4.3 Estimating catch at age

The majority of analytical stock assessments use age-based models. The age data from the reading of hard parts (Section 4.9) to supply such models is generally limited, due to the cost and complexities in obtaining and reading these structures. In contrast, catch-at-length data are more plentiful, as the collection of length information is relatively cheap. Length also provides some information on the age structure of the population, since age and length are correlated. However, there remains a need to convert catch-at-length into catch-at-age. A number of approaches to do this are available.

This section details the approaches to collect appropriate length frequency data for the purposes of ICCAT (sections 4.3.1 to 4.3.4). Approaches to convert catch-at-length to catch-at-age are detailed (sections 4.3.5 to 4.3.9).

4.3.1 Sampling for length frequency data

As already noted in section 4.2.4, biological information such as length can be collected from a number of locations:

At sea

The ideal location for measuring fish is at sea, aboard a fishing boat. If sampling can be achieved at the time of catch, all associated information (location, date, whether or not sampling was from a single school) can be recorded with accuracy. This approach may be the only method to obtain accurate biological and catch information from tuna caught for farming. These individuals are farmed in large cages before export, and are unlikely to be accompanied by information on their catch location without observation at sea. **See section 4.10 for further details.**

At the time of unloading at ports

If this approach is adopted, it is essential that the samplers have access to the fishing and/or engine log of the boat, so that the proper origin of fish from which a sample is taken can be identified. Even with this information, the identification of the exact location of the catch may be impossible to identify, although the larger catches taken by surface fishing vessels such as purse seiners may mean a well/hold is from a single school or a few schools caught within a short period in the same area. For longline catches this is particularly difficult, as the hold may contain fish from an extended period of fishing over a wide area. In the case of a coastal artisanal fishery, this may not be needed since most of the catches are made on the same day in an area very close to the landing site. The actual site of sampling can be as follows: in the fish hold of a fishing boat; on the deck of a fishing boat; on the pier (or beach) when the fish are brought up; on the vehicles (or carts) which transport the fish; and at the market when fish are laid out for auction or sale. Sampling at the time of unloading is generally the most economical, as one person stationed at a port can cover all the boats entering the port. Also, it provides a site for measuring fish safely and easy access to accurate auxiliary information on the location, date, gear etc. of the catch.

When transhipping from a fishing boat to a freighter

In order to cut down handling costs, a growing number of fishing boats unload fish directly to a freighter instead of to cold storage. If this transhipment is done at sea, only at sea (see above) or at port when freighters unload (see below) methods are valid. However, if transhipping to another vessel is done at port, a sampling method such as that at the time of unloading at ports (see above) can be applied. Transhipments should be carefully monitored as they are not necessarily done at the pier, but in the off-shore port area. A sampler might need to use a small launch to get to the freighter.

At cold storage or canning plant

This approach can be used when other methods cannot be pursued. However, it is only appropriate if the origin of the fish can still be traced.

At port when freighters (transshippers) unload

This is the least desirable approach since the origin of sampled fish can be traced only as far back as the fishing vessels that caught the fish. There is also a risk that the fish were sorted by size at a transhipping port and only part of the catch (of a certain size-class) was sent by freighter to the port where the sampling was performed.

Where all other approaches cannot be pursued, even sampling from freighters can provide some information on the overall catch composition of that particular fishery.

Whichever approach is used, it should be noted with the length frequency data when presented to ICCAT.

Fish should be sampled at random (see section 4.2.2), disregarding size. If sampling is performed during fishing operations (e.g. by observers), all the fish (for example in the case of longline operations) of a certain species, or one fish out of every 5 or 10 (or whichever frequency is most suitable) can be selected for measurement. Alternatively, where catches are larger, the first 10, 20, 30 or 50 fish of a species brought on board can be sampled, unless it is known that there is some difference in the size between the beginning and the end of fishing.

At a port, if fish are delivered by moving line (e.g. by a conveyor) one from every certain number of fish can be selected for measurement. If the condition of the selected fish is not suitable for measurement, the next fish can be measured, or that turn can be skipped. When more than one species of interest is mixed in a catch, first sample one species and then the other.

If circumstances do not permit the above procedure and the sampler has to select from a pile of fish, it is probably best to separate some fish from the top and bottom of the pile, and measure them. Caution must be shown, since larger fish may be selectively placed at the bottom of the pile (or vice versa). In this way, if only the fish at the top of the pile are measured, the sample is biased.

If the fish are already pre-sorted by size and/or species, special attention should be paid at the time of sampling. If this is the case, each pre-sorted section of the catch should be sampled independently and then raised to the catch of that size category (see section 4.2.6).

Assuming random samples from the population, the formulae presented in section 4.2.1 can be used to identify appropriate sample sizes per unit. Note, however, that the information needed on the size frequency at the required level of accuracy can usually be obtained (for tuna above 15kg) by measuring about 500 fish of each sampling area, period and each country and gear category. Where variances between sample boats and within a single boat are small, 200 fish may provide adequate data. However, for smaller-sized tuna, the number should be increased.

The following provides some examples for two different fisheries. The numbers provided are for indication, and should be confirmed for individual fisheries using appropriate statistical formulae.

Since longliners catch non-schooling fish at a great depth, and since a set extends as far as 120km to catch a few relatively large fish, the variance of fish size between samples from different boats is often no larger than the variance of fish size within a sample taken from one boat. For the target species (bluefin, yellowfin, albacore, and bigeye tunas, depending on the fishery), from 10 boats, around 50 fish each can be sampled to get 500 fish for each time-area stratum. For small coastal longliners, it may be better to take from 25 boats (5days x 5boats) 20 fish each. For species that are incidental to catches (billfishes, swordfish, sometimes even some major tuna species, depending on the fishery), it is unlikely that 500 fish could be measured for each stratum. In such cases, it is recommended that as many fish as are available be measured.

Purse seine, pole and line and trolling gears catch relatively small schooling fish near the surface. Their catches per day are much larger than those of longliners, even more so when viewed in terms of the number of fish, since the average size and weight of fish is smaller. In order to get the same coverage as for the longline fishery, the sample size must be increased. One fish per one metric ton of catch may provide sufficient sampling coverage and can be used as a guideline for establishing the sampling level. Sampling should be monitored and adjusted as appropriate to gain the required random samples.

Similarly sized fish tend to form schools near the surface. Therefore, a sample taken from a school has little within-sample variance of fish size. However, between-sample variance of fish size taken from different schools is large, meaning that if the same total numbers of fish are to be measured, increasing the number of samples while reducing the sample size should give better estimates.

The following guidelines for surface gears can therefore be put forward:

- A sample should be taken from a catch of a single school as often as possible;
- In stratified sampling (single species), each sample should consist of 50 fish (if fish are large) to 100 fish (if fish are small);
- In multi-purpose sampling (with mixed species) and when fish sizes are relatively large (over 15kg), 100 fish should be sampled. If fish sizes are small, 200 fish are recommended;
- Large industrialised purse seiners should be sampled twice to three times from different wells known to contain catches from different schools;
- About ten boats (in the case of industrialised large boats) should be sampled for each time-area stratum;
- For small coastal fisheries, from 25 boats (5 days x 5 boats) 40-50 fish each can be sampled to get 500 fish for each time-area stratum.

4.3.2 Equipment for measuring

A range of appropriate tools for measuring large pelagic species is available.

Callipers

Callipers may be the most convenient tool for measuring (**Figure 4.3.1**), particularly for tunas (**Figure 4.3.2**). They are easily made of wood, brass, aluminium and/or plastic.

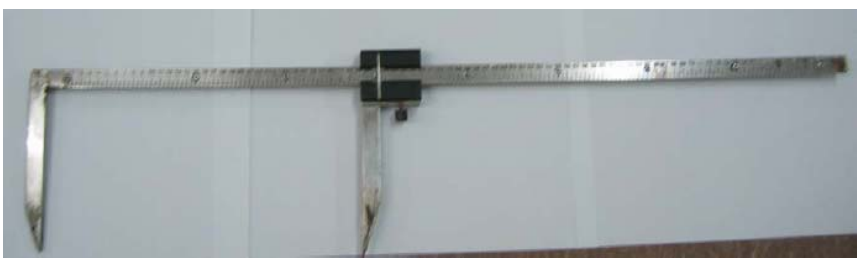

Figure 4.3.1. An example of callipers. Picture from Sarralde *et al*. (2005), reproduced with permission.

Measuring board

A measuring board may also be used **(Figure 4.3.2)**. A board is particularly suitable for measuring small fish.

Figure 4.3.2. An example of a measuring board. Picture from Sarralde *et al*. (2005), reproduced with permission.

Tape

A steel or fibreglass measuring tape can also be used, if there are no alternative methods. In this case, an attempt must be made to keep the tape straight. The best method would be to place a tape on the floor and place the fish on top of the tape, or to place the tape on the floor to the side of the fish being measured.

An exception is made for measuring the lower-jaw fork length of billfish, in which case the tape measurement should be over the body contour of the fish (i.e. curved body length). See section 4.3.3 for details.

Photographic techniques

In some countries, fishermen refuse to allow a sampler to touch the fish. In such a case, photographic techniques might be applied to estimate size composition. The basic principle is to take photographs of fish lying alongside a scale. Later, the fish length can be calibrated relative to the scale in the picture. Particular care should be taken so that the camera's line of sight is perpendicular to the plane of the fish.

This method is potentially costly (although digital cameras will eliminate film development costs), and provides less accurate data.

4.3.3 Measurements to be taken

The fish should be placed on a flat surface in the horizontal position while being measured. Fish with a broken snout (if snout-fork length is being taken) or tail, or frozen fish not in a straight position should be rejected.

Tunas

All species except billfishes must be reported to the ICCAT in **fork length**. This is a projected straight distance from the tip of the upper jaw to the posterior tip of the shortest caudal ray (fork). See figure 4.3.3.

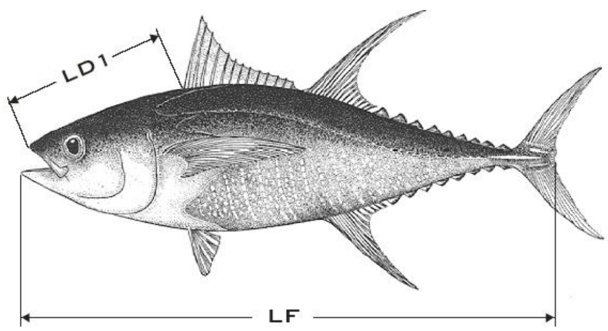

Figure 4.3.3. Measurements of tunas – Upper jaw-fork length (FL) and Upper jaw-1st dorsal (LD1). Picture from Sarralde *et al.* (2005), reproduced with permission.

It is best to measure fish in fork length. In particular, if smaller sized fish are abundantly found in the catch (e.g. skipjack, surface albacore), fork length measurements are recommended, although this is sometimes difficult to achieve. For example, it is not possible to measure the fish accurately when malformed due to freezing, the fish may be too large for equipment (callipers) being used; there is not enough room to handle long callipers (e.g. aboard small commercial fishing vessels); the fish tails have been chopped; or most of the fish are not lying straight. In these cases, the next best measurement is the pre-dorsal length (LD1), the straight distance from the tip of the upper jaw to the insertion of the first dorsal spine. **Do not** mix two measurements in one sample.

If the pre-dorsal length is measured, those data have to be converted to fork length prior to reporting to the ICCAT. The relationship between the pre-dorsal length and fork length **must** be established for each species and area, based on adequate samples, as they are quite variable. These conversion factors should be reported. Unless the data have been converted to the fork length or are received with an adequate conversion equation, the pre-dorsal length cannot be accepted for the ICCAT database.

Billfishes

An important difference in sampling billfish is that the fish should be sampled for length **and** for sex (see section 4.8) as far as possible. It is well known that male and female billfishes have significantly different growth rates. However it is sometimes impossible to identify the sex. In such cases, only length measurements should be taken.

The preferred and most reliable measure of body length for billfish is the lower jaw-fork length (LJFL) (see figure 4.3.4). For small fish, callipers are practical and provide an accurate straight line measurement. However, field use of callipers for large billfishes, which have a maximum length of over four metres, is impractical.

For purposes of standardisation, it is preferred that all length measurements of large fish be taken with a tape (fibreglass or steel if possible) over the body contour of the fish (curved body length). However, straight measurements by placing the fish over a board that has length scales are also acceptable.

As there is a difference in the value between straight and curved measurements, the measurements taken and equipment used **must** be clearly recorded on the sampling sheets and reported to the ICCAT with the data.

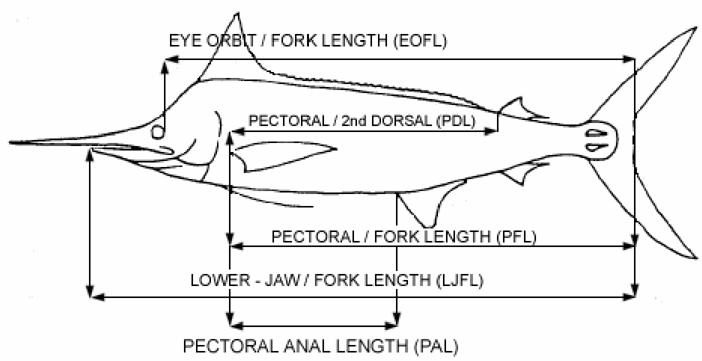

Figure 4.3.4. Alternative measurements of billfishes

Sampling from commercial billfish catches sometimes poses severe problems, since the fish are generally dressed on board, prior to freezing. This may cause some difficulties in species identification of carcasses, and/or affect the measurements.

Alternative measurements for billfish are (**Figure 4.3.4**):

- Eye-fork length. The projected straight or curved-body distance between posterior edge of the eye orbit to the fork of the tail.
- Pectoral-fork length. Projected straight or curved-body distance between the most anterior insertion of the pectoral fin to the fork of the tail.
- Pectoral-dorsal length. Projected straight or curved-body distance between the most anterior insertion of the pectoral fin to the most anterior insertion of the second dorsal fin.
- Pectoral-anal length. Projected straight or curved-body distance between the most anterior insertion of the pectoral fin to the most posterior rim of the anal sphincter.
- Dressed weight. Weight of the individual carcass. In this case, an accurate description of how the fish is dressed is essential (see below).

Measurements should be made in the vicinity of the lateral line. For example, when taking the Pectoral Second Dorsal Length (PDL), the distance to the anterior part of the second dorsal fin should be read along the lateral line, **not** up on the dorsal ridge of the back (regardless of whether a tape or callipers are used).

The measurements of length than can be taken on any individual carcass will depend on how it is dressed. The following measurements of length should be taken for the categories of dressed fish as follows:

- Whole (round) carcasses – lower jaw-fork length
- Bills, gills and fins off, gutted – lower jaw-fork or eye-fork length
- Dressed carcasses with heads and fins off and caudal peduncles present – pectoral fork length
- Dressed carcasses with heads, fins, and caudal peduncles off – pectoral second dorsal length and pectoral anal length.

As in the case of LD1 for tuna, if any measurement other than lower jaw-fork length (LJFL) is taken, the relationship between this alternative measurement and the standard (LJFL) must be studied so that the measurements can be converted to the standard. In order to develop a conversion equation for past measurements, as well as for new measurements from dressed fish where LJFL is not available, an adequate sample should be measured for all five alternative measurement categories given above, together with LJFL. Since the fish carcasses are landed dressed at many sampling sites, it would be impossible to take all the measurements. Until the conversion equations are well established, it is recommended that the samplers try to measure individuals by as many alternatives as possible, particularly where whole fish are available for sampling. All available conversion factors that may be useful in tuna statistics are given in **Appendix 4**.

Size class intervals

Most of the measurements discussed above should be made by 1cm size-class intervals. However, if necessary, fish over 60cm in fork length could be measured in 2cm intervals. If the fish is being measured by pre-dorsal length (LD1), the measurements require more accuracy, as 1cm of the pre-dorsal length is equivalent to 2 to 4cm in fork length, particularly in larger fish. For fish less than 35cm in fork length (although it is much more feasible to measure fork length rather than pre-dorsal length for such a small fish), Ld1 can be measured to the centimetre. However, for any fish over 60cm, LD1 should be taken in at least 5mm intervals.

Record the length to the nearest lower centimetre (less than a centimetre should be truncated, or 5mm, as in the following example:

13.0 – 13.9 cm = 13 cm
14.0 – 14.9 cm = 14 cm
94.0 – 95.9 cm = 94 cm

24.0 – 24.49 cm = 24.0 cm
24.5 – 24.99 cm = 24.5 cm

If for any reason your measurements are made to the nearest centimetre, rather than truncated, this should be specifically mentioned when they are reported to the ICCAT. Otherwise, the data will be assumed to have been measured in the standard way.

Recording data

Systems for recording data should be developed individually. Waterproof recording paper, if available, is invaluable. If one sampler were to perform the work, a tape recorder would prove useful. However, it should be ensured that the recorder is in working order and functioning properly when measuring the fish.

There are two distinct methods of recording. One is to record all the individual measurements directly as they appear; the second is to mark the appropriate size class, so that frequencies are recorded.

The recording sheet should have columns for dates, locations of catches, sampling, and other related data such as vessel name, catch unloaded at the time of sampling, well numbers which are sampled, weight of fish from that well, equipment used, type of length measurement made, sampling frequency applied, etc.

If sampling is multi-purpose and on mixed species, more information on catch and effort, as well as on species etc., would be required. In such cases, ICCAT Form 3-1 recording individual measurements would be more convenient as one sheet could be used for mixed species. On the other hand, if the sample is by species but species composition sampling is carried out at the same time, Form 3-2 may be used. If species composition sampling is not required, the column provided for it on the same form is not to be used.

4.3.4 Data processing

The procedure detailed provides a random sample of a specific unit within the stratum of sampling. This needs to be combined and raised to the level of the fleet/population. Raising has already been discussed in section 4.2.6.

Figure 4.3.5 presents a flow chart illustrating the steps to be followed when processing the raw data. The aim is to estimate catches with proper species breakdown and size. For this we have to estimate them by the appropriate strata, and add them. Catch by strata and size data (see section 4.3), as well as species composition (which will not be repeated hereafter, but should be understood) are essential to achieve this.

1. The raw data obtained from sampling have to be combined into the strata adopted (Level 1 data). During this process, raw size data could simply be combined. If a sub-sample of pre-sorted catches are taken, or if the samples are taken from different wells of the same boat and the catches are known by well, they could be partially extrapolated to the catch from which the sample is taken, prior to being combined (see below).
2. Then the Level 1 size data have to be matched to the catch reported for the corresponding stratum (Level 2). If any size data are missing for the catch, the size composition of that missing stratum should be assumed to be similar to some other size frequency (data substitution). Then, using the size data, catch by size in each stratum has to be estimated (raising the size to the catch).
3. This section explains procedural techniques. If the sampling is multi-purpose (size and species composition), the substitution and raising should be made in the same way for size and species all together, or first catches should be estimated by species in each time-area stratum and then by size. In either case the technique of substitution and raising is identical as explained here for size data (see below).

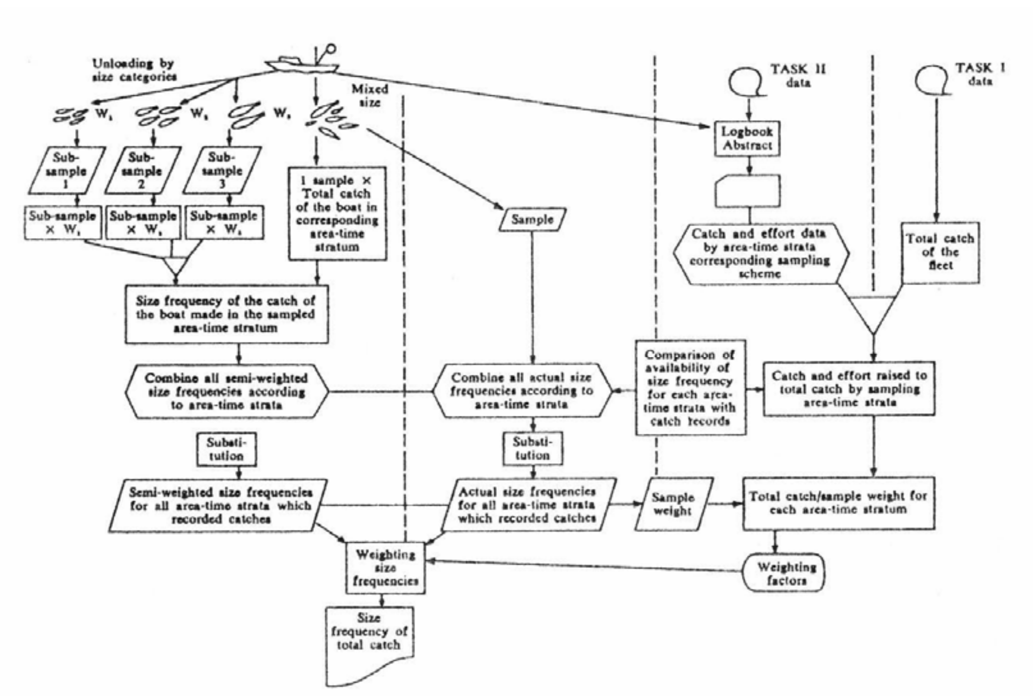

Figure 4.3.5 Flow-chart for weighting size data

Obtaining Level 1 data

The size data obtained from sampling have to be processed into the form required as Level 1 data and then eventually into the form of Level 2.

If the size data are, for some reason, recorded in a unit other than standard (fork length or lower jaw-fork length) such as LD1 etc., they should be converted into the standard (see section 4.3.3). If all the measurements are in the same unit, such conversions could be made after all the data are combined and raised. However, if various measurements are mixed, the conversion has to be made prior to combining all the samples.

If the catches were pre-sorted by size etc., prior to sampling, and consequently sub-samples were taken or the sampling can be identified by wells of boats and associated information (such as catch by wells) is available, the (sub-) samples should first be raised to the catch of the pre-sorted categories, or sampled wells, using the techniques described in section 4.2.6 and below.

Then, these (sub-) samples raised to the catches from which the samples were taken, should be accumulated to the desired minimum stratum (e.g. 1° x 1° and by 10-day periods, or 5° x 5° and by month).

If immediate raising is not possible (e.g. longline size data), a size frequency has to be generated by combining the size data recorded on daily sampling sheets for each unit of stratum. This can be done manually but more easily with any computer. ICCAT can provide programming assistance, if needed. The results of these Level 1 statistics should be reported to ICCAT using the forms in **Appendix 1**.

Obtaining Level 2 data

Data submission

The size data (Level 1) combined for each stratum have to be checked for their availability against the catch data compiled by the same time-area stratum. If a catch is recorded for any strata, but not size data are available, a substitution of data has to be made. There are several ways to do this:

1. Use size frequencies observed by the same type of fishery of another country in the same time-area stratum;
2. Use size frequencies observed by the same fishery in the neighbouring areas during the same time period;
3. Use size frequencies from the same time-area strata but from previous years;
4. Use size frequencies observed in the same area but during the time periods preceding or following the period from which data are missing;
5. Use size frequencies for the last several years combined for the same time-area stratum, by the same fishery.

The best substitution varies according to fishery, season, area etc. In the surface fisheries, 1) might be the best solution. In the longline fishery, 2) or 3) would be better than 1). If the results (Level 2) are to be used in virtual population analyses where catch-at-age for each year plays an important role, 3) should be avoided as much as possible. When using 4), one can even adjust the size by applying a growth curve. When data are very scarce, 5) is often used.

The reader must be aware that data substitution may lead to considerable bias in the Level 2 data. The resulting catch by size may be completely different depending on how the substitution was made, and may even lead to a different conclusion in the population analyses. It is important that **all** the substitution procedures adopted be well documented together with the data.

Raising to the total catch

When the substitution is completed, the size frequencies can be raised to the total catch (see also section 4.2.6). Raising should be done for each time-area stratum.

1) Size frequency expressed in terms of number of fish should be converted to weight using length-weight relationships. (This is not necessary if the catch is known in number of fish rather than weight. The total number of fish in the catch divided by the total number of sampled fish equals the raising factor). Now the fish in each length class is expressed in weight. The sum of those weights will give the estimated sample weight.

Example: Yellowfin tuna

Size classes	*Frequency (No. of fish)*	*Avg. weight of fish*	*Weight of fish in size classes*
52 cm – 53.9 cm	10	2.87 kg	28.70 kg
54 cm – 55.9 cm	12	3.11 kg	37.32 kg
56 cm – 57.9 cm	15	3.47 kg	52.05 kg
…	…	…	…
…	…	…	…
…	…	…	…
Total	250		1050.24 kg*

* sample weight

If all fish measured have also been weighed, the above procedure would be unnecessary as the sum of weights can be used as sample weight.

2) Total catches (in weight) recorded for each time-area stratum can then be divided by the sample weight. This will give raising factors.

For example: if the catch of yellowfin tuna in corresponding time-area strata is 1,520 MT, while the sample weight is 1,050.24 kg, the raising factor is 1, 520 MT divided by 1.05024 MT or 1,447.2882.

3) Actual size frequency should be multiplied by the raising factors in order to obtain catch by size.

Example: Yellowfin tuna. Raising factor = 1,447.2882

Size classes	*Actual Frequencies*	*Raised frequencies (No. of fish caught)*
52 cm – 53.9 cm	10	14473 (=10 x 1447.2882)
54 cm – 55.9 cm	12	17367 (=12 x 1447.2882)
56 cm – 57.9 cm	15	21709 (=15 x 1447.2882)
…	…	
…	…	
…	…	
Total	250	361822 (=250 x 1447.2882)

4.3.5 Age or cohort slicing

Age slicing divides a catch length range into different ages, partitioning it into catch at age.

Size distributions are separated into age classes by assuming there are distinct lengths which separate adjoining age classes. The lengths dividing age classes can be defined in a number of ways. Often these sizes are defined as being the length half way between mean lengths-at-age predicted from a growth curve. This approach assumes equal variability in lengths at neighbouring ages. Whichever approach is used to select the dividing lengths, it should be clearly stated, along with the growth curve used.

These dividing lengths are used in the following way. Fish smaller than the first dividing length are referred to as the 0-group, those of lengths between the first and second dividing length as the 1-group and so on. Some lengths will have to be distributed proportionally upon two age groups. If, for instance, the length class interval is 1cm, and the first dividing length is 12.6 cm long, then six-tenths of the fish in the 12-13 cm class are referred to age group 0, and four tenths to age group 1. If the length interval is 6 cm with a length class of 12-18 cm, then only a fraction of 0.6/6=0.1 of the fish goes to age group 0, while nine-tenths (0.9) end up in age group 1.

Age slicing can be performed on an annual, quarterly or monthly basis, dependent upon the growth patterns of the fish (e.g. seasonal growth as in yellowfin tuna) and the data available. If annual age frequencies are required, and age slicing is performed at time steps more frequent than an annual step, the number of individuals at age accumulates throughout the year.

The benefits of age slicing are that the approach is easy to use, and can take two-stanza growth patterns into account. However, it requires a number of strong assumptions, including that there is no overlap in length between cohorts. This assumption is not likely to be true, and hence there is the potential to over-estimate the strength of a weak year class, and underestimate a strong year class. This results in a smoothing effect in the catch at age data, decreasing the variability between cohorts. There also tends to be considerable overlap in length-at-age at older ages, biasing the number of older fish estimated.

4.3.6 Age-Length Keys (ALKs)

Put simple, age-length keys (ALKs) are generated through the ageing of a sub-sample of the population, and used to convert larger length samples from a population into ages. ALKs describe distributions of size for each age, and the relative number of individuals at each age, i.e. they represent a matrix detailing the probability that a fish of a given length is of a particular age. Once such a key is available, samples of fish that were only measured for length can be distributed over age groups according to the key. The use of ALKs assumes that the sample of aged fish and the sample of fish measured for length are simple random samples from the same population. Then, the probability that a fish is of a particular age, given its length is the same for both samples.

The ALK should generally be applied to length data from the same time period, since variability in recruitment and survivorship at age will change the age-length composition over time, and hence the number of survivors at age used to weight the size at age compositions will vary. The ALK may need to be seasonal if growth is temporally distinctive or seasonal migration occurs. A single ALK should only be applied to size data from a number of years if growth is reasonably stationary, and the approach of Kimura and Chikuni (1987) is used. Suitable justification should be presented for multi-seasonal or multi-annual application of ALKs. It must also be noted that the application of an ALK derived from a single time of year can cause serious bias if used to compute catch at age for the entire year.

Age-at-length data from hard parts should be combined into suitable length groups for required gears, time periods and locations. The size of these length groups will depend on the spread of lengths found within the catch length frequencies, the growth rate of the species, and the variability in length-at-age. Length-stratified sampling is required to ensure that the required number of fish (determined by the variability of length-at-age) is available over all length groups. Developing ALKs represent is laborious, and hence the optimum collection of information is desirable. Formulae exist to estimate the number of age determinations and length measurements necessary to guarantee a given level of accuracy. Oeberst (2000) developed a universal cost function for ALKs, for example.

The proportion at age is calculated as:

Number at age for a length group / Number of fish aged in that length group

The ALK for the time period is raised to the length distribution for that time period:

Raised numbers at age by length group = Numbers at length * Proportion at age for that length

If the ALK does not contain data for all the length groups in the length distribution then data in the length distribution may be assigned to adjacent length groups where data are present in the ALK. An appropriate age-length distribution by gear group and time period is then produced. Care must be taken since considerable biases can result, particularly at large lengths where individuals may be distributed over a wide range of ages.

The numbers at age by length group are summed over the length range to give numbers at age. The variances are also summed over the length groups and the two components labelled variance due to ageing and variance due to length sampling. This gives the age composition for the required time period.

Numbers at age for all gears can be calculated as:

$$\sum N_a * \left(\frac{W_{ct}}{W_{cs}} \right)$$

where $\sum N_a$ is the sum of sampled numbers at age, W_{ct} is the total commercial catch weight, and W_{cs} is the sampled commercial catch weight.

Variance due to ageing of numbers at age for all gears can be calculated as:

$$\sum Var_a$$

where $\sum Var_a$ is the sum of variances due to ageing.

Variance due to length sampling of numbers at age can be calculated as:

$$\sum Var_l$$

where $\sum Var_l$ is the sum of variances due to length sampling.

The variances should be raised by:

$$\frac{W_{ct}}{W_{cs}}$$

where W_{ct} is the total commercial catch weight, and W_{cs} is the sampled commercial catch weight.

A number of developments to ALKs have been put forward. Hoenig *et al*. (1994) describe a generalized 'inverse' key that can use information from previous years to aid in the estimation of the age composition in the current year. Kimura and Chikuni (1987) outlined an extension of the ALK approach, iteratively determining the age structure from a length sample using the key from a different sample. It assumes that the distributions of size for each age are known, which provides an ALK for the analysis. The proportions-at-age are then adjusted to find the best fit between the observed size frequency data and that predicted by the proportion-at-age and the ALK. The method can work well where the distributions of size for each age are close to those in the length frequency, but convergence can be slow. The reader is referred to the paper for more information.

4.3.7 Schnute and Fournier

The approach of Schnute and Fournier (1980) has been further developed into the MULTIFAN package (Section 4.3.8), which has been used for albacore (*Thunnus alalunga*). The approach of Schnute and Fournier is therefore only covered here briefly.

The approach assumes that mean lengths-at-age in a population represented by the catch length frequency data follow a von Bertalanffy growth curve, and the length at a given age is normally distributed. Proportions at age, growth parameters and a parameter defining the standard deviations of lengths-at-age can be estimated. The approach assumes that the number of age classes is known. Selected parameters represent the 'best fit' between observed and predicted length frequencies.

The Schnute and Fournier approach may present issues when trying to obtain unique solutions for all model parameters, and the mean lengths at younger ages (which may be identified from modes in the length frequency data) may need to be fixed. If this is required, it must be stated, and the assumed mean lengths-at-age presented.

4.3.8 MULTIFAN

The MULTIFAN approach is described in full in Fournier *et al*. (1990). It represents a likelihood-based analytical method for estimating growth and age composition parameters from multiple length frequency data sets. It uses a mixture of distributions approach, and allows the inclusion of biological constraints within the model.

MULTIFAN is an extension of the Schnute and Fournier approach (Section 4.3.7) to simultaneously analyze several length frequency data sets, sampled at different times. The assumed error structure differs between methods, and different estimation methods are used to estimate model parameters.

MULTIFAN makes a number of key assumptions, as described by Fournier *et al*. (1990). These are that 1) there is a normal distribution of lengths within each age class, around a mean length at age; 2) standard deviation of mean length at age varies as a simple function of that mean; and 3) growth follows the von Bertalanffy growth function.

The program varies the von Bertalanffy parameters and number of age classes, and compares the resulting fits of the probability of observing a fish at a given interval defined by the set of growth parameters with the observed proportion of fish in a given length interval, using the log-likelihood function. By examining the results from multiple models, a likelihood ratio chi-squared can be used to objectively evaluate alternative model hypotheses. This examines whether the addition of additional parameters (e.g. age classes) in the model results in a significant increase in the maximum value of the log-likelihood function.

The parameters estimated are 1) proportions within a sample at age; 2) mean length of the first age group; 3) mean length of the last age group; 4) von Bertalanffy parameter K; 5) two parameters predicting the pattern of the standard deviation of length at age; 6) a parameter related to the overall variance of the sampling errors in the length frequency data sets; and 7) a parameter describing the age-dependent selectivity of the fishing process. If the age of the first age class is unavailable, MULTIFAN assumes t_0 is zero.

MULTIFAN is sensitive to the time interval chosen between samples, and the characteristics of catchability and selectivity in the data. There may also be a tendency to group the final age classes together if mean lengths-at-age are not greatly different, or if there are small percentages of fish in those size ranges.

Care must be taken not to constrain the bounds on mean lengths to greatly. Given high variability in fish growth, highly constrained bounds may distort the results obtained. However, bounds must be sufficiently tight to insure that the correct age-class is associated with a mode. Care must also be taken to specify a sufficient parameter space for the programme to search through. This will help prevent identification of local minima during the search.

4.3.9 The performance of approaches

The performance of different approaches will be dependent on the data to which they are applied, and the background knowledge of the fishery and biology of the stock. The best way to identify which approach may work best is to test through simulation. For examples, see Mohn (1994), Goodyear (1997) and Restrepo (1995).

4.3.10 Further reading

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