
Lc or L50%	length at which 50% of the fish is retained by the gear and 50% escape	4.5
L75% or L75	length at which 75% of the fish is retained in the gear	6.1
Lm	optimum length for being caught	6.2
m	= K/Z	8.4
M	natural mortality coefficient or instantaneous rate of natural mortality or natural mortality rate (per time unit)	4.2
MSE	Maximum Sustainable Economic Yield	5.5
MSY	Maximum Sustainable Yield	5.5
N	number of survivors (VPA)	5.0
N(t)	number of survivors of a cohort attaining age t	4.1
N(Tr)	number of recruits to the fishery	4.1
ϕ'	(phi prime), $\ln K + 2 * \ln L_\infty$	3.7
q	condition factor, constant in length-weight relationship	2.6
q	catchability coefficient	4.3
R	recruitment N(Tr)	4.1
S	selection curve	6.1
S(L)	logistic curve	6.1
S.F.	selection factor	6.1
S/R	stock recruitment relationship	12.0
t	time (usually in years)	general
T	ambient temperature in °C	4.7
Tc	age at first capture (start of exploited phase)	4.1
Tm	longevity (maximum age)	4.7
Tm 50	age of massive maturation (50% of population mature)	4.7
t_0	t-zero, initial condition parameter (in years)	3.1
Tr	recruitment age	4.1
ts	summerpoint (0-1) (ELEFAN)	3.5

tw	winterpoint (0-1) (ELEFAN)	3.5
t50%	age at which 50% of the fish is retained in the gear (Thompson and Bell)	(5.3) 6.1
U	1-Lc/L	8.4
v	value (Thompson and Bell)	5.3
VPA	Virtual Population Analysis	5.0
W_∞	weight infinity, asymptotic weight (W infinity, mean weight of very old fish)	3.3
X factor	multiplication factor of F (Thompson and Bell)	5.3
y	yield	5.3
Y/R	yield per recruit	8.2
(Y/R)'	relative yield per recruit	8.4
Z	total mortality coefficient instantaneous rate of total mortality, total mortality rate (per time unit)	4.2

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1 INTRODUCTION

There are several excellent textbooks and manuals dealing with fish stock assessment wherein the theory behind the various models and methods is well explained, including the mathematical derivation of formulas (see for example Gulland, 1969 and 1983 and Csirke, 1980a). The problem is that from such manuals the beginning fishery scientists can usually not derive the precise instructions needed to perform each analysis. Where experienced scientists are around such instructions can easily be provided on-the-job and through participation in working group meetings. However, there are still many countries where such a transfer is not possible. This manual is in particular intended to assist the beginning fishery scientists. It is an attempt to put down in writing that part of the instructions that is usually transferred through on-the-job training. It concentrates on the application of methods, while less attention is given to detailed explanations of the theory behind them.

With the help of this manual the fishery scientist should be able to make a start with data analyses and building up the necessary skills and insight in solving stock assessment problems. After this initial step it should be easier to access more complex textbooks.

Stock assessment of tropical resources has developed rapidly in the last decade in particular through the work of Pauly (1979, 1980), Saila and Roedel (1980), Pauly and David (1981), Garcia and Le Reste (1981) and Munro (1983), but also because of the rapid development of microcomputer hard- and software. This manual is intended to further contribute to this development and for that reason emphasis has been placed on those methods which are particularly useful in tropical areas, while most of the examples given are based on tropical stocks.

The rapid introduction of special software for fish stock assessment, in particular that based on length frequency data, such as the packages COMPLEAT ELEFAN (Gayanilo, Soriano and Pauly, 1988) and LFSA (Sparre, 1987) also means that inexperienced fishery scientists may be placed in a position where they are using methods and models without fully realising the limitations of each method. The present manual should provide the necessary background knowledge on the methods to the users of the software mentioned above, in particular the LFSA package. This does not mean that this manual is directly related to computers. On the contrary, every method and exercise can be applied with the help of a good, programmable scientific pocket calculator. Further details on the use of this manual in training courses can be found in Venema, Christensen and Pauly (1988a).

1.1 The primary objective of fish stock assessment

The basic purpose of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources such as fish and shrimp. Living resources are limited but renewable, and fish stock assessment may be described as the search for the exploitation level which in the long run gives the maximum yield in weight from the fishery.

Fig. 1.1.1 illustrates this basic objective of fish stock assessment. On the horizontal axis is the fishing effort measured, for example, in number of boat days fished. On the other axis is the yield, i.e. the landings in weight. (If the landings consist of different groups of animals, for example shrimp, finfish and squid, it may be more appropriate to express the yield in terms of value). It shows that up to a certain level we gain by increasing the fishing effort, but after that level the renewal of the resource (the reproduction and the body growth) cannot keep pace with the removal caused by fishery, and a further increase in exploitation level leads to a reduction in yield.

The fishing effort level which in the long term gives the highest yield is indicated by F(MSY) and the corresponding yield is indicated by "MSY", which stands for "Maximum Sustainable Yield". The phrase "in the long term" is used because one may achieve a high yield in one year by suddenly increasing the effort, but then meager years will follow, because the resource has been fished down. Normally, we are not aiming at such single years with maximum yield, but at a fishing strategy which gives the highest steady yield year after year.

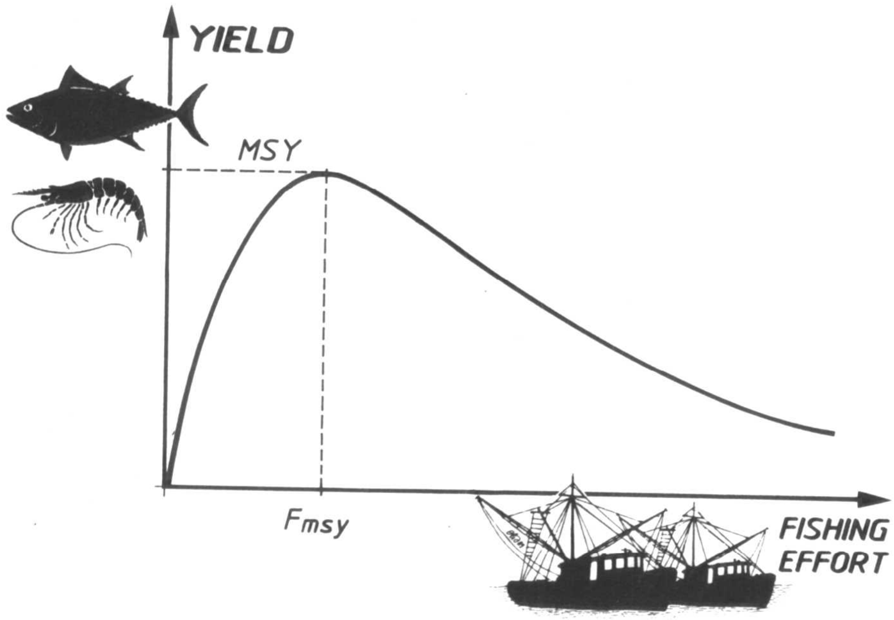

Fig. 1.1.1 The basic objective of fish stock assessment

1.2 The stock concept

When describing the dynamics of an exploited aquatic resource a fundamental concept is that of the "stock". By a "stock" we mean a group of organisms of one "species", having the same "stock parameters", and inhabiting a particular geographical area. The "stock parameters" are indicators of mortality and physiological features, for example, body growth.

A stock is a subset of a "species", which is generally considered as the basic taxonomic unit. A prerequisite for the identification of stocks is the ability to distinguish between different species. Because of the great number of different, but often similar species observed in tropical fisheries their identification can be problematic. The fisheries biologist, however, must master the technique of species identification if any meaningful fish stock assessment is to come out of the data collected. An aid to solve problems in species identification is provided by the so-called "FAO species identification sheets for fisheries purposes", (Fischer, 1978; Fischer and Bianchi, 1984; Fischer, Bianchi and Scott, 1984; Fischer and Hureau, 1986; Fischer, Schneider and Bauchot, 1987; Fischer and Whitehead, 1974) and in the "FAO species catalogues" (Allen, 1985; Colette and Nauen, 1983; Compagno, 1984 and 1984a; Holthuis, 1980; Roper, Sweeney and Nauen, 1984; Whitehead, 1985 and Whitehead, Nelson and Wongratana, 1988).

To the definition given above we can add that "stocks" are discrete groups of animals which show little mixing with the adjacent groups. One essential feature is that the population parameters remain constant over the distribution area of the stock, so that we can operate with the "stock parameters".

This definition may be too superficial for the taste of many biologists, and in the following a few more aspects of the stock concept are mentioned. A group of animals for which the geographical limits can be defined and therefore also the fisheries (the fishing fleets) which exploit this group of fish may be considered "a stock" in terms of fish stock assessment. Such a group of animals should belong to the same race within the species, i.e. be a group of animals which share a common gene pool. For species showing little migratory behaviour (mainly demersal species) it is easier to identify a stock than for highly migratory species, such as tunas.

Cushing (1968) defines a fish stock as one that has a single spawning ground to which the adults return year after year. Larkin (1972) defines a stock as "a population of organisms which, sharing a common gene pool, is sufficiently discrete to warrant consideration as a self-perpetuating system which can be managed", while Ihssen *et al*. (1981) define a stock as "an intraspecific group of randomly mating individuals with temporal or spatial integrity".

Perhaps, the most suitable definition in the context of fish stock assessment was given by Gulland (1983) who stated that for fisheries management purposes the definition of a "*unit stock*" is an operational matter, i.e. a group of organisms can be treated as a stock if possible differences within the group and interchanges with other groups can be ignored without making the conclusions reached invalid.

A definition of the term "stock" acceptable to everyone with an interest in intraspecific groupings may be unattainable. For reviews of the stock concept, see Booke (1981), Ihssen *et al*. (1981) and MacLean and Evans (1981).

Fish stock assessments should be made for each stock separately. The results may (or may not) subsequently be pooled into an assessment of a multispecies fishery. Therefore, the input data must be available for each species considered. The stock concept is closely related to the concept of "*population parameters*", of which the so-called "*growth parameters*" are an example. The latter are numerical values in an equation by which we can predict the body size of a fish when it reaches a certain age. Other population parameters are the "*mortality coefficients*", which reflect the rate at which the animals die, i.e. the number of deaths per time unit. The mortality rates considered in this manual are the "*fishing mortality*", which reflects the deaths created by fishing and the "*natural mortality*", which accounts for all other causes of death (predation, disease etc.).

An essential characteristic of a stock is that its population parameters remain constant throughout its area of distribution. Let us, as an example, partition that area into two parts, sub-areas A and B:

Sub-area A	<——— ———>	Sub-area B

The population parameters must be the same in sub-areas A and B, or in other words:

1) The animals in sub-area A must have the same body growth rate as the animals in sub-area B

2) The animals in sub-area A must have the same probability of death as the animals in sub-area B

If, for example, fishing takes place only in sub-area A, it is assumed that each individual fish in the stock has the same probability of being encountered in sub-area A and thereby also that it has the same probability of being caught. The individuals are supposed to move freely between the two sub-areas.

In order to determine whether a species forms one or more distinct stocks, we should examine its spawning areas, population parameters and morphological and genetic characteristics. We should also compare the fishing patterns in various areas and carry out tagging studies. The process is complicated, and often it is not possible with the knowledge in hand to determine whether there are several stocks of that species or not. There are two main reasons for failing to define a stock properly:

1) The full distribution area of the stock is not covered, so that only a part of the stock is considered, or the opposite

2) Several independent stocks are lumped together, for example because their areas of distribution overlap

Several countries may exploit the same stock. This is the case for many migratory stocks, e.g. tunas. It sometimes happens that a country assesses such a "shared" stock as if it were a national stock only exploited by that country. On the other hand, a fishery of a single country may exploit several independent stocks. Coral reef fish stocks may fall in this category.

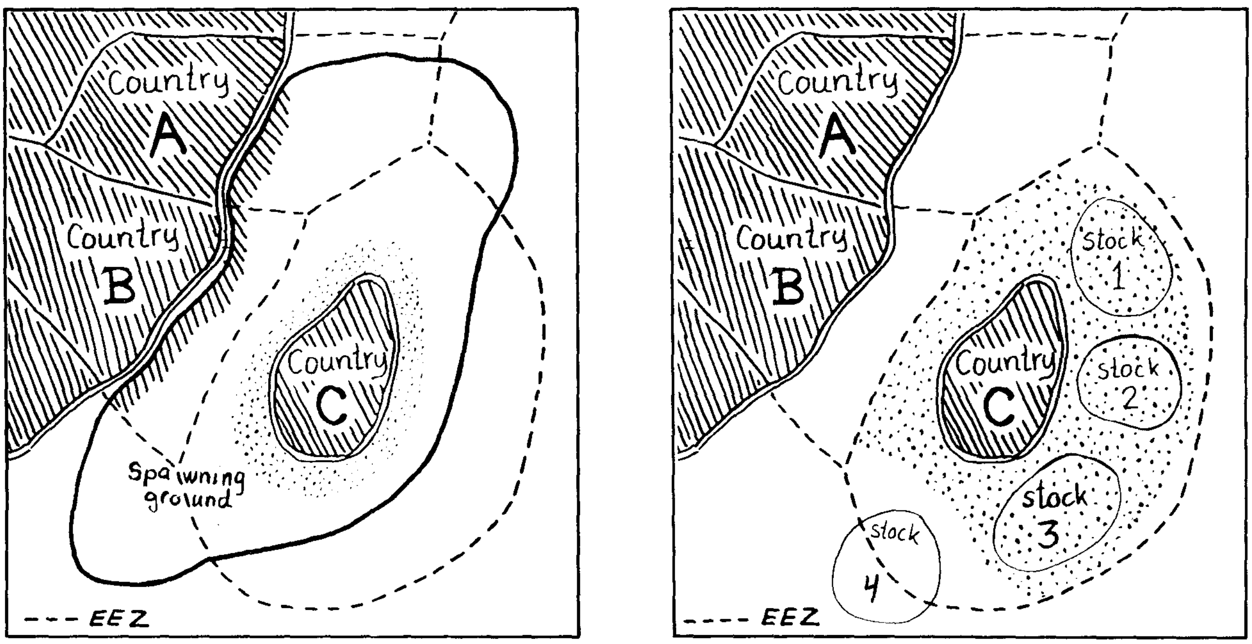

Fig. 1.2.1 Distributions of stocks related to management problems