An Indirect Rapid Methods Approach to Assessment

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Strategies and tactics are explored for increasing the usefulness of assessment information obtainable under manpower and budget restrictions. A concept of indirect rapid assessment is gradually emerging based on a collection of rapid methods of varying degrees of accuracy, sophistication, and data requirements. These tactics involve the use of statistics which are functionally related to parameters of interest. Stock composition, growth, morality, population size, intrinsic rate of increase, and stock production may be efficiently estimated with these methods. Short-term tonnaging is also possible. Tactics include group testing, correcting biased estimates, use of comparative studies, using length as a substitute for age, and remote sensing type assessments.

On exploite les stratégies et tactiques afin d'augmenter l'utilité des résultats d'évaluation qu'on peut obtenir sous des restrictions budgétaires et manuelles. Un concept d'évaluation indirecte et rapide se dévele à partir d'un ensemble de méthodes rapides dont le degré d'exactitude ainsi que les exigences de données varient. Ces tactiques engagent l'emprise de statistiques qui sont liées de façon fonctionnelle aux paramètres en question. Ces méthodes ont aussi l'avantage de faire l'estimation de la composition de stock, la croissance, la mortalité, la taille de la population, le taux intrinsèque de croissance et la production de stock. On peut également faire des estimations à l'échelle de l'année. Ces tactiques comprennent l'analyse en groupe, la correction des estimations biaisées, l'emploi d'études comparatives, l'utilisation de l'âge par la longueur ainsi que les données reçues par satellites et avions.

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isery biologists around the world must face the realities of assessing fisheries under budget and manpower constraints. In this paper, we examine indirect rapid assessment techniques which involve the use of easily obtained statistics that are functionally related to the assessment parameters of ultimate concern. We attempt to develop a general concept of indirect rapid assessment methodology by cataloging and reviewing diverse approaches which can be used by fishery biologists. These approaches include group testing, sampling with two measuring devices of different accuracy, using comparative studies, etc. Several approaches presented are new to fishery biologists.

Historically, there has been a number of rapid assessment techniques available but these techniques were generally quite crude. Hence, the term "quick and dirty" was an accurate description in many cases. Many of these techniques have evolved into sophisticated methods.

The variety of strategies available to fishery scientists for dealing with budget and manpower limitations can be contrasted by considering a simple example: suppose one wants to estimate the natural mortality rate in an unexploited fish stock. A traditional approach is to plot cycle length against age. The technologically oriented fishery biologist may try to develop a faster, automated system for preparing hard parts for examination, or to automate the process of measuring desk with a digitizer pad. The statistically oriented biologist might try to determine the minimum sample size which will provide the needed information and might advocate a sequential approach to collecting data. Both types of biologist may combine their general approach with the use of an age-length key. The key, which substitutes easily collected length frequency data for some of the harder to obtain age data, was one of the first "indirect rapid" techniques to be developed. The indirect assessment biologist has other options: age just enough fish to be confident of finding the oldest age in the sample and utilize the relationship between longevity and


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Group Testing

Suppose one wants to estimate the prevalence of a certain trait which is known to be rare. Then most units (e.g., animals) tested will show negative results, i.e., the absence of the trait. In this case, one may wish to look for a method of testing randomly formed groups of units.

For example, the parasitic copepod *Mytilicola tenuis* occurs in the blue mussel *Mytilus edulis* throughout much of western Europe's coastal waters. Detecting the presence of the parasite by dissection is a slow and tedious procedure. Dare (1977) devised a rapid procedure based on testing batches of mussels with *Sertularia* enzyme papain and then digesting through the residue under a low-power dissecting microscope to detect the undigested chitinous exoskeletons of *Mytilicola*. If mussels are randomly assigned to jars, then the number of jars showing the parasite must be related to the proportion of animals having the parasite.

The maximum-likelihood estimate is given by

\[ \hat{p} = 1 - \left( \frac{1 - \frac{m}{n}}{e} \right)^{1/e} \]

with asymptotic variance given by

\[ \text{Var}(\hat{p}) = \left( 1 - \frac{m}{n} \right)^{2/e} \frac{e}{n} \]

where \( p \) is the estimate of the proportion of animals with the trait (parasite), \( q = 1 - p \), \( X \) is the number of groups (jars) showing the trait, \( n \) is the number of jars, and \( m \) is the number of units per group (mussels per jar) (Gibbs and Gower 1960; Thompson 1962; Sobot and Ellenbogen 1975).

Suppose one only has time to do 50 tests and one wishes to estimate the proportion of animals that are infected when the infection rate is actually 0.05. If animals are tested in groups of one (i.e. 50 animals are individually tested), the standard error of the estimate would be \( \sqrt{\frac{50}{50} - \frac{50}{50} \times 0.05 \times 0.95} = 0.03 \). If animals are tested in groups of two (i.e. 100 animals tested in 50 tests), the standard error would be (approximately) 0.02.

Thus, it is clear that when dealing with rare traits, increased efficiency over ordinary binomial testing (one animal per test) can be obtained by testing randomly formed groups. This gain in efficiency can make it possible for a researcher to conduct larger, more detailed studies, e.g., of the importance of spatial or temporal pattern.

Care must be taken, however, not to place too many units in a group. Otherwise, all tests may turn out positive which leads to a maximum likelihood estimate of 1.0 even though the actual proportion could be much less. The statistical theory behind group testing has been described by Hoening (1981) and Loyer (1983).

For group testing to be worthwhile, it must be almost as easy to test a group of animals as it is to test an individual. This generally means that it must be possible to physically censurate tissue or body waste samples. For example, in testing for whirling disease (Myxosoma), one could macerate several fish heads simultaneously in a blender and stain the spores in the pooled sample provided there is no loss in sensitivity caused by dilution with uninfected fish (Markov and Wolf 1980). A procedure that involves histological examination of tissue would not be suitable for group testing as too few samples could be examined at once.

An extension of group testing is the estimation of multinomial proportions. Suppose there are three stocks or species whose spatial and temporal distributions need delineation. A simple procedure would be to process samples by electrophoresis from a large number of individuals from various areas, depths, habitats, and times. But consider the results of testing groups of two fish at a time. If the banding pattern of Ddr in toxins has at least one unique identifier, then there is no loss of information in testing groups of two. Thus, if each pattern is seen, both animals must have been from stock B; if A and B are seen, one must have been from A and the other from B. If group size is greater than two, the results become equivocal. For example, if group size is three and A and B are seen, there could have been two fish from stock A and one from B or one from A and two from B. It then becomes a statistical problem to estimate the stock proportions in a sample. Unfortunately, little theoretical work appears to have been done in this area. At present, methods based on common set may become more imperative to develop rapid biochemical tests for identifying processed foods so that handling statistics can be compiled on site. Biochemical means of identifying taxa are discussed in Suzuki et al. (1981) and Takamura et al. (1982).

Group testing procedures can also be adapted for other multivariate studies. For example, suppose one wants to study the co-occurrence of two rare parasites in a host species. The usual procedure is to record the presence/absence of the parasites sites in each individual host. However, by pooling samples of blood, feces, etc., one could test in groups. Estimation of the prevalence rate for each parasite proceeds as for the qualitative case (i.e. ignoring the information on the "other" parasite). However, it now becomes of interest to estimate and test the degree of association of the parasites (Hoening and Layton 1981).

In general group testing situations, less information is obtained per test (animal) tested than if the items were tested individually. However, for suitably chosen group sizes, the information gained per test can be considerably higher than when tests are tested in groups of size one.

Further developments include estimation when testing is possibly (Sobot and Elbroch 1975), group testing with a continuous variable (Sobot and Tong 1976), and development of a general theory of composite sampling (Robe 1979).

Correcting Error-Prone (Biased) Surveys

Suppose one has the choice of using an inexpensive but error-prone technique to estimate the relative abundance of certain traits or using a time-consuming or high-priced technique which is (more) accurate. The logical choice of a single technique would depend on a number of factors and thus is not easily specified. However, it is possible to use the inexpensive technique to conduct an extrapolation, and use both techniques on a small sample to derive correction factors (Hoening and Hesse 1985, 1986, 1987).

As a simple example, consider a survey to estimate the stock

235
composition in a fishery exploiting two stocks. The inexpensive, rapid technique might consist of assigning fish to stocks on the basis of meristic or morphometric characteristics. A more precise but expensive technique would be to use electrophoretic results to classify animals.

The extensive survey using the error-prone technique resulted in a vector of estimates denoted by

$$E = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \end{bmatrix} = \begin{bmatrix} \text{proportion stock X} \\ \text{proportion stock Y} \end{bmatrix}$$

The use of both techniques on a sample, not necessarily random, results in correction data of the form

<table>
<thead>
<tr>
<th>Actually</th>
<th>Classified as</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stock X</td>
<td>stock X stock Y sum</td>
</tr>
<tr>
<td>Stock Y</td>
<td>a b m</td>
</tr>
<tr>
<td>sum</td>
<td>c d n</td>
</tr>
</tbody>
</table>

Placing the tabled values in a matrix and dividing by the corresponding row totals gives the matrix

$$(3) \quad P = \begin{bmatrix} a/m & b/m & \cdots & m/m \\ a/n & b/n & \cdots & m/n \end{bmatrix} \times \begin{bmatrix} p_{11} & p_{12} \\ \vdots & \vdots \\ p_{m1} & p_{m2} \end{bmatrix}$$

which estimates the probabilities of classification. It follows, then, deterministically, that the actual stock composition, denoted by the vector $A$, is related to $E$ by

$$E = FA,$$

In words, this says that the observed number of stock X animals ($e_i$) is equal to the true number in stock X times the probability that an animal from X is classified as X ($p_{ix}$) plus the number in Y times the probability that an animal from Y is classified as X ($p_{iy}$). The vector $A$ can be estimated from

$$(4) \quad A = (P^T)^{-1}E$$

with variance estimated by the jackknife method (Hoenig and Hesse 1984) or the delta method (Polis and Robertson 1979). The approach generalizes easily to the case where animals can be classified into one of $k$ categories (e.g., stocks). It is then necessary to invert a $k \times k$ matrix in equation (4).

This method is intuitive but no claims for statistical efficiency have been advanced for it. Furthermore, the method sometimes produces unfeasible (negative) estimates. Cook (1983) developed an intuitive method for correcting the correct estimates, but the statistical properties induced by this modification are poorly known. Recently, Hoenig and Hesse (1987) developed the maximum likelihood (ML) estimators for the correction problem which are always feasible and are asymptotically normally distributed. Further, they showed that when the estimates obtained by equation (4) are feasible they are also the ML estimates; Cook's method produces ML estimates only for the binomial case (two classes in the population).

Estimates of stock composition are frequently obtained by using a discriminant function to classify animals. The results are unbiased only if the assumptions are fully met. However, the results can be corrected if animals of known identity are used to develop a correction matrix. This correction procedure is non-parametric since traits are not assumed to follow any particular distribution.

Another use of the correction method might be to make estimates of age composition obtained from scales comparable with estimates obtained from spines or otoliths. Although there are a number of other potential uses (Table 2), this technique has only been used a few times in fishery work to correct estimates of stock composition (see Hoenig and Hesse 1984 and Cook (1983 for review)).

It is important to note that the same set of correction data can be used to correct estimates from different times, locations, etc., provided only that the probabilities of misclassification (as estimated by (4)) do not change. That is, the researcher's skills must not change over time and the biological characteristics used to classify the animals (e.g., color, shape) must not change between samples. The relative abundances of the traits can, and in general will, vary between samples.


<table>
<thead>
<tr>
<th>Objective</th>
<th>Error-prone method</th>
<th>&quot;Exact&quot; method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex determination in fish</td>
<td>(1) Hematocrit&lt;sup&gt;1&lt;/sup&gt;</td>
<td>(1) Otoscope</td>
</tr>
<tr>
<td></td>
<td>(2) Proxe&lt;sup&gt;2&lt;/sup&gt;</td>
<td>(2) Surgical examination</td>
</tr>
<tr>
<td></td>
<td>(3) External characteristics&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Species identification</td>
<td>Morphometrics, meristic, anatomy</td>
<td>(1) Electrophoresis&lt;sup&gt;4&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stock identification</td>
<td>(1) Morphometrics, meristics</td>
<td>(2) Latex agglutination&lt;sup&gt;6&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(2) Scale pattern&lt;sup&gt;5&lt;/sup&gt;</td>
<td>(1) Electrophoresis</td>
</tr>
<tr>
<td></td>
<td>(3) Elemental composition&lt;sup&gt;6&lt;/sup&gt;</td>
<td>(2) Sample known stocks</td>
</tr>
<tr>
<td>Age determination in ponds</td>
<td>Tooth wear</td>
<td>Dental growth rates</td>
</tr>
<tr>
<td>Maturity stage</td>
<td>(1) External characteristics</td>
<td>Internal/histological examination</td>
</tr>
<tr>
<td>Composition of catch</td>
<td>Industry reports</td>
<td>Spot-checking by biologists</td>
</tr>
</tbody>
</table>

<sup>1</sup>Steele and Ashworth (1965).
<sup>2</sup>Gascoigne et al. (1962).
<sup>3</sup>Pike (1971).
<sup>4</sup>Gray et al. (1982).
<sup>5</sup>Isozaki et al. (1981).
<sup>6</sup>Cook (1982).
<sup>7</sup>Mulligan et al. (1983).

### Comparative Studies

Comparative life history studies have been used to study problems in physiology, ecology, and evolution by exploring relationships in compendia of life history parameter estimates. In its simplest form, the comparative study consists of plotting one parameter against another to visually check for possible relationships. In its most sophisticated form, it can involve any of the exploratory data techniques, including classification and discrimination methods and regression and correlation analysis. Applied ecologists have used comparative studies to seek easier ways to estimate parameters. That is, if a parameter which is difficult to estimate is functionally related to parameters which are easier to measure (or estimate), then these easily obtained parameters can be used to estimate the parameter of ultimate concern. This use of comparative studies is in contrast with studies which seek clues to basic physiological principles or ontogenic hierarchies.

One of the first comparative studies of life history parameters in fishery biology was the study of natural mortality rates by Beverton and Holt (1959) based on a compendium of mortality, growth, and longevity estimates. They showed that natural mortality is closely related to growth parameters within taxonomic orders, but failed to detect a general relationship. Taylor (1958, 1959, 1960) noted that subtle differences in temperature among stocks of a single species are correlated with growth and mortality rates. Putting these pieces together, Pauly (1980) was able to derive a multiple regression equation using data from 175 fish stocks to predict the natural mortality rate from growth parameters and mean water temperature. Using analysis of residuals, he found that only two groups, polar fishes and clupeoids, departed significantly from the relationship. Physiological considerations accounted for the departure of the polar group; a satisfactory explanation for the clupeoids is not currently available.

Another example is the prediction of the mortality rate from the maximum observed age. Obura (1979) found a functional relationship between these parameters in the Clupeidae. Hoening (1983) generalized the relationship to include mullusks and fishes (Fig. 1). However, the realization that maximum observed age depends on sample size led Hoening and Lawing (1985) to treat the maximum ages in a sample as order statistics from an exponential distribution. They thus developed an estimator based on the k oldest ages in a sample which requires a minimal amount of aging, since the oldest fishes can be found by

![Fig. 1. Relationship between the instantaneous mortality rate and the maximum age known for 125 stocks of fish, mollusks, and crustaceans (from Hoening 1983).](image)

aging just the largest ones. Alveson and Carney (1975) developed a method for estimating the natural mortality rate from estimates of maximum age and the parameter K of the von Bertalanffy growth equation.

A well-known comparative study in fishery biology is Ricker's (1965) development of the morphoecological index (MEI) to estimate total potential yield from lake depth and dissolved solids. This approach has received much attention and is still the object of much interest (Jenkins 1977; Toews and Griffith 1979; Schlesinger and Regier 1983; SPOF 1982; Hanson and Leggett 1982; Oplesky et al. 1987, and references in these works). Jenkins (1977) also empirically studied the numerical relationship between predators and prey. Simple physical models for predicting potential fish yield from rivers were described by Kolbring (1978) and Welcomme (1975, 1979, 1983). Garcia and LeKante (1981) discussed use of physical variables concerning rainfall and heat flux data for short-term forecasting of shrimp yields.

A tantalizing possibility is to estimate the intrinsic rate of increase, r, of a population from the adult body weight. Blueweiss et al. (1978), based on work by Fenchel (1974), showed these two parameters to be highly correlated in organisms ranging in size from viens to elephants (22 orders of magnitude). Pauly (1982) added whales and more fishes to the preceding compilation (Fig. 2) and pointed out that if further study confirms the strength of the relationship, it will be possible to employ Schaefer models without recourse to long series of catch and effort data.

Intrinsic rate of increase might be expected to be related to other life history parameters according to r-K selection theory. Heron (1972) showed that r, is related to generation time and reproduction per generation (Fig. 3). Thus we have two independent estimates of r, derived from life history considerations. Another compilation of life history parameters, which includes values of r, can be found in Caddy and Coutre (1983). One hopes that some useful generalizations will emerge as more observations are compiled and analyzed and the resulting theories are evaluated. Adams (1980) found that five other life history parameters, maximum size, growth rate, longevity, size at maturity, and natural mortality, varied in marine fishes in ways consistent with r-K selection theory. The recent volume

![Fig. 2. Relationship between the intrinsic rate of increase of various organisms and their adult body weight (modified from Blueweiss et al. 1978 by Pauly 1982).](image)

![Fig. 3. Relationship between the intrinsic rate of natural increase of various organisms and the generation time (modified from Heron 1972).](image)

![Fig. 4. Fish yields from African lakes as a function of fishing effort (from Martin and Polovina 1982).](image)
that catch-effort data from ecologically similar regions in Jamaica experiencing different fishing pressures could be plotted on one graph and used to fit a production model with data from one or two years (see Fig. 4, 5). The procedure was clarified by Caddy and Garcia (1982) and applied to a Mediterranean fishery by Garcia (1984). Goddard et al. (1987) applied the method to sport fisheries.

Cairke and Caddy (1983) presented another variation of stock production modeling in which catch per effort is plotted against total instantaneous mortality rate (Z). The method is of interest, in the context of indirect rapid assessment methodology, because the considerable problems in estimating total fishing effort are circumvented by substituting more easily obtained estimates of total mortality. Furthermore, Z can be estimated from mean length data using, for example, Beverton and Holt's (1957) equation (5)

\[ Z = KL - L(\frac{dL}{dZ}) + L_0 \]

where \( K, L, L_0 \) are von Bertalanffy growth parameters and \( L_0 \) is the mean length of those fish above the length \( L_0 \). If all the mortality estimates are derived from this equation, then \( K \) need not be known, since arbitrarily setting \( K \) equal to 1.0 would only serve to shift the location of the parabola along the x-axis and not change the shape. Also, \( L_0 \) can be approximated by dividing the average length of the three largest fish known from the stock (or a similar stock) by 0.95 provided the stock is not too heavily exploited (Pauly 1974b). Another possibility is to estimate mortality from the mean weight by solving the following expression iteratively for \( Z \) (Hoeght et al. 1987).

\[ W = \frac{3}{\sqrt{\pi}} \frac{\ln(1 - \frac{W}{W_0})^3}{Z + nK} \]

where \( W \) is the mean weight of animals above the weight \( W_0 \), \( W_0 \) and \( A \) are the asymptotic weight and growth coefficient, respectively, in the von Bertalanffy growth in weight curve, and \( U_w = 1, -3, 3, 1 \).

Further developments are possible. For example, if only a few data points are available for a freshwater system, or if the data are too noisy for fitting a parabola, one can use an independent estimate of maximum sustainable yield (MSY) (e.g., from the MEF or other empirical relationship) as a constraint in estimating the parameters of the parabola (Hoenig and Hoenig 1986). The constraint can be introduced into the normal equations using a Lagrange multiplier. The model of interest is

\[ Y_{obs} = b_0 X^2 + b_1 X + b_2 + \text{error} \]

where \( Y_{obs} \) is the observed equilibrium yield, \( b_0 \) are regression coefficients, and \( X \) can be either total mortality or fishing effort (with \( b_0 = 0 \) in the latter case). The predicted equilibrium yield has a maximum value of \( -b_2^2/(4b_1) + b_2 \) which is constrained to be equal to some value \( M \). Then instead of

\[ \min \sum(Y_{obs} - b_0 X^2 - b_1 X - b_2)^2 \]

the constrained least squares estimates consist of

\[ \min \sum(Y_{obs} - b_0 X^2 - b_1 X - b_2 + \lambda(-b_2^2/(4b_1) + b_2 - M)) \]

where \( \lambda \) is the Lagrange multiplier. The nonlinear expression routines in some of the major statistical packages allow regression with constraints.

Similarly, in Cairke and Caddy's (1983) version of the stock production model based on mortality estimates, the left x-axis intercept can be constrained to the value of an independent estimate of natural mortality rate.

Other examples of comparative studies include relating yield and community structure to physical parameters (Fig. 6–9) and relating yield to primary productivity (Fig. 10–11). Also, Jones and Hoyer 1962; Oglesby et al. 1987. Pauly (1984, chap. 3) showed that comparative anatomy studies could be used to determine approximate trawl selectivity factors for soft-rayed fishes, e.g., by examining the relationship between selectivity and girth to depth ratio. A review of data compilations and comparative studies can be found in Hoenig (1982).

A conceptual framework for comparative studies was presented by Anderson et al. (1980) (Fig. 12). The different types of studies they identified can be contrasted using a simple example. Suppose one wishes to determine what factors account
for the occurrence of undesirable events, such as winterkills or epizootics, in the lakes of a region. Suppose further that a potential "causal" factor (risk factor) has been identified such as shallow water depth. In a cohort study, a group of lakes with the factor (i.e., with shallow depth) and another group without the factor would be identified. Then the incidence of the response (winterkill or epizootic) would be contrasted in the two groups. This type of study can be conducted prospectively (identify lakes and then wait for the response) or retrospectively (identify lakes and then check the historical record to see if the response occurred). In a case control study, a group of lakes is identified in which the response is known to have occurred and, similarly, another group is identified in which the response has been absent. The occurrence of the potential causal (risk) factor is then compared in the two groups. Case control studies can only
### Table 3. Examples of indices in fishery science and their conversion to totals by ratio estimation.

<table>
<thead>
<tr>
<th>Index</th>
<th>Parameter</th>
<th>Estimator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catch per unit effort (CPUE)</td>
<td>Fish population size (N)</td>
<td>[ F = \text{(catch/unit)} \times f ]</td>
</tr>
<tr>
<td>Total effort (f)</td>
<td>Fishing mortality (F)</td>
<td>[ C = \text{(catch per unit effort)} \times f ]</td>
</tr>
<tr>
<td>Total effort (f)</td>
<td>Catch (C)</td>
<td>[ f = \text{(effort per unit)} \times S ]</td>
</tr>
<tr>
<td>Diesel fuel sales (S)</td>
<td>Effort (f)</td>
<td>[ f = \text{(trip-kg garbage)} \times g ]</td>
</tr>
<tr>
<td>Garbage left at boating facilities (g)</td>
<td>Effort (f)</td>
<td></td>
</tr>
<tr>
<td>Total catch (C)</td>
<td>Effort (f)</td>
<td>[ f = \text{(catch per unit effort)} \times C ]</td>
</tr>
<tr>
<td>Total effort reported (ef)</td>
<td>Total effort (f)</td>
<td>[ f = \text{(ratio of actual effort/reported effort)} \times e ]</td>
</tr>
<tr>
<td>Total catch reported (ac)</td>
<td>Total catch (C)</td>
<td>[ C = \text{(ratio of actual catch/reported catch)} \times n ]</td>
</tr>
<tr>
<td>Uncalibrated measure (U)</td>
<td>Actual total (A)</td>
<td>[ A = \text{(correction factor)} \times U ]</td>
</tr>
</tbody>
</table>

where correction factor = change in A

per unit of U

**Fig. 12. A conceptual framework for comparative studies (redrawn from Anderson et al. 1980).**

be conducted retrospectively. In a cross-sectional study, lakes would be simultaneously classified for the presence of the risk factor and the occurrence of the response. The type of study selected will depend on the availability of historical data and also the relative prevalences of the risk factor and the response. For example, if winterkills are uncommon, then a case control study may be preferable to guarantee adequate sample sizes in each group.

These examples demonstrate several important aspects of comparative studies: (1) comparative studies are relatively new, yet they have already produced some spectacular results; (2) vitally important parameters, which are difficult to estimate or measure directly, may be easily estimated indirectly from other parameters; (3) with time, the data bases become better, the analyses become more sophisticated, and the inferences become more insightful; (4) the empirical comparative studies can lead to better theoretical models and understanding of the systems by suggesting structural relationships which require exploration; (5) results from comparative studies can be used as preliminary estimates for traditional assessment analyses, thus providing a transition between empirical “seat of the pants” management and state of the art modeling.

A drawback of comparative studies based on literature data is that one may not have control over the quality of the data used. It may be difficult to develop objective criteria for deciding which published studies will be rejected for lack of adequate supporting information. Also, it may be difficult to obtain a complete list of pertinent studies or to obtain an unbiased sample of studies.

Holt (1962) called for more comparative studies. Recently, Banerji and Krishnan (1973) and Bakun et al. (1982) renewed the call. An international symposium held in Palazzina, Italy, in 1978 sought to review the bases for comparative studies of freshwater fisheries to promote this general approach (FAO 1980).

### Indices and Ratio Estimators

Sometimes a comparative study establishes that one quantity can be used as an “index” of another quantity. For example, fishing effort is commonly used as an index of fishing mortality and catch rate as an index of population size (Table 3). The ideal index is one that is directly proportional to the quantity it replaces.

In certain situations, an index can be converted into an estimate of population total. For example, diesel fuel sales (Levi 1976) and fish landings (Ricker 1975, p. 19) are both indicators of fishing effort. The following estimators of total effort can be used:

- Total effort = effort per line \times total sales
- Total effort = (catch per unit effort) \times total catch

331
The effort per gallon and catch per unit effort ratios are deter-
mined by sampling a portion of the fleet. These procedures avoid the
difficult problems of estimating relative fishing power of
various types of boats and gears.

Of course, if both auxiliary variables (catch and fuel sales) are
known, it is possible to use a multivariate ratio estimator for
increased efficiency as follows (with Blom et al. 1984):

Total effort = \( \frac{w}{1 - \frac{w}{\text{fuel}} + \frac{w}{\text{sales}}} \)

where \( w, \text{fuel}, \text{and sales} \) are the estimates derived from catch data and fuel
sales, respectively, and \( w \) is a weighting factor for combining the
estimates. If the two estimates are independent, then the
optimal weight would be given by

\[ w = \frac{\text{MSE} \text{(fuel)}}{\text{MSE} \text{(sales)}} + \frac{\text{MSE} \text{(fuel)}}{\text{MSE} \text{(sales)}} \]

where MSE is the mean squared error. Otherwise, if catch rate
and fuel consumption data are obtained from the same boats,
one would need to incorporate the covariance of the auxiliary
variables in the weighting calculations (Blom et al. 1984).

It should be noted that only the population totals, not the
individual values, are needed for the auxiliary variables when
the relationship between the variables and fishing effort is
linear. In the above example, if the relationship between fishing
effort and fuel consumption is non-linear, then one would have
not to accept added bias in the estimated total effort. However, if each
individual sale of fuel is known, instead of just total sales, then a
regression of effort on sales can be used to estimate the total
effort for each boat. This modeling-building approach is discussed
in more detail below under Aerial and Remote Assessments.

Williams (1978) described how auxiliary variables can be
obtained almost "out of thin air." For example, to estimate the
total landings in a port in a given day, one could guess at the
landings for each boat and use the sum of the guesses as the
population-total for the auxiliary variable. Then one randomly
samples some boats to estimate the ratio of actual landings to
guess landings. The observer's lack of objectivity does not
cause bias in the estimate per se. However, the ratio estimation
method is in general statistically biased for small samples. This
bias will depend on the extent to which the relationship between
guesses and actual landings violates the assumptions of the
method (i.e. a linear relationship through the origin with mini-
mal deviation from this relationship).

The variance, small sample bias, and use of the jackknife
method for reducing bias is discussed for ratio estimation and
related techniques in most sampling texts. Unfortunately, scant
attention is usually paid to the statistical aspect of ratio estima-
tion in fishery courses and texts despite the prevalence and
importance of the method in practice.

Length as a Substitute for Age
Length frequency data contain much of the information con-
tained in age frequency data. Thus, there has been a long history
of trying to extract useful information from length frequency
distributions since Peterson (1892) associated modes with age
classes. Various approaches were tried over the years to im-
prove upon Peterson's basic technique (review by Brothers 1980),
but a dependable procedure seemed elusive. Recently, Paul
developed and implemented an algorithm (in BASIC) called ELE-
FAN I which promises to be a significant improvement (Pauyl
and David 1981; Paul, 1987). The algorithm defines a set of
peaks and troughs in one or more length frequency samples and
then tries to maximize the goodness of fit of a growth curve by
passing the curve through as many peaks and avoiding as many
troughs as possible. A host of further algorithms for estimating
mortality, selectivity, and population size from suitable length
samples have been developed with the original ELEFAN
program. ELEFAN occupied a prominent position during the
recent International Conference on the Theory and Application
of Length- based Age Determination. Morgan (1987) modified the
ELEFAN algorithm so that supplemental growth information, e.g. from a
limited number of tag returns or age determinations, could be
incorporated into the estimation procedure. Shepherd (1987a) and Pauly and Caddy (1985) de-
scribed alternative algorithms to the ELEFAN method.

Estimation of mortality rates from length frequency data has
proceeded along two lines. Fridriksson (1934) developed the
age-length key in which an aged subsample is used to estimate the
age composition in the total length frequency distribution. The
method relies on the statistical concept of stratified random sampling. It qualifies as an indirect rapid
assessment tool since easy to collect length data are sufficient for
some costly age data. Properties and modifications of the
age-length key were presented in Kimmir (1977), Westheim and
Ricker (1978), Clark (1981), Bartus and Parker (1963), and
Hoening and Heisey (1987).

A classical age-length key can only be validly applied to a
population with the same composition as the one from which the
key was derived. Clark's method looks at the variability in
length about age instead of age about length. As a consequence,
his procedure can be applied to any number of populations, with
varying age compositions, provided the growth rate and
selectivity are constant. However, Clark's method assumes that
the age-length key data are known without error so that the only
uncertainty lies in the estimate of the length frequency of the
population. Known uncertainties in age composition is desired.
In general, age-length key data are based on small samples,
since age determinations are tedious and expensive to obtain,
whereas length frequency data are easily obtained for large samples,
since measuring fish is easy. It would therefore be more reason-
able to assume that most of the uncertainty lies in the age-
length key part of the data. Hoening and Heisey (1987) pointed out the
similarity between the age-length key problem and the correc-
tion matrix procedure for stock composition described earlier.
Their ML estimation procedure allows for stochastic length
frequency data and the age-length key data with the amount of error depending on the sample sizes.

Beverton and Holt (1957, 1957, p. 22) pioneered the other
approach of estimating the total mortality rate directly from
length statistics when growth rates are known (see equations (5)
and (6)). A number of extensions have been made over the
years which are reviewed by Hoening et al. (1983) and Paul

A problem with using simple statistics such as mean or
median length to estimate the total mortality rate is that one
cannot gauge the validity of the basic assumptions. As Powell
(1979) has shown, even a cursory examination of a length
frequency distribution can give useful insights into the popula-
tion dynamics of a stock (Fig. 13). Thus, it is significant that
Jones (1981) developed a rigorous technique for length fre-
quency data which allows one to visually inspect the goodness
of fit. Jones' technique involves the cumulative catch
function and log-log plotting. The resulting slope (except at
the ends of the line segment) estimates Z/R and L, from
which the coefficient of determination, Pauly


332
Fig. 13. Relationship between the ratio of Z/K (mortality to growth coefficient) and the shape of a length frequency distribution (from Pauly 1982). (1983, 1984a, 1984b) advocated the slightly different approach of analyzing a catch curve based on relative ages derived from a length frequency sample (Fig. 14). Since Jones' method uses cumulative catch, which is a monotonic function of log(L) (Lm = L), the slope will always be significant. Thus, Pauly's method seems to be on sounder statistical footing, but further work is necessary to study the properties of these techniques.

It is now feasible to think in terms of length-based virtual population analysis (VPA). The approach has been pioneered in papers by Jones (1974, 1979, 1981, 1984) and Pauly (1984b). Pope and Jiming (1987) developed a length-based multispecies cohort analysis. Holt (1977) proceeded in a different direction and considered the estimation of population size of sperm whales from changes in the mean size in the catches. It is clear that there is now considerable interest in the development of length-based assessment techniques. The estimation of growth parameters from length data is mainly of interest in tropical regions and for use on crustaceans, since direct age determinations are difficult in these situations. Short-term forecasting (Shepherd 1987b), mortality estimation, and estimation of population size are almost universally of interest.

Assessment by Analogy

Intuitive judgments about the fisheries in a lake can be sharpened by defining empirical indices that can be used for comparing ecologically similar lakes. The basic idea is that if easily measured statistics for a given lake, such as test netting data, are similar to lakes known to be in an acceptable condition, then the lake is probably also in good condition. Mean length might be plotted against standard deviation to develop empirical probability densities as a basis for comparison, and to try to cluster similar lake communities. Predatory-prey ratios and other indicators of community structure could be tabulated. These statistics can be used to "flag" lakes potentially in need of further study.

As an example, mean lengths and standard deviations of bluegill (Lepomis macrochirus) and northern pike (Esox lucius) were obtained from routine survey files for 41 lakes in central Minnesota with permanent fish populations (Fig. 15). Mean length appeared to be unrelated to standard deviation among pike populations (r² = 0.015, p = 0.550). Hence, unusual occurrences were taken to be indicated by extreme values of either variable. Among bluegill populations, mean length appeared to be negatively correlated with standard deviation (r² = 0.161, p = 0.002). Unusual populations were considered indicated by extreme outlier scores (Cook 1977) of data points about a linear regression line (e.g. those points with p values less than 0.10). This procedure is intended as an exploratory tool, not as a formal test of hypothesis, and is at any rate tentative.

An alternative approach was developed by Tom et al. (1983) who used various multivariate statistical techniques to classify lakes and relate community structure to habitat variables. They used these results as a basis for developing management strategies.

Ryder and Edwards (1985) recommend a holistic approach to ecosystem quality and suggested that key indicator species be monitored as guides to the rest of the system. The evaluation of impacts on key species, known as Representative Important Species (RIS), is a standard approach to meeting the assessment provisions of sections 318a and 316 of the United States Federal Water Pollution Control Act of 1972 (see EPA 1973a, 1987b). Regardless of what one thinks of this strategy, it is likely to play a prominent role in ecological impact assessment for many years for want of a better approach. It is also clear that
In Yellowstone Park, fisherman are asked to voluntarily submit reports on their fishing trips. A crew clerk makes spot checks so that in-season recession (calibration) can be used to adjust the estimates for reporting bias (R. Gresswell, pers. comm.). Further calibration of creel survey methods is given in the next section.

**Aerial and Remote Assessments**

The use of aircraft and remote sensing satellites may seem inconsistent with the rapid assessment goal of stretching the research budget. However, in many cases, assessments from the air can be highly cost effective. Some useful remote sensing data, generated as a by-product of other projects, can be obtained for a nominal charge. (Use of inexpensive kits has also been tried (Scotfin 1982).)

Aircraft can cover a few hours what a team of biologists on the water might take several days to cover. Aerial observers can count fishing vessels by size and gear (and other boat types), count fixed location gear, count and estimate the size of fish schools and identify them to varying degrees, count salmonid nests (redds) in streams, map reelfishes and marshes, etc. (Skuhr 1983; Parack 1976; Heggebreks et al. 1986).

Biotic and abiotic environmental conditions such as chlorophyll, phytoplankton taxa, riparian vegetation, surface temperature, wave-height, and current characteristics can be quantified (Klemas et al. 1980; Brahm et al. 1983), Crouse and Foddy 1984. Feldman et al. 1984; Fy and Chotin 1984). In addition, the observers can provide public services such as relaying the locations of fish schools and fishing areas and billfish, reporting mariners in distress, hazardous obstructions, etc.

These methods enter into indirect rapid assessment methodology when there is visibility bias which must be corrected (e.g. Cook and Jacobson 1979), where raw counts from the air must be apportioned to various categories based on surface studies of relative abundances (ratio estimation), or when remote sensing signals need calibration.

When the study area is too large to be completely observed, one can use line transect methods to count boats and fixed gear (see Earnham et al. 1980 for a review). Statistical and practical aspects of aerial sampling are discussed by Jolly (1979) and Jolly and Watson (1978).

An alternative is to make two (or more) independent counts in which each observer ignores or minimizes his location on a map or recording its license number. The results can then be analyzed using mark-recapture methods that is, the survey "marks" the boats by using identical observers; then the observer surveys "recaptures" a boat when a previously identified boat is spotted (Makhnach et al. 1978). If the whole area is not censused, then the boats must mix randomly between observation periods or the observers travel must follow random paths.

Mark-recapture methods have been tried (without the use of airplanes) on Liverpool taxicabs (Bishop and Bradley 1972) and crested fish (Regler 1971).

Another strategy that can be applied to catch and effort surveys is to correlate observations at one time (of day, of the week) with the total over a longer interval. For example, Parker (1950) found that sport fishing effort at one was highly correlated with the total daily fishing effort. This aspect has also been investigated by Powell and Bowden (1981). This suggests the use of a model-based approach to sampling whereby observed count or effort data can be fitted to a model by regression techniques. Total effort can then be estimated by integrating the

![Graph](https://via.placeholder.com/150)

**Volunteered Data**

Fishermen can be enlisted to provide a variety of types of information. The task is to estimate the reliability of the data and to deal with systematic errors.

One of the earliest uses of volunteer sportsmen was in the analysis of banding and tagging data. A highly sophisticated set of models and procedures, developed largely for bird banding studies, are now available to fisheries biologists (Oris et al. 1978; White et al. 1982; White 1983; Brownie et al. 1985). Unknown and changing reporting rates are handled by marking animals at two or more times. They, differences in return rates for the cohorts in a given year can reasonably be attributed to mortality (provided tag shedding and other factors can be accounted for).

Under suitable supervision, fishermen can provide quality information on catch rates, fish size frequencies, geographic distribution, etc. as well as quantitative tag return rates and biological samples. Eberns (1987) enlisted anglers to keep detailed diaries and also collected data at sport fishing tournaments. The data collected from both sources were comparable with data collected on biological surveys but entailed less manpower on the biologists' part.

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regression equation over the appropriate time interval (e.g. season). Variance, bias, and design considerations were dis- cussed by Hoegh et al. (1996).

Hydroacoustic surveys and use of resistivity fish counters in streams (Dushen and Shearer 1982) are conceptually similar to aerial surveys in that the recorded signals must be calibrated with biomass or numbers and apportioned to species or size groups. The use of automatic traffic counters at fishing access points also generates data which need calibration.

Perspective

Does the foregoing constitute the basis of a general strategy for managing aquatic resources? Or have we simply presented a collection of more or less unrelated techniques? Implicit behind the use of all of these techniques is the idea that a biologist, faced with a choice of methods, may choose a less accurate method (if the savings over using a more accurate method are substantial). The lower cost may allow one to process a large enough sample so that better results can be obtained using the use of a more accurate/precise (and more expensive) tech- nique applied to a smaller sample. But even if the less expensive technique necessarily gives inferior estimates, its use may still be warranted so that a greater number of samples (of species, geographical areas, etc.) can be processed. Greater detail in the assessment of a fishery may be preferable to greater accuracy for a segment and no information for the rest of the fishery. This may be particularly important to consider in multispecies stock assessments.

Of course, indirect rapid assessment methods do not have to be crude. In many instances, "quick and dirty" techniques have evolved into "quick and sophisticated" procedures. The use of length-based assessment and hydroacoustics has already been mentioned. Even "rules of thumb" can be improved or ex- panded. For instance, Boddenberg and Cooke (1983) evaluated Gulland's suggestion that MSY may be approximated by 0.5MB/LR where M is the instantaneous natural mortality rate and L is the virgin biomass. They proposed simple modifications to protect against recruitment problems.

It is reasonable to expect that ecological theory will benefit from the routine use of rapid assessment methodology for fisher- man's management. The benefits will accrue from the compilation of comparative data, the search for functional relationships, and the increasingly detailed studies possible with some rapid methods. It is difficult to combine these ideas into a definition of indirect rapid assessment methodology. But one cannot propose a concept without attempting to define it. Perhaps the following will serve as a working definition:

Rapid assessment methodology aims to increase the amount of assessment work that can be accomplished under fixed manpower and budget constraints by seeking faster and less expensive methods. Indirect rapid assessment methodology seeks to exploit the functional relationship between easily measured or estimated quantities and the parameters of ultimate concern. Indirect methods may sometimes be chosen for their ability to provide greater detail in assess- ments (even though this may sometimes be at the expense of less accuracy or precision).

The rapid assessment approach is almost universally appli- cable. In tropical waters, a single trawl haul may contain more than 100 species for which basic life history parameters are

largely unknown. This led Pauly (1980, 1982, 1984b) to adva- nce a set of rapid assessment techniques for tropical fish stocks. His procedures should also find use in other regions. In the major groundfish fisheries of the North Atlantic, basic param- eters have long been known for the most important species, yet stock identification is still a large problem, and attempts to develop working multispecies models are hindered by lack of information on the minor species. In the State of Minnesota, there are some 10,000 lakes; hence, it is not an exaggeration to say that there are more than 10,000 stocks to manage. Most of the managers of these fisheries would probably agree that some information is better than no information. Presumably, rapid assessment techniques could be a long way in fitting their needs.

In the universities, students are taught to use state-of-the-art technology and are counseled to learn statistics in order to increase the quality and quantity of assessments. Perhaps it is time to counsel them to also look to where the "quick and dirty" recipes can lead. We may develop a well-stocked toolbox of rapid assessment techniques ranging from crude to highly so- phisticated. Perhaps the dictum "correlate, calibrate, and com- pare" is worth remembering.

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335
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