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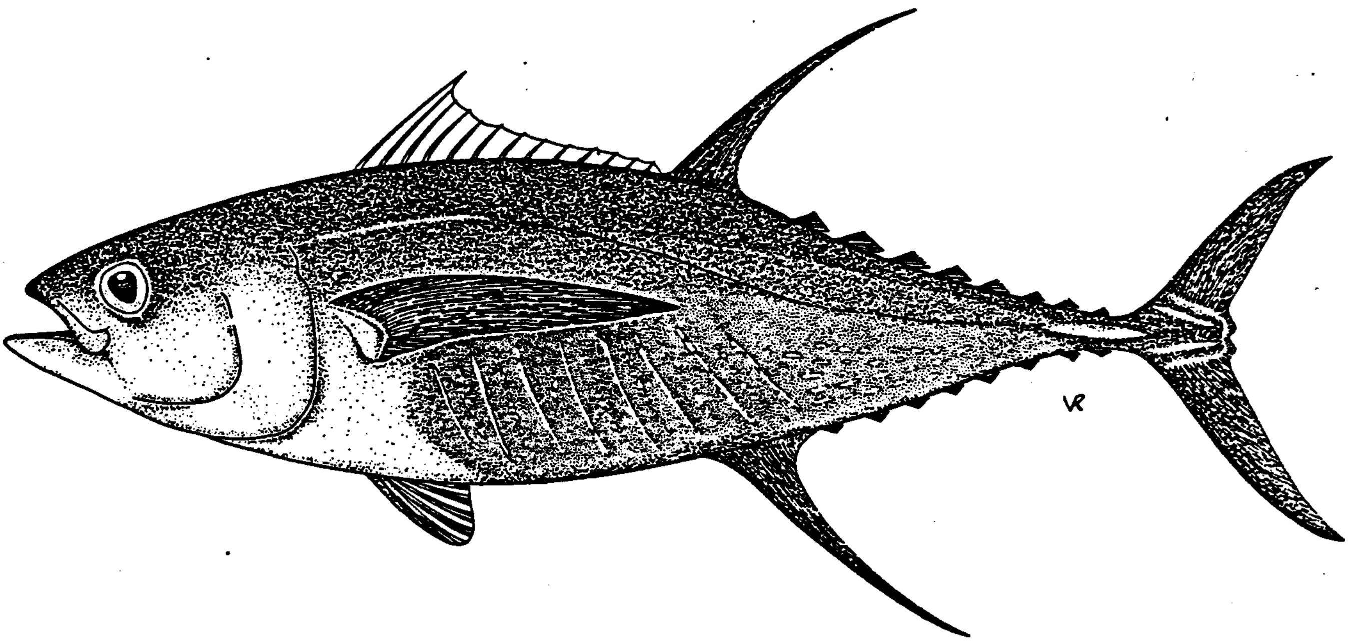
WORKING PAPER 1

POSSIBLE APPROACHES AND DATA REQUIREMENTS FOR YELLOWFIN TUNA STOCK ASSESSMENT IN THE WESTERN PACIFIC



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1. Introduction

Yellowfin tuna are distributed throughout the Pacific Ocean, encompassing a latitudinal range of about 40°N-40°S, but with higher population densities found in tropical areas. The stock structure is not known with absolute certainty, although various fishery and biological data support hypotheses of semi-independent western, central and eastern Pacific stocks (Suzuki et al. 1978) or a clinal population structure (Lewis 1981). It is somewhat clearer that yellowfin inhabiting the area west of 180° constitute a relatively homogeneous population, and that the western boundary for this population lies somewhere in the Philippine-Indonesian archipelagoes.

In the Pacific Islands region, yellowfin are caught mainly by purse seine (which also targets on skipjack) and longline (which also targets on bigeye), although smaller catches are also recorded by industrial pole-and-line and artisanal fisheries. The purse seine fishery is mainly concentrated in the area 10°N-10°S and 130°E-180°, although there has been some recent easterly expansion of this range (Figure 1). The longline fishery concentrates in much the same area as the purse seine fishery, with some seasonal longline effort occurring in higher latitudes, especially along the east coast of Australia (Figure 2). Purse seiners generally catch smaller yellowfin than longliners, however substantial overlap in the size composition does occur, particularly with the increasing trend of purse seiners setting on free-swimming schools of large yellowfin.

FIGURE 1: Geographical distribution of yellowfin tuna catch by purse seiners in 1990. Source: Regional Tuna Fisheries Database. Catches by one-degree square are proportional to the areas of the circles; the maximum circle size represents a catch of 500 t or larger.

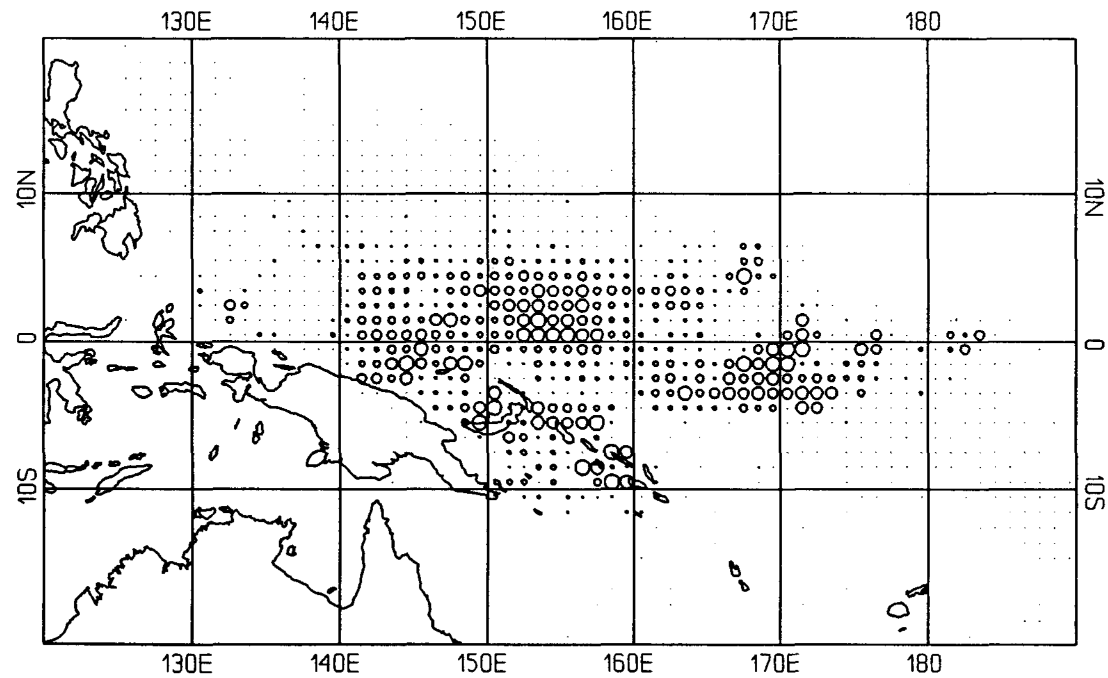
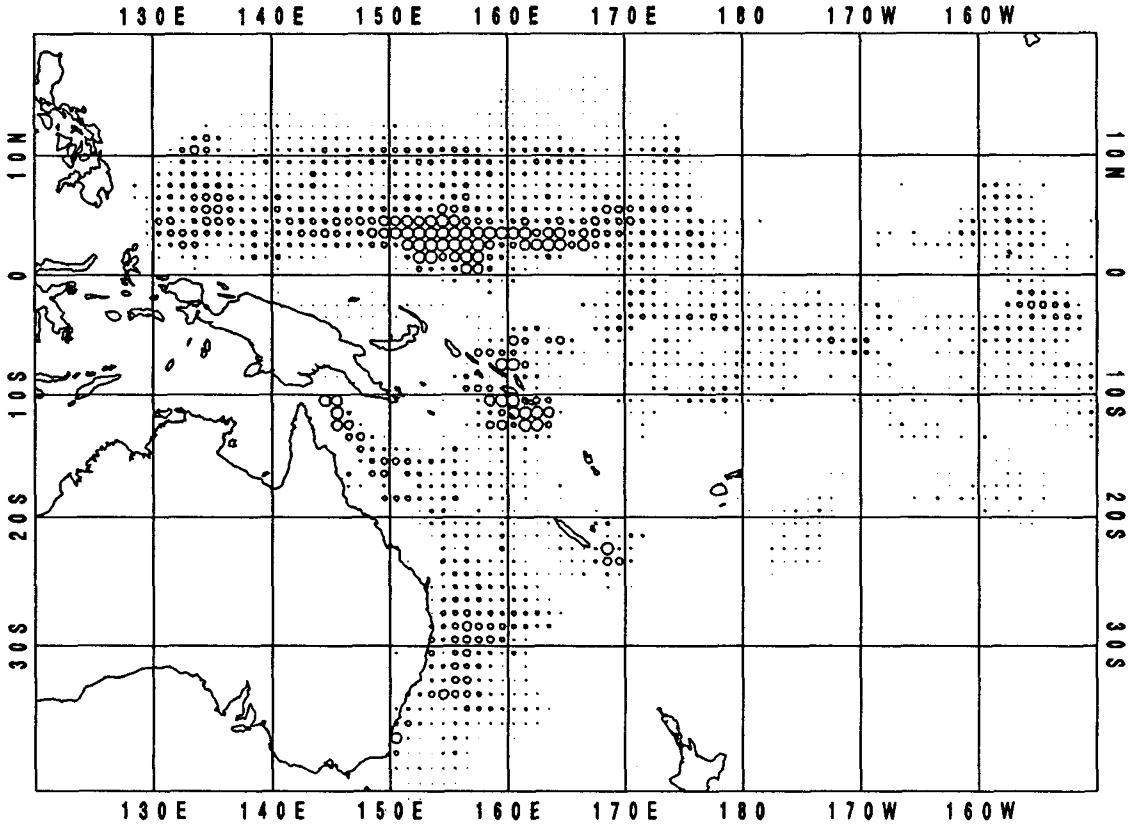


FIGURE 2: Geographical distribution of yellowfin tuna catch by longliners in 1990. Source: Regional Tuna Fisheries Database. Catches by one-degree square are proportional to the areas of the circles; the maximum circle size represents a catch of 100 t or larger.



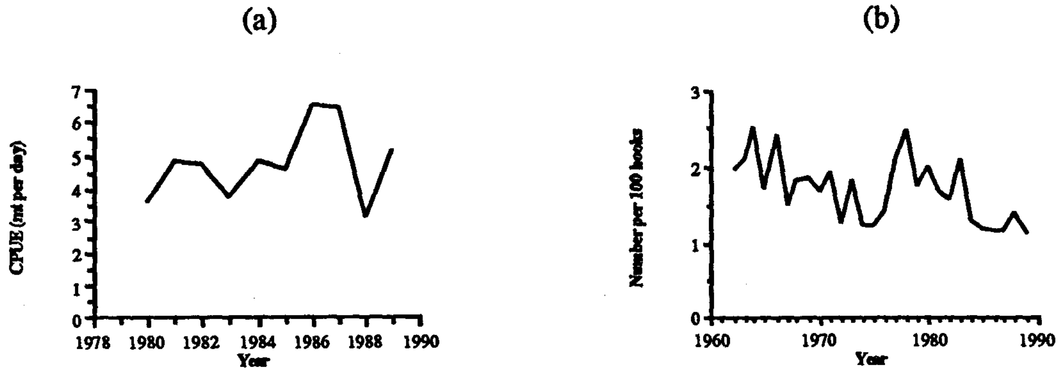
In 1989, total purse seine catches of yellowfin in the above area are estimated to have been about 127,000 t, with longline catches totalling about 32,000 t. In addition to this, domestic fisheries in eastern Indonesia (pole-and-line, purse seine and handline) and Philippines (ringnet, purse seine and handline) caught approximately 35,000 t and 58,000 t of yellowfin, respectively, in 1989. Thus, the total catch of yellowfin (including about 3,000 t by pole-and-line vessels) from the greater western Pacific region, which might be defined for the purpose of stock assessment as 40°N-40°S, 120°E-170°W, was approximately 250,000 t in 1989.

In the western Pacific, yellowfin stock assessment has been limited by (i) lack of a comprehensive database covering *all* major fisheries for yellowfin and (ii) limited information on a variety of important biological parameters[1]. As a consequence, previous stock assessment work has been somewhat piecemeal and largely inconclusive. This previous work has concentrated mainly on the interpretation of time series of catch per unit effort (CPUE) or other indices of apparent abundance from the purse seine and longline fisheries (e.g. Suzuki et al. 1989; SPC 1990; Figure 3). These studies reached the tentative conclusion that total western Pacific catches of the order of 200,000-220,000 t appeared not to be detrimental to the stock or the fisheries

[1] These limitations will at least be partially rectified through the Western Pacific Yellowfin Research group and the Regional Tuna Tagging Project, among others.

although no conclusions could be reached regarding long-term potential sustainable yields, the sustainability of the current catch or the effects of continued expansion of the fisheries.

FIGURE 3: Trend in western Pacific yellowfin tuna CPUE in the area 10°N-10°S, 130°E-180° by (a) the Japanese purse seine fishery (source: Regional Tuna Fisheries Database) and (b) the Japanese longline fishery (source: 1962-1980 Japan Fishery Agency annual statistics; 1981-1989 Regional Tuna Fisheries Database).



In spite of commitments by a number of Pacific Island Nations to limit effort in their Exclusive Economic or Fishing Zones, it appears likely that total purse-seine effort, and possibly effort by small, fresh-sashimi longliners, will continue to increase for the foreseeable future. Also, a major development of purse-seine and other tuna fishing in eastern Indonesia is likely during the next five years.

All indications are, therefore, that the catch of yellowfin in the western Pacific will continue to increase to unprecedented levels. Thus, there is some urgency to undertake a more comprehensive stock assessment of western Pacific yellowfin to answer a variety of questions that will be important in any future management regime. A logical first step to facilitate the work of the Western Pacific Yellowfin Research (WPYR) group is to propose several questions or classes of questions that should be investigated, review some of the techniques that might be applied and detail their data requirements.

2. Stock Assessment Methods and Data Requirements

The term "stock assessment" is a general term that encompasses a range of specific fisheries research problems. For the purpose of this review, stock assessment has been classified into three categories, each of which pertains to a particular question or class of questions that fisheries managers often ask of scientists. The first question relates to stock status, but might be specifically framed along the following lines:

> *"What is the current size of the stock and how has it changed over time in response to fishing?"*.

This question is often extended from stock size to also incorporate age and/or size structure.

The second question, particularly important in developing fisheries is:

> *"What is the exploitation potential of the stock?"*, or *"What levels of long-term, sustainable catches are possible?"*.

Finally, the third question, which is important both in developing fisheries and in fisheries subject to management regulation for rehabilitation or other purposes, is:

> *"What will be the effect on the stock and its component fisheries of a particular fishing development or harvesting strategy?"*.

Each of these questions are important and each must be examined at some stage in the evolution of management of the fishery. Most of the techniques used in fish stock assessment are directed at one or more of these questions, and are classified accordingly below.

2.1 Determining Current and Historical Abundance Trends

It is very useful for fisheries managers to know how fishing has affected the stock over the history of its exploitation. In particular, recent trends in stock abundance may be used to indicate whether effort can be increased, should remain at the current level for the time being, or should be decreased. Also, the current stock size relative to the stock size before exploitation began can be used as a general indicator of stock condition and as an index of the risk of recruitment failure[2].

2.1.1 Monitoring CPUE Trends

CPUE trends are the simplest indicators of historical fluctuations in abundance, however they rest on the assumption that the fishing method used is randomly sampling the entire stock. This assumption is rarely satisfied in practice, because the fish are never randomly distributed in time and space, and fishermen will tend to concentrate their effort in areas and seasons of higher abundance in order to maximise catches. Various treatments of the data can be used to eliminate or reduce this bias (e.g. Honma 1974), however problems may still remain. For example, the fishing gear used may only exploit a portion of the total stock (such as the portion forming surface schools vulnerable to purse seining), and if this available portion is subject to variation, bias in abundance indices will result. Also, the accurate estimation of "effective" effort may be difficult in many cases. For example, Hanamoto (1987) concluded that only a fraction of the hooks on longline sets were actually fishing within the preferred temperature/oxygen habitat for bigeye tuna, and so abundance indices of bigeye based on catch divided by *total* effort (number of hooks) would almost certainly be biased.

2 The term "recruitment" refers to the number of young fish entering the exploited phase of the population per year (or other unit of time). Recruitment is affected by a large number of variables, including factors influencing larval survival, such as food availability, exposure to predators, water temperature, salinity, etc., and tends to be inherently variable. The size of the spawning stock has rarely been found to affect recruitment until fishing has substantially reduced the stock to some critical level. At this point recruitment declines sharply or is subject to large fluctuations. This critical spawning stock varies for different species, but is generally less than 50% of the unexploited spawning stock (although cases have been documented in which recruitment has apparently been unaffected by reduction of the spawning stock to less than 20% of its unexploited level).

Data requirements: In the simple case where CPUE can be assumed to accurately reflect relative abundance, only a random sample of the total catch and effort, by year or other time period, is required. If effort is known to be concentrated in areas or seasons of higher abundance (this can be tested using the "concentration index" approach), catch and effort data stratified by areas and seasons (within which density is assumed to be homogeneous) are required. If complications such as the bigeye example mentioned above exist, detailed logbook data may be required in order to accurately estimate "effective" effort.

2.1.2 Statistical Modelling of Abundance Trends

Statistical models of CPUE, of which the so-called General Linear Model (GLM) is the most often applied, are a further development of the concept of using CPUE as an index of abundance. These models attempt to "standardise" CPUE by eliminating effects due to variables such as vessel size, various characteristics of the fishing gear (e.g. net dimensions), fishing strategy (e.g. area/season effects) and various environmental factors (e.g. sea surface temperature, wind speed). These factors are all assumed to have a linear effect on CPUE, and the model may be specified as:

$$CPUE = M + A_i + B_j + ... + F_k$$

where M is the mean and A_i ... F_k are the effects of factors on CPUE (which in some cases is log-transformed). One of the factors is normally specified as a "year effect" which is assumed to result entirely from fluctuations in abundance. A good example of the application of this type of model is for the yellowfin purse seine fishery in the eastern Pacific (Punsley 1987), where search type, vessel speed, season-area and year were found to be significant factors affecting CPUE.

Data requirements: The data requirements for statistical models of CPUE will depend on the factors incorporated into the model. If the eastern Pacific example cited above is indicative of the sort of data that would be required to undertake a similar analysis in the western Pacific, detailed logbook data would be required to estimate effective effort (searching time) and classify sets; individual vessel specifications would be required to test the effects of vessel capacity, speed, net dimensions and helicopter usage; and pertinent environmental data, such as sea surface temperature and thermocline depth would also be required. The list of factors that might be tested for inclusion in the model is limited only by the imagination and the size of your computer.

2.1.3 Tag-Recapture Methods

The tag-recapture method of estimating current stock status is particularly valuable when a long time series of catch and effort data is not available, e.g. in a developing fishery. This method essentially provides a "snapshot" of the stock for the period over which the tagging experiment is conducted and tags are recaptured. A good example of this type of approach is SPC's Skipjack Survey and Assessment Programme (SSAP), conducted throughout the central and western Pacific during 1978-1981.

Basically, it is assumed that the tagged population is subjected to the same fishing and natural mortality as the population in general. To facilitate this, the tagged population must be assumed to be randomly mixed with the untagged population at some point (hopefully early) in the experiment. The number of tag returns by time period then provide the basic data to which the model is fitted, and a non-linear estimation procedure, such as weighted least squares or maximum likelihood, used to estimate the parameters of interest. A range of alternate models may be used, some of which are detailed in Kleiber et al. (1987). In most cases, estimates of natural mortality rate (including emigration away from the recapture fishery), fishing mortality rate by time period, and average stock size may be estimated. The ratio of the current catch to throughput (average stock size x total mortality rate), or the ratio of fishing mortality to total mortality, are indicators of the degree of fishing pressure to which the stock is currently subjected. If several tagging experiments have been carried out at different times and, ideally, at different stages in the development of the fishery, several such estimates of stock size may be used to infer changes due to fishing.

One of the difficulties of such "spatially aggregated" models is that they do not explicitly account for fish movement. This can cause bias in parameter estimates, for example, if mixing of tagged fish with the untagged population is slow, or if tagged fish tend to move away from the fishery for some period and then back into the fishery at some later time. One technique that has been used to overcome this problem is to partially disaggregate the model by defining areas that are connected by movement rates (e.g. Sibert 1984; Hilborn 1990; Hampton in press). However, there may be problems in parameterising models of this class, particularly if the number of areas is greater than about three. A promising approach currently being developed in a collaborative project by Canadian and Japanese scientists, FAO and SPC involves the specification of a movement sub-model, in which movement is partitioned into random and directed components. For this completely "spatially disaggregated" model, stratification into many areas is unnecessary, and estimates of movement parameters and other stock parameters of interest (free of any bias that might otherwise have been introduced by ignoring movement) are obtained.

Data requirements: Apart from the tagging data, estimates of total catch and effort by the recapture fishery, aggregated by the same time periods used to aggregate the tag returns, are required for the spatially aggregated models. For the spatially disaggregated models, information on the location of fishing effort and tag recapture is required. For both classes of model, information regarding all potential sources of tag loss, including tag shedding, tag-induced mortality and non-reporting of tags recovered by the fishery, is essential for the sensible interpretation of parameter estimates. These "nuisance" parameters (particularly non-reporting) are frequently difficult to resolve, and considerable effort is required to estimate them or minimise their effects.

2.1.4 Age-Structured Models

Age-structured models have formed the basis of much stock assessment work in fisheries. The models used are commonly referred to as "cohort analysis" or "virtual population analysis", although these are in fact specific models in the more general class of age-structured models. A comprehensive and excellent review of age-structured models currently available is given in Megrey (1989), so a detailed account is not attempted here. The common thread of all such models is that they are based on a catch equation, the most often used of which is:

$$C_i = \frac{F_i}{F_i+M} N_i \left[1-e^{-(F_i+M)}\right]$$

which is combined with :

$$N_{i+1} = N_i e^{-(F_i+M)}$$

to specify the age structures of the stock (N_i) and catch (C_i) and the rates of natural (M) and fishing mortality (F_i). In some cases, linear approximations to these equations have been used to reduce computing time and model complexity.

Estimates of total catch numbers by age class are the primary input data to these models, from which a complete history of stock numbers by age class over the period of exploitation (or from which data are available) can be constructed. It is therefore possible to trace changes in total stock size or components of it (e.g. spawning stock and recruitment) over time.

Age-structured models can easily be further structured to estimate gear- or fleet-specific fishing mortality rates for different gears or fleets fishing a common stock; such models are useful for estimating interaction between fleets or gears. In cases where stock homogeneity cannot be assumed, the total area can be stratified into smaller areas that are connected by assumed or known movement rates. This type of approach has been used in simulation studies of fishery interaction (e.g. Kleiber and Baker 1987), but the methodology is not well developed for estimating historical stock sizes and fishing mortality rates (although Fonteneau 1986 describes a study along these lines).

Data requirements: Total catch estimates are required, in conjunction with sampling data that allow estimates of catch by age class, usually in numbers, to be derived. Stratification of data by gear, fleet or area is required if this additional structure is incorporated into the model. Age composition may be derived directly from samples (e.g. estimated from otolith annuli counts) or inferred from the length composition of the samples if supplementary information on the relationship between length and age is available. Because the cost of routine direct age sampling is high, methods based on the inference of age composition from length composition are usually preferred. The MULTIFAN estimation procedure (Fournier et al. 1990) is a recent development of this type that is suited to stocks with seasonal spawning activity. In this case, a time series (e.g. monthly) of length composition samples, in conjunction with total catch estimates, are used as input to MULTIFAN, from which estimates of age composition by time period are derived. Other methods where length composition is converted to age composition require independent knowledge of the length-age relationship, and if total catch estimates are only available in terms of biomass, a weight-length relationship is also required.

In addition to estimates of catch at age, various other data are required for some of the models in this class. Some methods require fishing effort in order to parameterise fishing mortality or to "tune" the cohort analysis. Most methods also require an independent estimate of the natural mortality rate, although this parameter can be estimated by some age-structured models (see Megrey 1989 for details), and some, such as cohort analysis, may additionally require an independent estimate of fishing mortality for one age class of each cohort.

2.1.5 Size-Structured Models

Some age-structured models have been modified so that the time taken to grow from one size to another, rather than absolute age, is referred to explicitly by the model. An example of this type of model is length-based cohort analysis (Jones 1981), which provides estimates of fishing mortality for length classes, rather than age classes, and estimates of stock numbers at specific lengths, rather than ages. This method is essentially little different to its age-structured analog where length composition is converted to age composition using an age-length relationship.

Few methods can be deemed to be truly length-based in so far as they do not require prior knowledge of the age-length relationship. One promising method currently under development is an extension of the MULTIFAN system to, not only estimate age composition directly from length-frequency samples, but also to use the derived age composition in a full age-structured analysis. The great advantage of this approach is that the processes of age-composition estimation and mortality and stock size estimation are carried out simultaneously rather than sequentially, thus the error structure in the original length-frequency data can be expressed as realistic variance estimates and confidence intervals for the final parameters of interest, e.g. time-series of recruitment and spawning stock size.

Data requirements: Estimates of total catch, by length class and time interval (e.g. monthly) are required. Length-based cohort analysis additionally requires prior knowledge of the age-length relationship so that the time required to grow from one length interval to the next can be predicted. Ancillary data similar to age-structured models (effort, natural mortality rate, etc) may also be required, depending on the particular formulation used. The MULTIFAN approach requires only a time series of length-frequency samples and similarly stratified total catch estimates (with a length-weight relationship if these are in biomass). However, an attractive feature of MULTIFAN is that additional information or data can easily be incorporated if they are available.

2.2 Determining Exploitation Potential

Regardless of the current status of the exploited stock, its long-term, sustainable exploitation potential remains an important question for fisheries managers, and in fact much of the pioneering work on fisheries assessment and management was based on this question. The production model, estimating "maximum sustainable yield", is one of the earlier methods used to estimate exploitation potential, while other methods are extensions of the tag-recapture and age- or size-structure methods described earlier.

2.2.1 Production Models

Production, or surplus yield models, consider stock biomass production as a single process. Biomass produced in excess of that required for exact stock replacement is regarded as "surplus" and can therefore be harvested. Most early production models used a simple logistic model (symmetrical S-shaped curve) to describe biomass growth (Schaefer 1954), where the only parameters needed to define the model were the maximum stock biomass, B_{∞}, to which the stock tends to approach under unexploited conditions, and the biomass growth rate, k. Other versions of the production model use asymmetric (e.g. Fox 1970) or more generalised biomass growth curves (Pella and Tomlinson 1969), but the concept remains essentially the same.

Generally, the model is fitted to catch and effort data, with the level of effort (f_{opt}) resulting in the maximum equilibrium (sustainable) yield estimated.

While these models are seductive in their simplicity, this simplicity means that real features of the stock, such as age structure, are ignored, while others, such as tissue growth, mortality and recruitment are subsumed by the biomass regeneration model. Biological realism apart, there are three key reasons why production models are inappropriate for determining the yield potential of western Pacific yellowfin: (i) A key assumption is that each catch-effort observation comes from a population at equilibrium. This assumption is almost never satisfied and is particularly inappropriate in a developing fishery characterised by rapid increases in catch and changes in population age structure. (ii) Even given compliance with this assumption, accurate estimation of f_{opt} requires actual effort observations both below and (importantly) above this level. Indications are that most, if not all, annual effort observations in the western Pacific yellowfin fishery have been below f_{opt}. (iii) Production models were largely developed in single-gear fisheries, where a single effective effort could be readily calculated. Therefore, they are structurally unsuitable for multi-gear fisheries such as western Pacific yellowfin, where an appropriate *combination* of fishing efforts by the different gear types, rather than a single, optimum level of effort, needs to be considered.

Data requirements: As noted above, estimates of total catch and effective fishing effort, each assumed to be taken from a stock under equilibrium conditions, are required.

2.2.2 Tag-Recapture Methods

Some simple extrapolations of the results of tagging experiments can be used to derive "ball park" estimates of exploitation potential for developing fisheries. Once again, the SSAP provides a good example. The SSAP estimated the equilibrium standing stock of skipjack throughout the SPC region to be 3,000,000 t, with a rate of attrition of 0.17 mo^{-1} (Kleiber *et al.* 1987). This implies a total throughput (or recruitment) of skipjack of 6,200,000 t per year. It was clear that these population characteristics would allow much larger catches than those being taken at the time of the SSAP (about 260,000 t per year); such catches had resulted in an estimated harvest ratio (catch divided by throughput) of only about 0.04. One method of deriving an approximate potential yield for skipjack was outlined by Kleiber et al. (1987). They point out that, based on the Beverton and Holt yield per recruit (YPR) model, a harvest ratio in the neighbourhood of 0.5-0.7 should result in the maximum skipjack YPR. Assuming no detrimental effects on recruitment, the potential skipjack yield from throughout the SSAP study area is therefore approximately 3,100,000-4,300,000 t per year.

It must be emphasised that the range of uncertainties associated with most tagging experiments means that such estimates of exploitation potential should be used as a guide only. As fishery development proceeds, data collection procedures should be established to allow corroborative analyses to be carried out.

Data requirements: As outlined in section 2.1.3.

2.2.3 Age- or Size-Structured Models

Various extensions of the models described in sections 2.1.4 and 2.1.5 can be used to estimate exploitation potential (most have been derived from age-structured models, but in theory, they could also be developed for size-structured models as well). Probably the most common method used is the Beverton and Holt (1957) yield model. The basic strategy here is to extrapolate the results of the age-structured analysis to determine the level of fishing effort, or combinations of fishing effort by different gear types, which would maximise YPR[3]. This is done by investigating the changes in YPR that result from modifying recent estimates of fishing mortality by age class and gear type by the application of a range of effort multipliers. Some combination of effort multipliers will result in a maximum YPR, which can then be multiplied by the estimate of average recruitment from the age-structured analysis to give an indicative exploitation potential conditional on the mix of gear types indicated by the effort multipliers. As with the estimates based on tagging experiments, it must be assumed that this effort will not adversely affect recruitment to the stock.

An extension of the YPR concept was developed for the southern bluefin tuna fishery (Majkowski and Hampton 1983), where there were concerns that recruitment may be adversely affected if only YPR considerations were applied. In this approach, a target level of spawning stock, which is assumed to be "safe" in terms of guaranteeing a continued supply of recruits, is specified. The procedure then estimates combinations of effort multipliers (relative to current effort levels) that, given a constant harvesting pattern with respect to age structure by the fisheries, would maintain the spawning stock at this "safe" level. This method, then, has the advantage of incorporating a stock size consideration into the YPR approach.

Data requirements: As specified in sections 2.1.4 and 2.1.5.

2.3 Predicting the Effects of Particular Fishing Strategies

This third category of stock assessment approach encompasses the range of "what if" questions that fisheries managers need to consider. Typically, these questions are most often asked when the evolution of management arrangements is quite advanced and actual regulatory measures are being considered. However, the types of models that are used to address these questions may be extremely useful tools at all stages of development of the fishery. In the western Pacific context, the most frequently asked "what if" question to date has been about fishery interaction - what will be the effect on fishery A if fishery B does such and such? These questions, and those regarding the effects of fisheries on the stock itself, can be examined using several modelling approaches.

2.3.1 Simple Age- or Size- Structured Models

A number of approaches to this problem are possible using age- or size-structured models. For the purposes of this discussion, age-structured models are referred to, but equivalent size-structured models could also be derived. The use of YPR models to estimate potential yields has

3 It should not be assumed that maximising overall YPR will necessarily be a management objective, especially in a multi-gear, international fishery, where allocation issues may well be at odds with maximising YPR.

been previously discussed. These models can also be used to predict what will happen to the equilibrium yield or YPR, possibly specified by gear type or fleet, and the equilibrium stock size and age structure if certain specified changes in the fisheries occur. The sorts of changes that can be investigated are changes in effort, catch or minimum age-at-entry restrictions of one or more of the fisheries. Again, note that these models are equilibrium models and a constant level of recruitment must be assumed.

It is often useful to relax the assumption of equilibrium and introduce a time dimension so that dynamic changes can be observed. It is relatively easy to extend the age- or size-structured models described in sections 2.2.4 and 2.2.5 to predict the results of various harvesting strategies. Stock numbers by age class for the most recent year are used as a starting point, the catch (or effort) to be applied, and its distribution by age class (and gear or fleet, if applicable), are specified, and some assumption is made about future recruitment to project the population and fisheries forward in time. The behaviour of various parameters of interest under the specified fishing regime and recruitment assumption can then be examined.

Of course, attempting to predict the future behaviour of recruitment is not a simple task, and these models are always limited in this respect (but no more so than the YPR models, where constant recruitment is implicit). Two approaches are commonly used to deal with recruitment. In the first, it is assumed that future recruitment will simply be constant at some average level. Such an assumption might not be unreasonable if the estimates of past recruitment from the age-structured analysis were fairly constant at this average level, and the projected spawning stock does not decline to levels that are judged to be "unsafe". The second approach is to derive a mathematical relationship between spawning stock size and subsequent recruitment, and use this relationship to predict what the future recruitment levels will be. While this approach is more intuitively appealing in that it recognises the reality that recruitment must eventually decline if the spawning stock is fished to very low levels, in practice the relationship is rarely well defined, therefore its use as a predictive tool is limited. However, it is often useful to employ both approaches and treat the outcomes as "optimistic" and "pessimistic", respectively.

Data requirements: As specified in sections 2.1.4 and 2.1.5.

2.3.2 More Complex Simulation Models

The approach described in the previous section can be used as the basis for developing more complex simulation models. The models can be enhanced in numerous ways, depending on the data available and the structure of the fishery, to produce more realistic estimates of the parameters of interest. One general "enhancement" is to recognise that error (in the statistical sense) is introduced into the model from various sources, and to incorporate this error into the model to give some form of confidence limits to the results. The Monte-Carlo approach[4] is frequently applied for this purpose.

Various structural enhancements can also be made to investigate hypotheses regarding the dynamics of the stock or fishing. Some possible structural enhancements include the addition of spatial structure, various density-dependent effects on the stock, the effects of economic factors on the dynamics of effort, the effects of management, including data gathering, assessment,

4 Repetitive simulations are carried out, with errors in stock sizes, mortality rates, catches, recruitment, etc, sampled individually from specified distributions. The frequency distributions of output parameters of interest may then be examined and confidence intervals constructed.

scientific advice and regulation, and various effects of the biological and physical environment. The data requirements of these models are obviously dependent on the processes that are simulated.

3. Conclusions

The three types of fisheries assessment question, and associated methodological approaches, outlined in this paper are all relevant to the management of the western Pacific yellowfin fisheries. In terms of the future work of the WPYR group, it might now be appropriate to develop an overall strategy for western Pacific yellowfin assessment, outline the data requirements and consider means of collecting these data.

Largely because of the constraints with respect to existing data, a combination of assessment approaches will probably be required. In the short term, the development of statistical models of CPUE, such as the GLM approach, could provide useful information on the current status of the stock additional to that provided by raw CPUE data. In the medium term (within two years), data from SPC's Regional Tuna Tagging Project (RTTP) will be available to undertake assessments of current status and exploitation potential based on tagging data. In the longer term (within five years), more detailed assessments will be required, and those based on age-or size-structured models appear most suitable.

Purse-seine and longline logbook data now held by SPC could be usefully applied to the GLM-type analysis of CPUE trends. However, the coverage of such data (which should include detailed descriptions of vessel characteristics) needs to be representative, and in particular needs to sample without bias all area/time strata, gear types, vessel nationalities, operation types and any other factors that may affect CPUE. As the data currently available are derived almost exclusively from bilateral access agreements, the addition of data from the high-seas activities of DWFNs is required. It is recommended that the overall coverage rate of logbook data[5] be targeted at about 80%, similar to that achieved in the eastern Pacific yellowfin purse-seine fishery by the Inter-American Tropical Tuna Commission (Dr James Joseph, pers. comm.).

In addition to detailed logbook data, estimates of total catch and effort by strata would be required. A minimum stratification would be 5° square, month, gear type, vessel nationality and set type (log/FAD/school for purse seiners, deep/conventional for longliners). Such data could be compiled from cannery and/or transhipment receipts (purse-seine and pole-and-line fisheries), air cargo manifests (fresh-sashimi longliners) and data held by fisheries agencies and/or industry sources of the fishing nations.

For the application of age- or size-structured models, the primary data required, in addition to the above, are size composition data and information on growth[6]. It is anticipated that a substantial body of information on age and growth of yellowfin will be available at the completion of the RTTP, in the form of tagging data and otolith samples. Currently, size composition data are collected from US purse seiners and are made available to SPC. Additionally, size composition data from locally-based fisheries in Solomon Islands and Fiji are, or soon will be, available. Some sampling of Japanese purse seine and longline fisheries is undertaken by the Japanese Government, but the extent of sampling and availability of data is

5 Total catch (or effort) reported on logbooks divided by the actual total catch (or effort) multiplied by 100%.

6 It is assumed that routine sampling of age composition of the catch by direct means (e.g. otoliths) would be a formidable task beyond the combined resources of the countries concerned.

unknown. Sampling of the catches of other distant-water fleets (Korea, Taiwan, Philippines, Indonesia) is not known to occur. The catches of domestic tuna fisheries in the Philippines are sampled at various landing ports, and it is believed that these data can be made available for scientific analyses. In the expanding Indonesian fishery, no routine size composition sampling is presently carried out.

In addition to the compilation and consolidation of all existing size composition data for western Pacific yellowfin, it is clear that a substantial sampling effort needs to be initiated to remedy the many existing gaps in coverage. A sampling design (stratification) would need to be established so that the major causes of variation in the size of fish caught could be distinguished; stratification similar to that specified above for total catch and effort may be appropriate and it may be possible to use the US purse seine sampling design as a guide.

Major port sampling and scientific observer programmes are a focal point of the draft TBAP Strategic Plan and a funding proposal to cover these activities has been prepared. However, even if funding is provided for SPC to carry out these programmes, considerable support will also be required from all participants in the fisheries to facilitate data collection.

In the light of the foregoing, it is suggested that this group consider in some detail the following issues:

1. Major questions relating to western Pacific yellowfin stock assessment and appropriate methods of investigation.

2. Means of assembling existing data required for stock assessment, including:
   (i) detailed logbook data;
   (ii) stratified estimates of total catch and effort;
   (iii) size composition data.

3. Design of port sampling and observer programmes for the collection of required size composition data, and arrangements for facilitating these programmes.

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