4 MONITORING AND SAMPLING STRATEGIES

Key outputs of observer programmes are data and summary information for fisheries management. Of course, data should not be just a random collection of whatever is available to observers placed indiscriminately on any vessel steaming off to the fishing grounds. Their collection instead needs to be based on an overall strategy. Conditions vary from fishery to fishery, and each observer programme will to some extent be unique. However, any collection strategy should specify:

a) which vessels are sampled in the fleet;

b) which events on the vessels are sampled; and

c) what catch is sampled from a fishing event.

Furthermore the formulation of any strategy involves the following steps:

- evaluation of the **baseline information** available on the fishery in relation to the programme objectives;

- assessment of whether **complete monitoring** or **sampling** is appropriate for the fishery;

- assessment of **operational considerations** for the fishery and the programme;

- **strategy design** in relation to vessels, events and catch to be monitored;

- implementation of a **pilot phase** to validate the design strategy and methods for data collection; and finally

- establishment of a **feedback mechanism** between the observer programme and the fisheries authority to ensure that data satisfy the objectives and current environment.

The rest of this chapter explores each of these areas in more detail.

4.1 Baseline information

Baseline information describes the overall fishery and is essential to establish a good data collection scheme. Information can be gathered from many sources such as fishing logs, vessel registers, research cruises, maps and charts. It should include a description of the following features:

- The **fishing grounds** and associated water body.

- **Ports:** their locations, patterns of distribution and accessibility.

- **Fishing fleets:** the numbers of vessels by type (e.g. in relation to fishing gears), their size distribution and ability to take observers, and their geographical distribution in relation to home or landing ports.

- **Fishers, companies and fishery associations** in relation to the fleets (above) and related to the activities (below).

- **Fishing activities and patterns** related to the home and landing ports, noting any seasonal movement between fisheries.

When no information is available for any of the above parameters, this in itself is an important observation, which would stimulate efforts to obtain it. After a pilot phase has been completed the available information will have increased and the baseline picture of the fishery can be re-assessed.

4.2 Complete monitoring and sampling

Complete monitoring (also known as complete enumeration or census) and sampling are the two options available for data collection in an observer programme. Although opportunities for complete monitoring are improving (see Box 10), some sampling will inevitably occur. Even in a very small fishery, where observers can monitor every vessel (complete monitoring of vessels) and possibly even monitor every fishing event (complete monitoring of fishing events), they cannot monitor every fish.

Box 10

Technological developments are increasing the opportunity for complete monitoring in some areas of fisheries. These include vessel monitoring systems and electronic logbooks that can be used when no observers are on-board, to improve the level of monitoring. To date the only advances in this field available for use by observer programmes have been electronic measuring boards, electronic logs and forms and the use of video cameras on vessel decks.

There are three main stages in preparing a sampling strategy for a given fishery: a) which vessels are sampled in the fleet; b) which events on the vessels are sampled; and c) what catch is sampled from a fishing event.

The aim of either complete monitoring or sampling is usually to derive a fishery statistic from raw data, e.g. catch per unit effort. To find out the true value of any statistic complete monitoring is required. For example, if observers are placed on every vessel in a fishery, statistics on the catch, the gear used and the number and duration of fishing events (effort) could be calculated exactly.

When should a variable be completely monitored and when should it be sampled? The choice is usually controlled by financial and human constraints. Complete monitoring rarely makes operational sense, particularly when a sampled statistic is sufficient to meet information requirements. There are three significant exceptions where complete monitoring is the normal case.

- **Compliance controls, regulatory conditions, and conservation and management measures:** when the monitoring of violations is only possible by observers, e.g. when strict gear controls are required; when discard of undersized or by-catch species is prohibited; or when expensive fines are imposed as a deterrent.

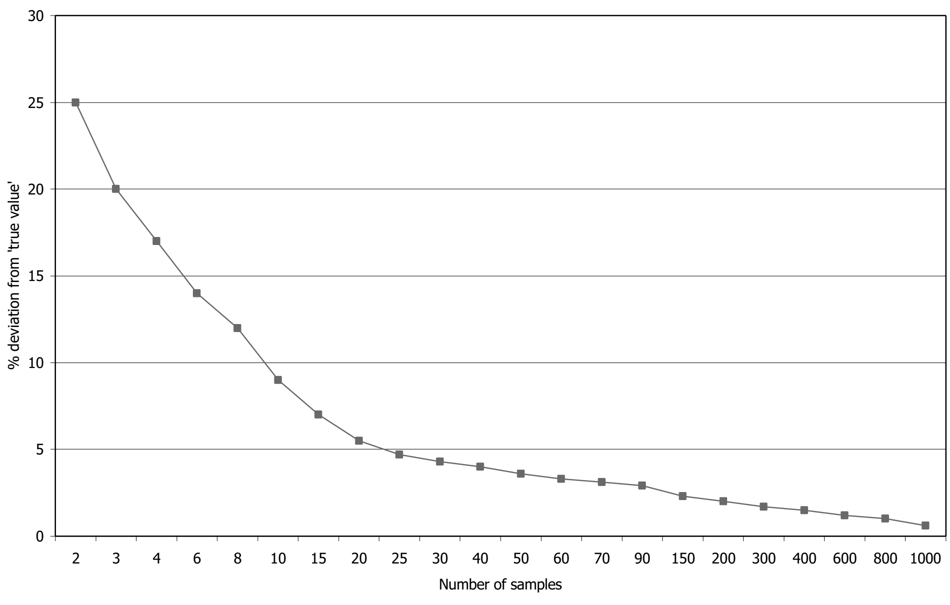
- **Pilot schemes** are used for baseline data collection, especially if the data collected is required to make statistical assessments for determining long-term sampling strategy.

- **Data variability is high and the sample is small:** e.g. in a fishery with very few but very different vessels (e.g. in their size or crew characteristics). In a case like this, little effort would be saved in creating a viable sampling scheme.

When sampling is used, an estimate is made of the true value of a statistic, and the aim is to make that estimate as accurate as possible. For example, if an observer samples 10 baskets of fish out of every 100 to determine the overall species composition of the catch, the results of the 10 samples will be multiplied by 10 (thus raising the figure) to produce the sampling estimate.

The key question is, how many samples should be collected, with what frequency? The more samples collected, the more likely they are to be representative of the underlying data population (i.e. their accuracy in relation to the 'true value'). The question of sampling frequency is dependent on the variance (difference) between the samples. However, increasing the number of samples does not proportionally increase the precision of the value. This means that the cost of decreasing the variance (getting closer to the 'true value') gets disproportionately higher the closer you get to the 'true value'. This is a clear case of diminishing returns, as demonstrated in Figure 5.

Figure 5 The relationship between the number of samples and the deviation from the true value



The above example shows that halving variance from 5% to about 2.5% (which may, of course, be desirable) will increase sampling frequency (and hence effort and cost) by 10 times from about 20 to 200 samples.

Decision-making on sampling frequency - the sampling methodology - needs to be based on sound statistical analysis. However, at the start of an observer programme, perhaps even after a pilot phase, there will be very little data to allow for such analysis. Simulated data (generated by computers) can be used as an alternative but these data are rarely adequate substitutes for the real thing. What can be done? The answer is to design a sampling strategy based on the knowledge gained during the development of baseline information, common sense, and a few simple guidelines given in the sections below.

4.3 Operational considerations

A sampling strategy should be based on long-term planning for the financial and human resources that it will involve. This planning may also need to include training (Chapter 3) and information systems (Chapter 5).

Factors and information to assess operational constraints to be taken into account when designing sampling strategies include:

- Number and distribution of ports (long distances apart may make the placement of observers difficult and costly).

- Length of fishing trips and possible movement of vessels out of the EEZ to fish or to off-load fish (or observers!).

- Conditions at-sea and facilities for sampling on the vessels.

- The average number of fishing events per 24-hour period (hauls or longline/basket sets).

- The level of safety awareness, equipment and certification on the vessels.

- National labour and employment laws relating to overtime, days off in lieu of weekends and public holidays worked, etc.

- Financial requirements, including human, capital and operational costs.

4.4 Sampling strategy design

The aim of strategy design is to sample the catch in a way that best represents the whole catch. The challenge is to avoid sample **bias**. Bias is different from variance; it is a measure of the difference with the true value because the samples are not representative of the data population. This is commonly caused by, for example: observers picking out the biggest, brightest or most beautiful fish, rather than from all fish; or by observers persuading coordinators to let them go on to the more comfortable vessels. In other words, selection of the sample is not random.

The most common solution to the problem of bias is to **stratify** the data population and to **sample randomly** within the strata.

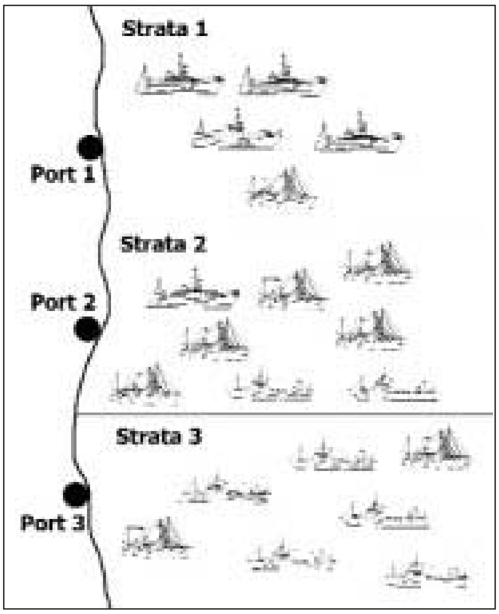
4.4.1 Stratification

Most sampling strategies are stratified. This means that the vessels or the fish are divided into groups related to how similar they are. This stratification makes it easier to obtain a better result from the applied sampling effort. This works because the strata systematically remove some of the data variability, e.g. the difference between samples that may be taken on small or large vessels, or by different fishing gear types. After the data are collected they can be raised according to the different strata to produce a more accurate estimate of the true value than if all the data were raised together by a common raising factor.

A multispecies catch will require careful random sampling (P.E. Bergh).

The aim is to make the variability *between* the strata greater than the variability *within* the strata (Figure 6).

Figure 6 The variability between the strata is greater than the variability within the strata



Usually, the allocation of strata is initially made through operational considerations and common sense, for example by homeports, fleet details, fishing gear or vessel type (see Table 9). The data collected can be statistically analysed by setting up a null hypothesis that there is no difference between the strata and then statistical testing to see if this is correct. Depending on the results, the sampling design may need to be adjusted by increasing the sample sizes, number of samples or by further stratification. Allocating sampling effort between

To reduce the bias and variance of the estimate a good sampling strategy is needed. To reduce mistakes good training and a positive attitude are needed.

It is important to differentiate between the catch and the fish stock. Observers are performing sampling on commercial catch, while research sampling will often aim to sample the entire fish stock.

strata should also be managed and not just done by chance. There are three basic rules known as the Von Neumann allocation that optimises the allocation of sampling effort between strata (see Box 11).

Box 12 gives examples of the types of sampling strategy analysis that can be used and provides details of further information on the subject.

Box 11

Von Neumann allocation
More sampling effort should be given to strata with:

i. Greater size
ii. Greater variation
iii. Lower cost

Table 9 Possible strata for observer programmes

Strata Groups	Stratification	Comment
Spatial	Homeport	Ports can not be ignored even if they do not relate to the distribution of fish stocks. When not all ports are covered it is important to select ports that are representative. Following Von Neumann, the largest ports (most vessels) should receive the most sampling effort, but also practical considerations of location and cost will be important.
	Fishing grounds	This is often a difficult stratum in practical terms as the destination fishing ground is often not known when a vessel leaves for sea, or if it is known the captain will keep it as a closely guarded secret.
Temporal	Fishing season	This is generally determined by the fleet stratification. Fishing methods, gear and target species may vary over seasons that can be determined by the life cycles of the fish or by external factors such as the monsoon.
	Year, month, week	These natural time strata are used for raising the data in time blocks smaller than a fishing season.
	Day or night	In certain fisheries this division will be significant and may also relate to a change in fishing gear or method.
Commercial	Companies/ co-operatives	These generally remain fixed throughout the year due to legislation and use rights, but may change. International agreements may feature in this group as one or more strata.
	Fishing associations	Affiliations to unions or associations work in a similar way to companies and co-operatives.
Vessel and Gear	Fleets	Group together uniform vessels, which are approximately the same size, have similar construction and similar technology. These groupings may vary over time.
	Gear	Group together for similar gear type e.g.: ▪ Dredges ▪ Seines ▪ Purse seines ▪ FADS ▪ Gillnets (set, drifting) ▪ Trawls ▪ Lift nets ▪ Traps ▪ Covered pots ▪ Fyke nets ▪ Pole-and-line ▪ Jigs
	Vessel type	Group together the types of vessels e.g. artisanal, semi-industrial, industrial and foreign
	Engine capacity	Group by engine size e.g.: ▪ No engine ▪ 0-45 hp ▪ 45-150 hp ▪ 150-500 hp ▪ 500 hp

4.4.2 Random, non-random, systematic and adaptive sampling

Random sampling (i.e. non-selective sampling) is required by most statistical analyses. In theory, random sampling seems simple, but in practice it may be quite complicated to achieve.

For example, when choosing which **vessels** to place observers on, random sampling is difficult to achieve. A random number generator can be used to generate random numbers within a specified range (e.g. 1 to 5 or 1 to 20) and then observers are placed on the vessels due to leave port in relation to these numbers. The difficulty with this approach is to cover each stratum (the vessels) adequately, with neither too few nor too many observers. It is often easier to use systematic placement of observers on vessels, by choosing, for instance, to place an observer on say every 5^{th} or 20^{th} vessel leaving port.

It is sometimes possible to use adaptive sampling for the placement of observers. Adaptive sampling is when a random or systematic system is overruled by circumstances. The opportunities for this have increased with the introduction of new technology such as vessel monitoring systems (VMS). For example if VMS reveals that all the vessels with observers on board are in the northern fishing grounds it may be appropriate to place an observer on a vessel that is headed south.

When choosing which **fishing event** to sample, random sampling is rarely successful. Vessels and observers have routines and generally observers prefer to sample fishing events systematically. The main problem here is when observers follow a pattern that introduces bias, such as by only sampling in the morning or only in daylight. Procedures are required to ensure that such bias is avoided; to specify this to observers and to check that they are not 'stuck in a routine.'

Random sampling, nevertheless, can be applied in most cases on vessels to sample **fish** for size frequency, sex ratio, and maturity data (see Chapter 5, on collecting the sample).

An alternative method is systematic sampling when, say, every fifth basket or one-hundredth fish is sampled. This can be quite complicated and time consuming, and is usually not feasible.

It is important that observers get a representative sample of the fish that are caught and not those that are processed. Emphasis must be placed on collecting the sample before any sorting has taken place. Non-random sampling can be used for collecting fish that will be used for length weight or conversion factor purposes as well as for certain collection schemes such as for otoliths, statoliths, stomachs etc.

4.5 Pilot phase

Before launching a full observer programme for the first time, or before starting a collection scheme on a new fishery, a pilot phase should be carried out. Its primary purpose of which is to gain familiarity with the fishery conditions and data types available, rather than to collect data for direct use. A pilot phase is limited in time and space, but often very inclusive in the types of variables collected and the procedures used. This enables 'testing' of the suitability of different variables and different procedures for collecting it (sampling methods). Box 13 gives an example of a simple strategy that could be used for a pilot phase.

4.6 Feedback mechanism

Proper programme maintenance requires continuing 'feedback checks' since situations change very quickly, even for well-designed strategies, and a flexible system is more likely to succeed.

The primary feedback check is to analyse the data to ensure that the data, and estimates derived from them, are statistically valid. This will provide the opportunity to evaluate the success of the stratification, the appropriateness of the number of samples and sample sizes, and to make any necessary changes.

Other feedback mechanisms could include checks on how well the programme is following the sampling strategy. For example, if the strategy proposes to cover 10% of all fishing trips this can be easily checked on a regular basis. This kind of simple check allows for constant re-adjustment of the strategy, especially in the early days when operational constraints are starting to be more fully appreciated.

It is important that observers get a representative sample of the fish caught and not those that are processed.

The primary purpose of the pilot scheme is to gain familiarity with the fishery conditions and data types rather than to collect data for direct use.

It is statistically better to take many small samples from many different vessels than fewer larger samples from fewer vessels.

Box 12

Statistical analysis of sampling strategy
There are many good references for statistical analysis. Standard texts include Box, Hunter and Hunter (1978), Cochran (1977) and Sokal and Rohlf (1995). There are also many user-friendly statistical software packages available that will make the analysis quite straightforward. Examples include EASYSTAT, MINITAB, SAS, SPSS, Statistix and SYSTAT. When designing a sampling strategy it is very worthwhile to consult with a statistician (or scientist with some statistical knowledge). Many pitfalls can thereby be avoided. The type of analysis used could be as follows: • Before any 'real analysis' can take place the data will need to be tested for 'normality' (i.e. are the data 'normally distributed' around the central point with no skews or one-sidedness. If the data are not normally distributed they can often be transformed, for example by natural logarithms. This needs to be done for the data within each stratum for the period being analysed. A possible test would be the Lilliefors variation of the Kolmogorov-Smirnov test (Chakravarti, Laha, and Roy 1967). • Another pre-test that is required is to examine the variances for homogeneity. Strictly speaking, for most statistical tests 'homogeneity of variances' is required. However, the consequences of moderate deviations are not too serious for the overall test significance, so long as the interpretation of results is made with due caution. The Levene test (Levene 1960) for homogeneity of variances is an example of a simple test to use or the Bartlett test (Snedecor and Cochran 1989). • The real null hypotheses testing can be made using several different methods. An example would be the one-way or two-way analysis of variance (ANOVA) tests (Sokal and Rohlf 1995) that examines if there is a significant difference between variables across one or two strata. • If significant results are found investigation into them can be made using unplanned comparisons such as the Tukey's honestly significant difference method (Sokal and Rohlf 1995).

Box 13

An example of a general and simple strategy that could be used (with adaptations) to start a pilot scheme on a new observer programme
1. Collect data for one full year to have a complete annual cycle of data available for analysis in order to plan a longer-term strategy. 2. Sample at least 20% of the fishing trips per month, covering as many fishing areas, vessels (size and horse power) and gear types as possible (i.e. distribute effort within the different strata). 3. Monitor all fishing events during the sampled fishing trip for catch and effort. 4. Sample at least 50% of the fishing events in every 24 hour period, varying the time of day or night that fishing events are sampled. 5. Randomly sample for catch composition in these sampled fishing events (sample at least 4 baskets per event). 6. Randomly sample 200 specimens for length distribution and sex in each sample.