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Report of the Workshop on Practical Implementation of Statistical Sound Catch Sampling Programs

8 - 10 November 2011

Bilbao, Spain

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Executive summary

This workshop, chaired by Jon-Helge Vølstad (Norway) and Mike Armstrong (UK) was held in Bilbao, Spain, from 8–10 November 2011. Twenty-eight participants representing eleven countries including Iceland and the United States were present. Alan Lowther (USA), an external contributor, provided particular expertise in sampling small-scale fisheries.

Prior to the workshop, participants from each country were provided with a questionnaire to collect standard descriptions of their on-shore and at-sea sampling programmes. These were collated at the workshop. The objectives, descriptions and the practical issues relating to setting up national programmes were looked at in more detail in presentations of eight case studies covering at-sea sampling (Denmark and Sweden), sampling using a reference fleet (Norway), port sampling (UK England & Scotland; Iceland) and sampling of small-scale, artisanal fisheries (Malta, Basque Countries).

WKPICS recommends the use of probability-based sampling schemes with sampling frames, primary sampling units and strata optimised to deliver the required estimates for species, fleet metiers, fishing grounds or other variables of interest. Such schemes allow samples to be easily extrapolated to the target population using weighting factors based on inclusion-probabilities. For sampling on shore, sampling frames generally consist of sites and days (sites being ports or other access points). For sampling at sea the frame is based on a list of vessels.

The key advantages of a probability-based sampling scheme, with simple random sampling within strata, is that different types of fishing trips (gears used; areas fished etc.) within a sampling stratum will tend to occur in roughly the same proportion in the samples as in the fleet as a whole. This is an advantage if the fishing areas or gears used change unpredictably between years. The desired balance of sampling across métiers is achieved by adjusting sampling rates within vessel or port strata according to the expected distribution of métier activities of the vessels.

WKPICS advises against using the alternative and widely adopted sampling method of setting "quotas" for numbers of fishing trips or fish to sample within multiple, highly resolved and dynamic fleet activities (e.g. EU Level-6 métiers). This method involves searching for specific types of trip to sample in order to meet a quota for a specified time period, and as a consequence alters the selection probabilities for all other métiers in the sampling frame. This can lead to bias and reduced precision.

Many practical problems are encountered in implementing fishery sampling schemes, such as difficulties in gaining access to catches to sample (including refusals to allow observers on boats, catches offloaded directly to lorries or split between different landing sites), or logistical issues in implementing randomisation schemes. The problems for sampling on shore and at sea are quite different, and a subgroup for each of these fields was established at WKPICS to review the experiences and the practical implementation of probability-based sampling schemes.

WKPICS highlighted the importance of recording non-events, such as documenting failed sampling attempts where procedures were followed but fishermen or merchants barred access to landings or a trip. These events could create bias so need to be accounted for in raised estimates. Documenting their occurrence and their impact on the raised estimates, when presented to stake holders, has improved access to trips and landings as documented in two of the case studies.

The post-stratification and raising of sampled fishing trips to the total fleet, and methods of developing data quality indicators, were only touched on briefly and these processes will be reviewed in detail using case studies in WKPICS2.

1 Introduction

1.1 Terms of reference

WKPICS1 is the first of three workshops aimed at providing guidance on the design of fishery sampling programmes. The Terms of Reference for WKPICS1 are given below, and the scientific justification is given in Section 1.3. The proposed ToRs for WKPICS2 are in Annex 3.

WKPICS1 – Workshop on practical implementation of statistical sound catch sampling programmes

2010/2/ACOM47 The **Workshop on practical implementation of statistical sound catch sampling programmes** (WKPICS1), chaired by Jon-Helge Vølstad*, Norway and Mike Armstrong*, UK, will meet in Bilbao, Spain, 8-10 November 2011, to:

a) On the basis of case studies examine how statistically sound programmes for sampling fishing vessels at sea can practically be implemented.

b) On the basis of case studies examine how statistically sound port/market sampling schemes can practically be implemented.

c) On the basis of case studies examine how statistically sound sampling schemes targeting small-scale fisheries can practically be implemented.

WKPICS1 will report by 21 November 2011 for the attention of PGCCDBS, RCMs, STECF/SGRN, ACOM.

1.2 WKPICS1 participants and meeting agenda

The list of participants and the adopted agenda are in Annex 1 and 2, respectively. All the working documents, presentations and national sampling scheme reports are located on the meeting SharePoint site.

1.3 Purpose of the WKPICS series

The data collected from fisheries have a primary function of supporting stock assessments and informing fleet-based management decisions. To this end, the overall aim for a design-based sampling strategy is to:

1. Collect data in a way that accuracy (bias and precision) can be reliably assessed at national and regional level
2. Ensure that sampling intensity is allocated in a way that would maximize precision at the level where it matters most in the context of assessment of stocks and fisheries.

The use of statistically robust, design-based sampling schemes that are fully documented is a prerequisite for transparency in the data collection-assessment-advice process. Only with the use of such schemes can bias be properly controlled for, and the variance associated with different estimates correctly calculated. It also enables the usage of the data in a wider scientific/management community since the applicability of such data is readily apparent.

ICES has established a series of expert groups since the inception of the EU Data Collection Framework (DCF) in 2002, to focus on improving and demonstrating the quality of data underpinning scientific assessments and advice. These groups, which contribute to implementing the ICES Quality Assurance Framework (Nedreaas et al., 2009), include the Planning Group on Commercial Catches, Discards and Biological Sampling (PGCCDBS), WKACCU (procedures for evaluating bias; ICES, 2008), WKPRECISE (procedures for evaluating precision; ICES, 2009a), WKMERGE (sampling survey design for commercial fisheries; ICES 2010), WKSMRF (ICES, 2009b) and subsequent PGRFS and WGRFS (survey design for recreational fisheries) and SGPIDS (practical implementation of discard sampling plans; ICES, 2011)[1].

The series of three WKPICS workshops in 2011, 2012 and 2013 are an essential follow-on to WKMERGE to establish a methodological support system to facilitate the design and practical implementation of statistically-sound fishery catch sampling schemes, such as are required under the EU Data Collection Framework and its successor the Data Collection Multi-Annual Plan, and to further develop procedures for documenting data quality.

WKMERGE documented a number of approaches for designing shore-based and sea-based sampling surveys but did not have time to examine the detailed practical applications. The main tasks for WKPICS1 were therefore to: i) clarify the concepts and terminology for catch sampling surveys, ii) collate the experiences in European countries of implementing such surveys, iii) identify the main, recurring problems that can impact their design or implementation, and iv) advise on how to identify and mitigate the effects on data quality.

The objectives, descriptions and the practical issues relating to setting up national programmes were detailed in national reports requested in advance of WKPICS1, and in presentations of a diverse range of European case studies covering on-shore and at-sea sampling of large scale fisheries and sampling of small-scale (artisanal) fisheries.

The WKPICS2 meeting in 2012 will consider regional coordination of sampling schemes, develop guidelines for design-based and model-based data raising and parameter estimation, and further develop the WKACCU (ICES, 2008) scorecard to provide an audit trail of data quality indicators for fishery sampling.

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[1] All reports available at http://www.ices.dk/workinggroups/WorkingGroups.aspx by entering acronym

2 Concepts and terminology for fishery catch sampling schemes

2.1 Overview

Sampling schemes can be most easily understood, designed and implemented if there is a consistent underlying set of survey concepts and terminology. This Section of the WKPICS1 report is intended to establish a consistent framework building on existing literature on survey design in a wide variety of disciplines. In the following we will describe some basic concepts of survey sampling design using terminology from classical literature on statistical survey techniques (e.g., Cochran, 1977; Jessen, 1978; Særndal et al., 1992). We highlight some of the main practical problems affecting the ability to design and implement a survey, and refer to the Case Studies, which are detailed in Section 3, for illustrations. Section 6 provides a Glossary of Terms to help with interpretation and consistency.

2.2 Defining types of fisheries for sampling

2.2.1 Concepts and terminology

For planning purposes it is useful to group commercial fisheries into categories (see Baird and Stevenson, 1982) based on how catch sampling schemes can be implemented in practice.

In WKPICS we have classified fisheries into two main categories: large-scale fisheries and small-scale fisheries, which can loosely be defined by number of fishers they employ (or catch per fisher employed), vessel size and number, catch per vessel, value of the catch, and relative amount of catch used for direct human consumption or industrial purposes (Carvalho et al., 2011; Therkildsen, 2007; Sumaila et al., 2001).

From a survey point of view, the most relevant differences between small- and large-scale fisheries are to do with: (i) documented knowledge of the number, size, composition and activities of the vessels and their catches (e.g. vessel registers and logbooks); (ii) accessibility for sampling (e.g. ability to take observers; identification of landing sites and their accessibility); and (iii) presentation and disposal of the catch (e.g. filleting and freezing at sea; how the catch is disposed off when landed). In general, large-scale fisheries are better documented than small-scale ones, assisting survey design, but can often pose problems in relation to how the catch is processed at sea and landed.

Biological sampling of catches from large-scale fisheries is in practice often carried out by a combination of at-sea and on-shore sampling. Sampling at sea may be required to obtain reliable information on position, depth, and total catch characteristics and discards, but this may not be possible on many of the vessels in small-scale fleets.

2.2.2 Practical application

There is no clear division between small-scale and large-scale fisheries. It is often a continuum from small single-handed vessels deploying a few pots, nets, lines or dive sessions during day trips, and landing small volumes, to large ocean-going trawlers with many crew, operating for extended periods in distant waters and processing large catches on board for industrial or human use. For practical design of surveys, the most important requirement is to have a detailed inventory of the data available on the entire fleet (numbers of vessels; fishing and landing patterns; fishing effort and gears used; accessibility of vessels and catches etc.), both before and after the sampling year. The availability and completeness of these data will determine the design of appropriate sampling frames, sampling units and selection schemes for different fleet sectors and the need for separate surveys to estimate fleet composition and activity.

2.3 Planning a sample survey

2.3.1 Concepts and terminology

The important steps for designing a catch sampling survey are the same for all types of surveys of small-scale or large-scale fisheries:

1) Carefully and clearly define the **objectives** of the proposed survey;

2) Determine what **data** are needed to achieve these objectives;

3) Establish if it is possible to collect the appropriate data, and identify feasible **sampling designs and estimators** (including associated precision estimators) that can be employed, and identify the most problematic aspects;

4) Calculate approximately the **sampling intensity** required to obtain the required survey precision, and the resources required.

All aspects of the survey design, objectives and planned data analysis (including data storage) should be thoroughly documented before the survey is conducted.

The specific categories and related estimates that are required are commonly referred to as estimates for the **domains of interest** – e.g. annual discards estimates for different gear types and areas; age compositions of landings of a stock.

2.3.2 Practical issues

A particular practical problem at this stage is dealing with multiple or highly-resolved domains of interest. Where there are too many domains, for example for highly resolved fleet components and areas, the attempt to cover all can lead to bad survey designs such as over-stratification and under-sampling or no data for some strata. It is important that end-users are advised of the resources needed to deliver the required estimates and precision based on statistically-sound surveys, so that objectives can be prioritised or adequate resources provided.

2.4 The target population

2.4.1 Concepts and terminology

Once the main objectives of the catch sampling scheme are established, the next step is to define the population that will be sampled to fulfil the survey's objectives. Put simply, the **target population** is all the individuals of interest (e.g., all fish in a fleet-wide catch, all fish from a particular stock in a fleet-wide catch; or the total catch including discards for a métier) from which the relevant biological samples need to be collected.

Once the target population is defined, the next step is to determine how it can be accessed to collect samples and data that are representative of the whole population.

The target population that is accessible for sampling will typically be distributed in clusters of ports, vessels, trips, hauls (Figure, 1), and knowledge of the structure is important for designing the sampling scheme.

2.4.2 Practical application

The definition of the target population is straightforward – it is the population for which estimates are required. For estimates of catches and catch composition, the catch is the target population, not the vessels or fishermen. The latter would be the target population if the objective of the survey was to estimate the number of vessels or fishermen and their characteristics.

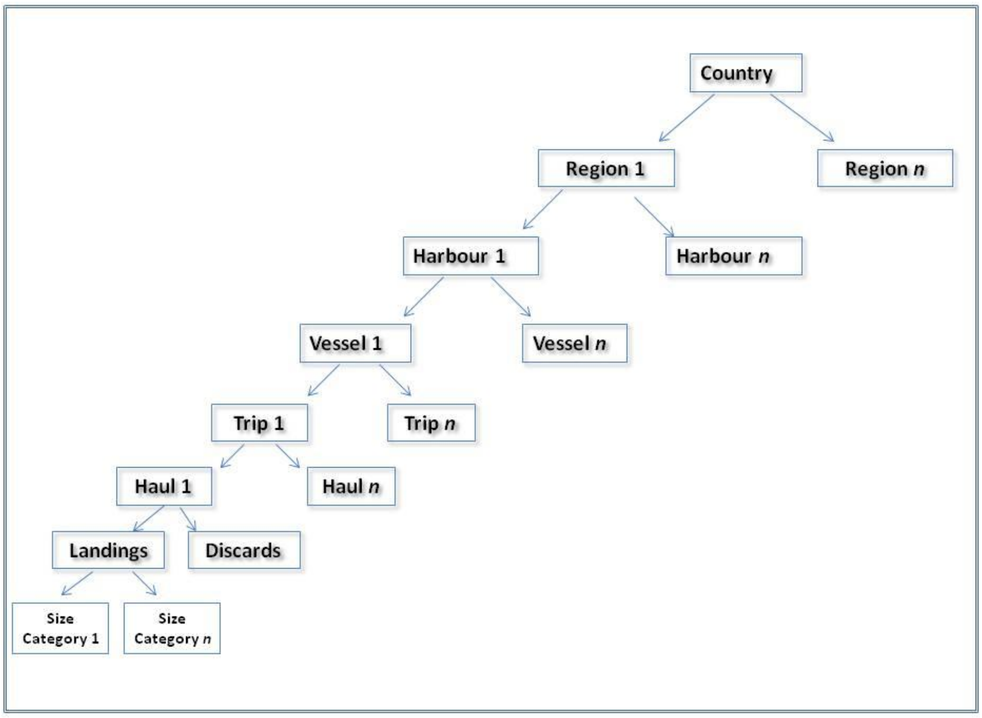


Figure. 1. Hierarchical distribution of fish catches in clusters of harbours within regions, vessels within harbours, trips within vessels etc., requiring a multistage sampling design. The hierarchical distribution within each harbour may also vary over time, for example with varying number of vessels delivering catches on a selected day.

2.5 The sampling frame

2.5.1 Concepts and terminology

Fish catches are almost always structured in a hierarchy of clusters (Figure 1), which influence how they can be accessed for sampling. For example, an observer can select a fishing vessel and record and sample the vessel's entire catch, including discards, during one of its fishing trips (Figure 2a). Alternatively, the landed catches of a particular cluster of vessels at a port can be sampled at the selected port on a selected day (Figure 2b). Another approach could be to select an individual fisher and ask him to record his activities and catches in a logbook for an agreed period.

These all represent a possible initial point for selecting a segment of the catch (e.g. fish from a fishing trip) of the target population for sampling, and hence are called

primary sampling units (PSUs). The complete set of these non-overlapping units (e.g. all vessel trips in a year, all site-day combinations in a year, or all fishers) is the **sampling frame**. The PSUs represent the highest (most aggregated) level in a hierarchical, multi-stage sampling scheme (Cochran, 1977; Allen et al, 2002).

Every item in the target population (e.g. an individual captured fish) can occur in one and only one PSU. Sampling can then be performed by selecting a sample of PSUs from all the PSUs according to a defined sampling procedure.

Each PSU may itself be structured into **secondary sampling units or SSUs** (e.g. vessels landing at a selected port and day; individual hauls of a selected fishing trip; individual trips in a selected fisher's logbook), which in turn may comprise tertiary or even lower level sampling units as shown in Figure 1, which can be sub-sampled or in some cases enumerated through a census.

a) Vessel list		b) List of ports

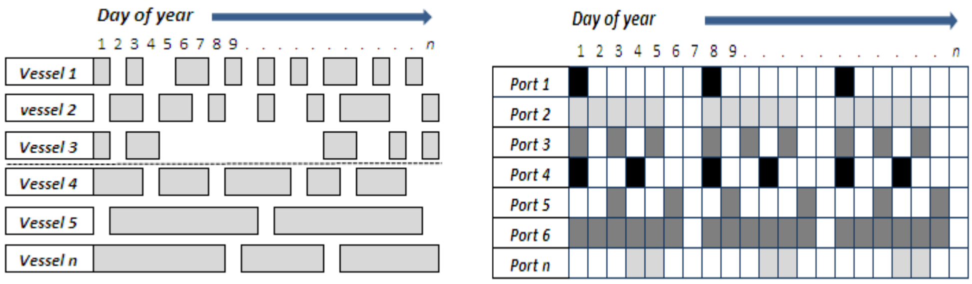


Figure. 2. Structuring of the target population (catches) in space and time for (a) a list of vessels with trips of varying duration, and (b) a list of ports with varying frequency of days when catches are landed and can be accessed (degree of shading in boxes indicates "size" of port – e.g. nos. vessels or size of catch landed per day).

2.5.2 Practical applications

2.5.2.1 Identifying the most appropriate form of PSU

This is one of the most critical aspects of a sampling scheme, yet is often the subject of confusion. A key requirement for a sampling frame used for estimating population totals (such as the total amount of discards) is that the total number of PSUs is known, so that estimates based on the data from the sampled PSUs can be raised to estimate the total for the entire population using raising procedures based on sound statistical principles. For estimation of means or proportions (such as the mean length or the proportion of catch at age), which can be derived from the sampled trips alone without raising to the total fleet, it is not necessary to know the total number of PSUs. However, it is important to record the sizes of the sampled PSUs so that the proper weighted estimator can be applied.

The choice of PSUs depends on how much is known about the activities of the fleet as a whole. The PSUs for sampling a poorly documented small-scale or recreational fishery may be of a quite different nature from those for a well documented large-scale fishery, as illustrated below.

PSUs for large-scale fisheries

In a typical large-scale fishery, the fishing trips and port landings are documented through exhaustive logbook data, making it possible to reconstruct all the vessel trips or port-days with landing events as shown in Figure 2. Sampling can be scheduled according to a probabilistic design, supporting design-based raising from a sample of PSUs (e.g. port-days or vessel trips) to all PSUs for a time-block (e.g., quarter or year).

If vessel trips within a sampling stratum can be selected on shore or at sea on an effectively random basis (e.g. selection of the individual trips in Figure 2a), these can be treated as PSUs in the analysis phase, and the raising factors can be easily calculated provided cluster effects are accounted for. In practice this may be difficult to implement when the fishing trips are not known in advance of the sampling period and the spatio-temporal patterns in fishing activities and landing sites are complex. In this case, the most appropriate PSU should be chosen from the hierarchy of sampling levels (Figure 1) to give the greatest control over sampling design and probabilities, such as at the level of ports (clusters of fishing vessels and their trips on a day or other period) or vessels (clusters of trips of given vessels).

A further issue with treating individual fishing trips as PSUs is that all trips of all vessels should have a probability of being sampled. This can result in individual vessels coming up two or more times in a random selection of vessel trips from the frame. In practice, it is often desired to sample as many different vessels as possible, and minimise repeat trips on the same vessel, as discussed in SGPIDS (ICES 2011, 2012) and considered further in Section 2.7.1.1 below. Taking at-sea sampling as an example, it is necessary to select n vessels from the complete list of N vessels in the stratum, and then pick one or more trips to sample on that vessel. The first sampling level (PSU) is the vessel, and the individual trips are secondary sampling units (SSUs). The trips must be selected in a way that ensures that everyone has a chance of being sampled.

An example of how such a scheme could operate for at-sea sampling is shown in Figure 3. In this example, where the stratum contains vessels with very different trip durations and catch rates, it is clear that sampling each vessel only once results in a much smaller sampling fraction for small vessels with day trips than for large vessels with multi-day trips. The four trips sampled in Figure 3 cannot be considered as equal-probability sampling of all trips in the stratum. If the trips are treated as PSUs, then raising by the fraction of PSUs sampled (trips), or by effort, will lead to biased results. Unbiased results are obtained by first raising from the sampled trip of a boat to all trips of that boat (e.g. raising factor of 16 for vessel A, or 4 for vessel D) then combining the raised data for sampled vessels before raising to the fleet as a whole, using appropriate raising factors (effort, landings etc.). This is similar to raising the length frequencies from sampled boxes within a trip to the total catch of the trip before combining over sampled trips, and follows the cluster sampling hierarchy.

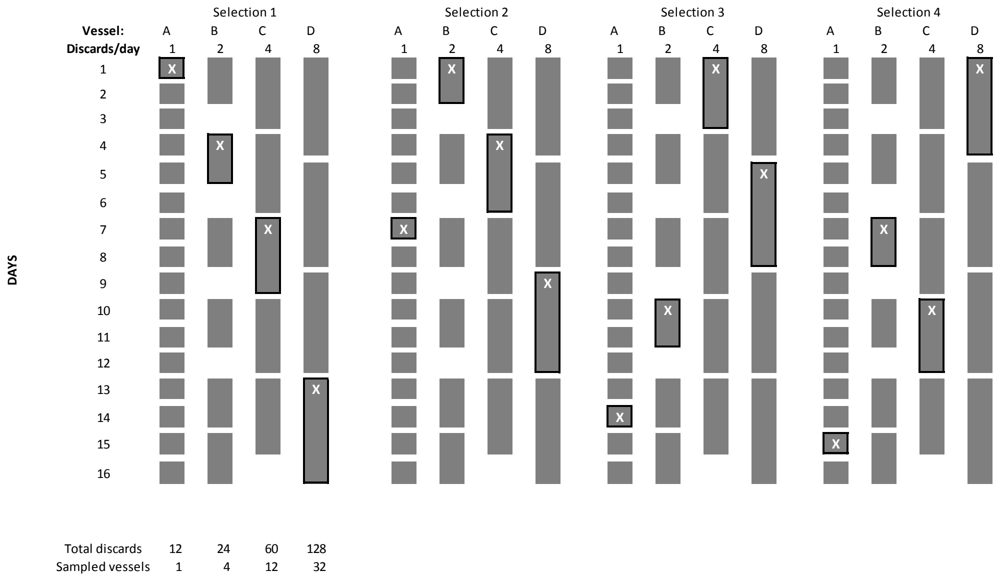


Figure 3. Selecting vessels to sample at sea: example of a stratum with four vessels with varying trip duration and where larger vessels with longer trips discard more per day than small vessels with short trips. Four possible selections are shown where trips are sampled <u>without replication of vessel</u>. There are four PSUs (vessels A,B,C, & D over the 16-week period), and the selected trips are the secondary sampling units within vessels.

The exhaustive fleet activity data for a year can be used to allocate sampling effort for the next year to try to achieve a desired sampling probability for ports, vessels or trips.

Examples of large-scale fishery PSUs are given in the Case Studies for England, Scotland, Denmark, Sweden and Norway.

PSUs for small-scale fisheries

In a small-scale commercial fishery or a recreational fishery, there may be limited or no reported information on total fleet activities. When landings are distributed along beaches and stretches of the coastline, and not confined to a list of ports, for example, an area-frame could be employed (Pollock et al. 1994). The PSUs may in this case be defined by site-days, where the sites are segments of the coastline. If vessel-trips or port-days are adopted as PSUs, raising factors may be poorly known because there is limited or no knowledge of total fleet activity at the end of the sampling year. In many recreational fishery surveys, complementary surveys are conducted to estimate total catch (Pollock et al. 1994). Fishers are intercepted at a random sample of access-points, and data from their completed fishing trips are used to estimate mean catch per unit effort. A separate survey of the human population is conducted to estimate total effort and hence develop raising factors. The population survey can be done through nation-wide random stratified postal or telephone surveys, for example.

A more direct method would be to define the sampling frame and PSUs as a complete, non-overlapping matrix of vessel - time blocks (e.g. vessel-weeks or vessel-months) or port-time blocks (e.g. port-days). The total number of PSUs is therefore known exactly (e.g. 50 vessels x 52 weeks, or 20 ports x 365 days). In the example shown in Figure 2b, the total annual catch and its length composition could be estimated by taking a random sample of port-day combinations from all the PSUs in the frame (whether or not vessels landed) and record the total catch landed at each of the selected port-days. This is equivalent to sampling a patchy population using quadrants. The length compositions for the port-day would be obtained by sampling the catches. The catches at length from the sampled port-day PSUs (including null catches) are then raised to the total number of port-days in the frame. Since these are known exactly, the sampling probability is fully controlled (the scheme could be made more efficient if port-days that never have landings can be excluded - see next section on **stratification** of PSUs). This approach could also be used for large-scale fisheries, particularly if there are concerns about accuracy of reported catch statistics required for raising the sample data.

When fishermen/vessels can be accessed through a registry, a similar outcome could be obtained using a completely different sampling frame, where the PSUs are the individual fishermen/vessels. A random sample of fishermen can be selected at regular intervals and asked to keep a daily logbook for the next week or a longer period to record catches. This will include reduced or null returns if they have low or zero fishing activity in the requested period, or could be catches from only part of a trip if it extends beyond the reporting period (Figure 2a). A method like this is described in the Case Studies of the small scale fisheries of Malta and Spain in the Mediterranean (Section 3.3).

Four examples of fishery sampling schemes are given in Table 1, to illustrate how sampling frames, PSUs and associated sample selection and data raising, could be designed for sampling small-scale and large-scale fisheries either at sea (observers or self sampling) or ashore.

2.5.2.2 Under coverage of the sampling frames

An important consideration for designing sampling frames is their **coverage**. Ideally the entire target population is completely covered by the frame. If only part of the population is covered, the frame has **under-coverage** that will lead to bias unless the variables of interest (e.g. discard rates; species or size compositions) are the same in the parts of the population covered or not covered, or if only a very small part of the population is not covered. An example of under-coverage would be the non-sampling of vessels of a national fleet that land in another country. This fraction may vary from year to year leading to a variable bias if activities, gears etc. differ from vessels landing in the home country.

In some cases, under-coverage can be controlled to reduce bias. In the Case Study of the Norwegian reference fleet (Section 3.1.3), a small fraction of vessels is selected for sampling year-round, and all other vessels have zero probability of being sampled in that year. Similarly, in the Scottish demersal fishery Case Study, many small ports are excluded from the sampling frame, otherwise substantial resources would be diverted to travelling to small remote sites that contribute relatively little to total national catches of the key assessed species. These examples represent controlled under-coverage – the non-covered PSUs are effectively a stratum of PSUs within a known frame of PSUs, where the sampling probability is deliberately set to zero.

2.5.2.3 Vessels leaving / entering fleet

Sampling frames comprising vessel lists are seldom static due to changes in fleet composition. New vessels may enter the fleet whilst older ones are decommissioned, may move for all or part of a year to a completely different region or may be out of action for repairs for an extended period. It is recommended that vessel lists are updated regularly so that a quarterly sampling frame, for example, is based on the most up-to-date vessel list.

2.5.2.4 Cluster sampling

An important consideration for sampling frames and PSUs is the effects of **cluster sampling**. In general, the PSUs will contain a cluster of individual fish (e.g. the fish in a single haul; hauls within trips; vessels landing at the same time and place). Because fish that are caught together in a fishing operation or closely spaced operations tend to be more similar than the fish in the entire target population (i.e. there is positive intra-cluster correlation), the effective sample size will be much smaller than the total number of fish sampled (Pennington and Vølstad 1994; Bogstad et al. 1995; Pennington et al., 2002; Pennington and Helle, 2011). It is therefore important when entering the data to record the PSU from which a fish was sampled. Also, since the PSUs usually vary in size (often greatly) it is important for analysing the data to record the size of each PSU that was sampled (for example, the size of the total catch of a sampled fishing trip). Any analysis that does not take into account the sizes of the PSUs may, and probably will, produce highly biased estimates.

2.5.2.5 Multiple sampling frames

A final question regarding sampling frames and PSUs is "can there be multiple sampling frames for sampling a given fish stock?" An example could be the existence of a small-scale polyvalent fishery landing at many ports, some of which are larger ports from which a large-scale fishery operates. An individual fish can only be in one catch, so the catches of the small-scale and large scale fisheries can be treated as separate target populations with their own sampling frames, PSUs, sample selection schemes and raising procedures tailored to the characteristics of the fishery. Examples of multiple sampling frames are given in the Case Studies on the English and Swedish fisheries.

More problematic is the existence of separate sampling frames and PSUs for sampling the same fleets at sea and on shore. For discarded fish, this is not a problem, but for retained fish, the two frames and PSUs cover the same target population but with different sampling designs and selection probabilities. In principle, the retained fish sampled at sea could also have been sampled in port on the landing day had a port visit been scheduled then. One approach is to make independent estimates of length compositions at the fleet level for retained fish, from the at-sea and shore-based schemes, and combine them with inverse variance weighting provided there is minimal overlap in sampled vessels and cluster sampling is accounted for. The advantage of this approach that systematic differences in length compositions between fish sampled at sea and on shore can be investigated.

Table 1. Four examples of fishery sampling schemes based on vessel list frames or lists of landing sites where catches can be accessed for sampling. Examples 1 & 2, and 3 & 4 provide contrasting scenarios of knowledge of fleet activities, perhaps typical of small-scale and large-scale fisheries.

EXAMPLE	SAMPLING FRAME TYPE	SOURCE OF LIST	SOURCE OF FLEET ACTIVITY DATA	FRAME PSUS	EXAMPLE SAMPLING SCHEME	RAISING FACTORS FOR DISCARDS ESTIMATES OR LENGTH COMPOSITIONS ETC.	TYPICAL TYPE OF FISHERY
1	Vessel list frame	Complete fleet register	Complete census data (e.g. logbooks)	Vessel list or a"virtual" frame comprising individual fishing trips known at end of year.	Vessel selected at random from vessel list, contacted and boarded by observer for duration of trip. On completion, another vessel is selected at random. Process continues over year or fishing season.	Derived from fleet activity census: e.g. total annual no. trips / no. sampled trips; total annual days fished/sampled days. Other auxiliary raising variables possible (e.g. landings).	Large scale fishery with full activity documentation and able to take observers
2	Vessel list frame	Survey of vessels at ports	Not available or incomplete	Boat x day; boat x week etc.	Vessels identified from survey are selected at random each week or month and asked to complete a catch diary for that week or month) including non-fishing days.	(total PSUs)/sampled PSUs e.g. (100 boats x 52 weeks)/(*n* boat-weeks sampled); total fleet number is from survey.	Small scale fishery with no or limited documentation, often typical of recreational charter boat fisheries
3	List frame of landing sites	Fishery landing statistics	Complete census data (e.g. logbooks)	Site x day	Random selection of sites from all possible sites x days, e.g. lattice scheme with one site visit per week.	Derived from fleet activity census e.g. total fleet landings divided by landings of sampled vessels.	Large scale fishery with full activity documentation.
4	List frame of landing sites	Survey of known or potential landing sites	Not available or incomplete	Site x day	Random selection of sites from all possible sites x days, e.g. lattice scheme with one site visit per week.	(total PSUs)/sampled PSUs e.g. (50 sites x 365 days)/(*n* site-day visits).	Small scale fishery with no or limited documentation, often typical of recreational shore or private boat fisheries

2.6 Stratification of the PSUs to improve sampling

2.6.1 Concepts and terminology

Stratification refers to the process of dividing the PSUs in a sampling frame into two or more sets, and making separate selections from each set. Levy and Lemeshaw (1991) note that the concept of simple random sampling is useful for understanding sampling theory but is rarely adopted in practice without some form of stratification or inclusion of systematic elements to improve coverage.

An example is given in Figure 4a, which shows a sampling frame with port-month PSUs, using a sampling scheme that randomly selects port-month combinations for conducting sampling trips. (The day on which sampling takes place each month would be chosen as a secondary sampling unit.)

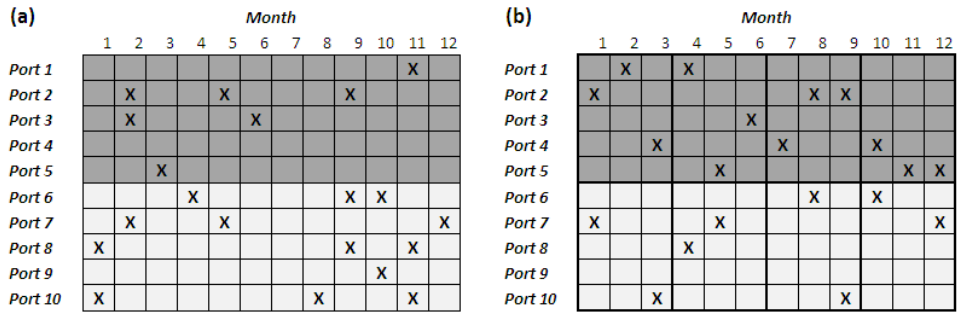


Figure 4. A sampling frame of port-month PSUs where dark-grey shaded cells are "large" ports and light-grey shaded ones are "small" ports. In (a), 20 PSUs are selected using simple random sampling without replacement and without stratification. In (b), a stratified random sampling scheme is adopted: the frame is stratified into eight strata – defined by quarter and port size. Three PSUs are sampled per quarter in the large ports strata and two per quarter in the small ports strata. A "lattice" scheme is used in (b) to spread the sampling as evenly as possible over months (e.g. one port sampled at random each month for large ports).

Figure 4a shows that a simple random selection could by chance lead to an inefficient coverage of the frame – for example poor coverage in some quarters, or sampling staff spending more time visiting small ports than the large ones where most of the target population (catch) is located. In any circumstance where PSUs vary widely in terms of the part of the target population that they contain, and where the variation is predictable, there are benefits to grouping similar PSUs into two or more strata and sampling each stratum independently. Statistically, this has the effect of minimising the variance within strata and maximising the variance between strata. Sampling effort can then be increased in a controlled way in strata that contribute most to the variance of the overall population estimate, whilst ensuring adequate coverage in all strata.

In Figure4b, the PSUs have been stratified into four quarterly strata for large ports and four quarterly strata for minor ports. Three visits per stratum are scheduled for strata containing large ports and two per stratum of small ports. This achieves a desirable result of ensuring even coverage of all quarters, and allowing an increased sampling intensity for large ports in a controlled way. A scheme such as this is described in the Case Studies for England and Scotland (Sections 3.2.1 & 2).

For an at-sea sampling scheme, vessels could be stratified into those that typically have short trips and those that have long trips (see Figure 2a). This is desirable to avoid over-sampling of very numerous small vessels that have very small catches and are more available for sampling than vessels that undertake long trips and land relatively infrequently. An example of stratifying by trip duration is given by Rago et al. (2005).

There are many reasons for stratifying a sampling frame (FAO 2002). These could typically include:

- Ensuring more even coverage of the population.
- Allowing controlled variation of sampling probabilities on different parts of the population to improve overall precision.
- Increasing the sampling rate for parts of the frame where there is a need for more precise data for domains of interest – e.g. for a particular region or class of vessels.
- Controlling the sampling and estimation between vessel / trip subsets participating in extensive gear trials and those undertaking "normal" trips.
- Resolving logistical issues related to availability of sampling staff in different locations or the cost of sampling in more remote locations.

Two important requirements for a stratification scheme are: (1) the probability of selecting PSUs for sampling should be controllable (e.g. the number of PSUs in the stratum should be known in advance, or a controlled systematic sample selection is adopted if knowledge of the number of PSUs is only built up as sampling progresses), and (2) all defined strata should receive sufficient sampling effort (absolute minimum of two samples per stratum to allow variance to be calculated).

2.6.2 Practical application

2.6.2.1 Choosing variables to define strata

A key requirement for defining strata is that the component PSUs are defined by factors or variables that are relatively stable and predictable, for example a grouping of ports according to their "size", or segmentation of a vessel list according to vessel size (which may be correlated with trip duration or catch per unit effort) or typical type of fishing (where this is largely dictated by technology – e.g. pelagic trawlers, beam trawlers or shellfish dredgers). The predictability of these variables allows more accurate control over sampling probabilities. As discussed elsewhere by WKPICS1, the use of dynamically changing variables (e.g. mesh size or selectivity devices) is generally not appropriate for defining survey strata in advance – these variables could change rapidly due to legislation or other drivers and lead to poorly controlled sampling probabilities.

2.6.2.2 How many strata are enough?

There is often a very large variation in vessel types, gear usage, target species, areas fished etc. in a fishery, and there is a natural desire to try and break the target population up amongst these components and sample each one independently. Attempts to do this without adequate sampling resources can lead in the worst case to many more strata than there are observations. To compensate, complicated imputations may be needed to make inferences for missing data for some strata, which can lead to bias and an inability to reliably estimate precision. A combination of over-stratification and choice of dynamically-varying strata such as DCF Level-6 metiers should be especially avoided.

Cochran (1977, page 133) suggests that there will usually be little reduction in variance by employing more than 6 strata although this will depend on individual circumstances and available sampling effort. It is better to have the minimum number of strata that are sufficient, while ensuring proportional allocation of effort between strata and avoid not being able to sample some strata.

In a study on different methods of raising discards data - including simple random sampling, model-based methods and ratio or regression estimators - Allen (2009) concluded (for the fleets examined) that it was better to select vessels for sampling using equal probability and to post-stratify the data, rather than attempt to comply with an intricate stratification scheme (available resources were insufficient to comply with a detailed stratification scheme), and assess the bias due to non response.

2.7 Selection of primary and lower-level sampling units

2.7.1 Concepts and terminology

Once a practical sampling frame for a survey is defined, the next design step is to decide how the PSUs should be sampled and how many should be selected. The "how many" question is a function of the desired survey precision for key parameters, and this can only be determined by the end users of the survey's results.

Usually the sampling design involves **multi-stage sampling** where there is a hierarchy of sampling decisions (Figure 1). The sequence for sampling fish is: 1) selection of a cluster of fishing trips to sample from (e.g. all landings at a port during a defined time window); 2) selection of vessels/trips to sample within the cluster; 3) selection of fish to measure or age from the catches of the sampled vessels/trips.

Any survey design where the samples are selected at each stage with known probability is said to use **probability-based sampling**. Such designs are very desirable because they are based on well-understood statistical principles and have relatively straightforward methods for raising data according to the probabilities of selecting the sampling units.

The simplest sampling scheme would be to select at random n PSUs, with equal inclusion probabilities. A very important point to note when designing a survey is that the reason random sampling is so effective (e.g., generates unbiased estimates) is because the probability of selecting any PSU is known – for the simple random case every PSU has an equal chance of being selected. If the random draw is repeated many times, the expectation is that all PSUs will be sampled the same number of times. This also applies to secondary and lower-level sampling units.

Selecting all PSUs with equal probability may not be a very efficient use of resources if the PSUs vary widely in the quantity or diversity of the target population. A lot of time and money could be spent sampling vessels or ports that will contribute very little to the final estimates for the overall target population (see Case Study for port sampling in Scotland). In this case, major improvements in cost-effectiveness can be achieved by varying the probability of sampling vessels or ports according to their contribution to the final estimates. For these survey designs, a PSU is selected with unequal but known and predetermined probability, using one of the following approaches:

Stratified random sampling in which the PSUs that comprise the sampling frame are divided into two or more groups which are sampled with different intensity (see example in Figure 4b where ports are stratified by a measure of "size", and large ports are sampled more frequently than small ones).

Unequal probability methods, such as probability-proportional-to-size (pps) where the probability of selecting each PSU is directly proportional to a measure of its expected "size" with respect to a known auxiliary variable that is likely to be highly correlated with the parameter to be estimated. This leads to more precise point estimators. For example, landing sites in an area list frame or vessels in a vessel list frame could be sampled with probability proportional to their total fishing effort or landings in the previous year (or preferably to their contribution to the overall variance of estimates required). A pps method can also be applied within defined survey strata (e.g. to ports within regions and quarters). The weights (sampling probabilities) for pps schemes are known and are accounted for in the raising procedure using Horvitz-Thompson or Hansen-Hurwitz type estimators depending on whether or not PSUs (e.g. vessels from a vessel list frame) are selected with replacement. See standard texts for more details (e.g. Levy and Lemeshow, 1999).

The Case Study of the Icelandic fisheries (Section 3.2.3) describes a port sampling scheme that triggers visits to ports according to real-time data on cumulative landings by species and gear as the year progresses. Numbers of samples to be taken per tonne landed is identified by in advance by species and gear. Real time monitoring of landings then triggers a sampling trip at specified tonnage intervals. The intention of this scheme is to ensure that the sampling rate is proportional to landings, so it will achieves a similar result to pps sampling though it is not based on any randomisation of PSUs.

Sampling with a view to using model-based estimators. This refers to estimation procedures that predict variables such as discard quantities for non-sampled vessels using a model (e.g. a regression model) fitted to data from sampled vessels. These rely on being able to identify robust and significant linear correlations between the variable to be estimated y and one or more auxiliary variables x. An example could be a linear correlation between quantities discarded and landings, fishing effort, vessel length (or a linear combination of several variables) quantified from a sample of vessels. The **regression estimator** parameters are then applied to the trip data for each of the non-sampled vessels in the fleet to predict their discards. The **ratio estimator** is in effect a special case of the regression estimator where the intercept is assumed to be zero (e.g. the ratio of discards to landings or discards per unit effort is constant). Ratio and regression estimators are not the same as pps schemes, as they could use non probability based schemes to improve the regressions. However, the need for the ratio or regression estimates to be representative of the population as a whole remains, and the methods can be used with pps or other probability based sampling schemes with the advantage that the estimation can default to design-based estimators if needed. A fuller discussion on the merits and potential problems with model-based estimators is given by WKMERGE (ICES, 2010).

2.7.2 Practical application

2.7.2.1 Different approaches to taking samples of primary units

Random sampling with, or without replacement?

Sampling with replacement from a finite population means that each element drawn is returned to the population before the next draw (Rasch et al., 1994). This approach permits the same element to be sampled several times. If, when taking a sample from a finite population, the sample units are not returned to the population after selection, sampling is said to be done **without replacement**. In this case, the population changes as a sample unit is selected, so the probability of a particular unit being selected also changes (Rasch et al., 1994).

For fishery sampling schemes, where the PSUs are port-days or vessel-trips, it is obviously not possible to sample with replacement, as you cannot re-sample a day or a trip that has already passed. However, if a design is chosen where port-days or vessel trips in a stratum are selected at random, some ports or vessels may be sampled relatively frequently by chance. This is inefficient, and many practitioners will consider such a sample to go against common sense. Practitioners may reject particular unfavourable samples, thus ending up with samples where the probability of selecting each PSUs is unknown. Such ad-hoc schemes may be avoided by using sampling which avoids or controls repeat sampling of ports or vessels.

Efficient spread of sampling across ports or vessel-trips may be achieved by stratification of PSUs (for example grouping of ports, grouping of vessels), and by using a randomised and ranked port list or vessel list within each stratum, or using systematic "bus route" sampling of ports (see next section). The selection of successive sampling trips can then be done by working down the ranked list or bus route (see example in Figure 3). For at-sea sampling from a vessel list, this implies that the PSU within each stratum is in fact a vessel. The selected trips within each vessel are secondary sampling units. The raising of the data for estimating totals should follow this hierarchy of sampling units.

If there are more sampling trips than there are vessels or ports, then there will have to be repeat sampling of the same vessel or port in the stratum. However it would be desirable to control this to avoid over-sampling individual vessels or ports. Repeat sampling of vessels or ports in a stratum may be advantageous, even if the sampling fraction is small, if the variability in estimates between repeat visits to the same vessel or port is greater than the variability between ports or vessels. This could be evaluated within an experimental design that would allow an estimation of the components of variance between vessels/ports and between sampled trips/days within the vessels or ports.

As an example, say you have a budget to schedule 12 sampling trips to cover a population of 50 ports over a year. The following designs could be used to pick ports and weeks for sampling:

1. Pick 6 ports randomly without replacement, and then pick 2 weeks per port for sampling.
2. Pick 12 ports randomly without replacement, and then sample 1 week randomly for each port. This is equivalent to picking port-weeks randomly without replacement.

The sampling day in each week may be scheduled randomly, or based on knowledge of fishing activity over the week.

When implementing a sampling program such as given in the above example, it is recommended to start with design option (1). This design would allow an analysis of variance to estimate the components of variance between ports and between sampled days within ports. If the empirical data suggest that the largest component of the variance is between ports, for example, then it would be recommended to switch to design option (2).

An alternative approach to random sampling without replacement to spread out sampling amongst ports or vessels is to adopt some form of systematic sampling scheme with random elements. This is discussed in the following sections.

Systematic random surveys: spreading sampling evenly over time

Simple random sampling of PSUs, which in fisheries will have a time component, may not always be feasible or desirable from a logistical point of view. For example, in Figure 5a, the days for sampling within a quarter are effectively random, but lead to some clumping of dates. An alternative approach is to space the dates out systematically (e.g. every two weeks in Figure 5b). This form of systematic sampling over time is referred to as a "lattice" scheme (Vølstad et al. 2012). It is only appropriate if there are no regular patterns that could coincide exactly with the periodicity of sampling (e.g. there is a pattern in fish sizes or discards related to spring or neap tides).

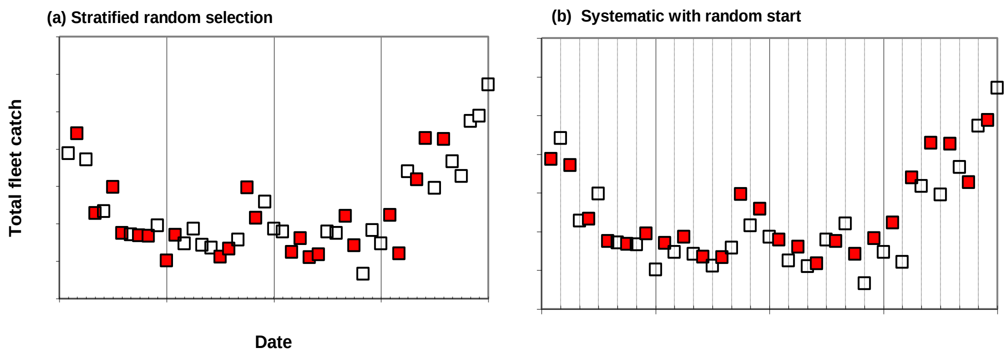


Figure 5. (a) Random sample of weeks to sample within quarterly strata; (b) Systematic selection of every second week. Filled squares are sampled weeks, open squares non-sampled weeks.

Another example of systematic selection over time is during a port visit, where sampling (e.g.) every second or third landing would be a suitable approach if intercepting vessels landing at intervals during a day, without any advance knowledge of which vessels will be landing.

It is good practice to randomise the first sample within a systematic scheme – for example if every fifth landing is sampled during a port visit, the first sample should be a random selection of the first five samples.

Systematic random surveys: spreading sampling evenly over time and geographic location

Systematic sampling can also have a spatio-temporal basis. A common problem with simple random sampling of port-days is that if the ports are very far apart, substantial travelling time and costs may be incurred moving from one selected site to the next one in a random fashion.

If equal-probability selection is required, every *n*th port could be visited in successive sampling events, ensuring a random start in each temporal stratum (e.g. quarter). This is commonly known as a "bus route" sampling scheme.

The situation is slightly more complex if the ports are a mixture of large and small ones that are to be sampled with different probability using a stratified random scheme. In the hypothetical example shown in Figure 6a, six "large" ports and 14 "small" ports are to be sampled with one visit in each week selected as secondary unit. Over the 12 weeks shown, there are 72 port-week PSUs for the large ports, and 168 PSUs for the small ports. Hence the large-port PSUs are sampled with almost three times the probability as the small port ones. Figure 6a shows a lattice sampling scheme where the two port-size strata are sampled in alternate weeks, selecting a port at random (without replacement of ports in this case). To implement this sampling scheme would require travelling up and down the coast in a random fashion at large cost. In Figure 6b, the weekly selections have been re-ordered so that the survey moves progressively down the coast, resulting in a substantial saving in travel time. For the next quarter, the process would be repeated, possibly in reverse order.

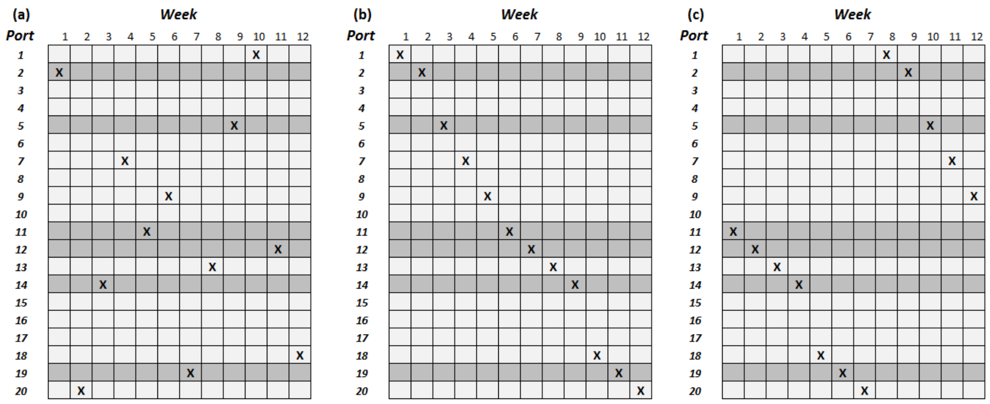


Figure 6. A port sampling scheme where six port-week combinations are to be sampled per quarter from a "large port" stratum (dark grey cells), and six from a "small port" stratum (light grey), with one port to be visited per week (lattice design). Ports are in geographic order. (a) strata sampled in alternate weeks, with port selected at random (without replacement of ports); (b) selections from (a) are ordered in a "bus route" scheme with random starting port; (c) is another bus route with a different random start point.

It is <u>essential </u>in this form of bus route sampling that the first port to sample on the route is chosen at random. Figure 6c shows a scenario where Port 11 is the random selection for week 1. Essentially, instead of selecting PSUs randomly and independently (as in throwing a quadrant at random), the port-week PSUs are aligned in what is in effect a transect running diagonally through the frame. If the schema in Figure6b was simply repeated each quarter, most of the PSUs would have zero probability of being selected. By randomising the first port to be sampled in the sampling time period (see Figure 6c), all PSUs have a chance of being selected. It should be noted that the alignment of PSUs in a bus route scheme means that neighbouring ports are also sampled closer together in time, causing a potential autocorrelation in estimates from PSUs.

A further elaboration would be necessary if there are multiple sampling frames within the port list (e.g. separate site-day frames for pelagic, demersal and crustacean fisheries). A schema as shown in Figure 6a could be set up for each, and the separate frames "stacked" then sorted as in 6b/c to produce a bus route.

The main problem with "bus route" schemes is if the time it takes to progress along the coast is so long that there is an interaction with seasonal patterns in the variables of interest, if they also vary spatially. For example, consider a situation in Figure 6 if there was a seasonal fishery for large mature fish in the second half of the time period and mainly in ports 1–10. The bus route in Figure 6b would miss these fish altogether, whereas the route in Figure6c would have coverage of this component. Previous data should always be reviewed to look for spatio-temporal patterns that could lead to bias in some survey designs such as bus routes. If necessary, suitable stratification schemes could reduce the potential for bias.

2.7.2.2 Optimal allocation of sampling effort

If the between-PSU variability in a domain (e.g. quantity of a stock discarded) is known from previous sampling years and is thought to be the best representation of the coming sampling year, it is relatively straightforward to determine how a given amount of sampling effort should be distributed across strata to minimise the overall variance of estimates. Optimum allocation may be used to determine the sample size for each stratum in stratified sampling. This can be viewed as a non-linear optimisation problem, where the objective function is the variance, which is subject to a cost restriction, or vice versa. For optimum allocation given a fixed total sample size, often referred to as Neyman allocation (see, e.g., Cochran 1977; Sukhatme and Sukathme 1970)), the number of samples in stratum h (n_h) is chosen proportional to the standard deviation S_h of a single decision variable times the stratum size N_h ($n_h \propto S_h N_h$). Neyman allocation yields the maximum precision (minimum standard errors) obtainable when the total sample size is fixed.

A more complex situation arises where it is necessary to optimise the precision over a whole range of estimates from the same sampling scheme – e.g. discards of many species for which estimates are required. The discarding by species may vary widely by gear type, area, time of year, quota uptake etc. This is usually complicated by the fact that the different estimates may have different variances, which means that the sample sizes for each characteristic may vary. In multipurpose surveys it is recommended that the stratification scheme represent a compromise (Kish and Anderson, 1978). Miller et al. (2006) present analytical results for the sampling fractions and sample sizes for primary units within each stratum of a stratified sampling design employed for the North Pacific Groundfish Observer Programme, that are optimal with respect to a weighted sum of relative variances for multiple estimation objectives.

A Case Study for estimating discards of multiple species in the French Demersal fleet was described in ICES, 2010 (WKMERGE). This illustrates a method of allocating sampling effort between sampling strata so that at least X% of species meet the desired precision target. See also Rago et al. (2005) for an example of optimisation of sampling effort across strata for an observer scheme.

2.7.2.3 When estimates are required for groups of trips according to fishing grounds, gear designs or mesh bands that vary dynamically with time.

It may be that more information is needed for particular types of fishing trips, such as trips using trawls with a particular mesh size or selectivity device, or fishing in a particular area. These are characteristics that may change dynamically over time.

It is generally not appropriate to define PSUs by such dynamic characteristics, or to pre-stratify the resultant frame by these characteristics, as this can lead to **quota sampling** where the sampler must use his or her judgment to select the sampling units (e.g. trips) from each métier to obtain a prescribed sample size. This subjective choice of sampling units means that quota sampling is a non-probability sampling scheme.

For example, if there is a quota to sample 20 fishing trips at sea from fleet métier *a* in fishing ground *b*, the sampler will search for suitable trips in order to meet the quotas. Even if a randomisation scheme is used (e.g. from a vessel list), random selections may be sequentially rejected until vessels are found where the skipper says they will be using the desired gear and fishing in the desired area. This alters the selection probabilities for all other métiers in the sampling frame. Quota sampling may therefore produce biased estimates because not every primary sampling unit gets a chance of being selected (see Cochran, 1977). The problem is exacerbated if the activity in one or more of the métiers has reduced substantially – sampling staff may waste considerable time sifting through vessels or port-days to locate a sufficient number of fishing trips of the specified métier.

The example below illustrates what could happen if sampling quotas for trips using a particular mesh size are set based on a previous year but the use of meshes has changed in the sampling year:

	Fleet trips in 2011	Desired sampling probability	Quota of samples for 2012	Actual fleet trips in 2012	Actual sampling fraction
OTB_DEF_70-99	1000	5%	50	1000	5%
OTB_DEF_100-119	500	5%	25	100	25%
OTB_DEF_120+	100	5%	5	500	1%

In this example, a shift in use from 100-119mm mesh to 120mm+ leads observers to frequently reject trips using 120mm+ mesh when they come up on a random draw list, in favour of vessels still using 100-119mm mesh. By so doing, resources are wasted searching for scarce trips to sample, and the sampling fractions are skewed in a very undesirable way with major implications for precision. In the worst case, some métiers may end up with no samples.

A more suitable approach to achieving a desired sampling rate per métier is to set up the frame and PSUs as a list of vessels or sampling sites which are relatively stable and predictable, and then stratify them according to their predominant métier or other characteristics of interest. The allocation of sampling effort between strata can then be optimised to provide a balanced sampling design (see Tillé 2006) with equal or unequal inclusion probabilities for the primary sampling units. By using all recent information available about the fishery to guide the survey design, the sample sizes obtained for each métier will be close to the desired number. Though the achieved sample sizes are likely to vary from the prescribed values in many cases due to changes in the fishery, the possibility of biased estimates caused by quota sampling will be eliminated.

Quota sampling may only be justified for small samples where the possible reduction in sampling errors may offset the effects of unknown biases (Jessen 1978), or where information is required for only a small number of types of fishing trips mixed in an unpredictable way amongst many others for which sampling is not needed.

2.7.2.4 What if random sampling is missing small numbers of landings that represent the bulk of the annual catch of a species?

An argument for quota sampling may be that simple random sampling can easily miss sporadic large landings of an individual stock, and these make up the bulk of the annual catch of that stock. By chance, the length compositions could be derived entirely from vessels with very small by-catches of the stock. In this case, historical data should be examined to see if there is a subset of vessels responsible for these landings (e.g. a few vessels targeting the species), and which ports they land into. On the other hand, using judgment sampling to pick some large catches to sample could also lead to bias if these are a non-random sample of all the large catches made by the fleet. If there is a specific request for accurate data for this particular fish stock, the vessels with large catches could be identified as separate sampling stratum with increased sampling rates based probability sampling. A more elaborate scheme could involve these vessels in self-sampling schemes to ensure better coverage of the largest catches of the stock in question.

2.7.2.5 Identifying sources of bias

Practical implementation of catch sampling schemes involves many decisions about achievable design, and problems with implementation, that can cause the "ideal" of fully representative sampling to be compromised to varying degrees. It is important for the end-use of the data that the existence of bias, and the potential (or known) direction and magnitude, are clearly documented, along with measures or indicators of precision. This subject will be explored in detail in WKPICS2, further developing the scorecard approach to documenting bias developed by ICES WKACCU (ICES 2008). The following text provides an overview of issues highlighted at the WKPICS1 meeting during discussion of national programmes and Case Studies.

Restricted access to catches for sampling

There are several practical problems in taking representative samples from fishery catches related to accessibility of catches for sampling, that WKPICS1 showed were common across many European sampling schemes. These include:

- Refusals by skippers to take observers on board;
- Processing of catches at sea (freezing, filleting) preventing recording of length, maturity etc;
- Catches partially retained on board or split between different markets/processors;
- Catches offloaded directly from the vessel to a lorry;
- Very variable trip duration (e.g. very long trips may not be sampled).
- Difficult access to landing sites
- Catches of different vessels are mixed

- Catches landed at one port may be sold in another port also sampled
- Sampling of pair teams at sea
- Limited time on markets, especially where there is a requirement for "concurrent" sampling of all or most species in a landing.

Refusals (non-response) remains a major issue for many at-sea sampling schemes reviewed by WKPICS1. Three situations that can produce a biased sample of vessels are (Vølstad and Fogarty, 2006): (1) some selected vessels cannot be observed because operators refuse to take observers; (2) observers are unable to board some selected vessels because they are not certified as safe under current deployment rules; and, (3) some vessels within the sampling frame do not have accommodations for observers. Systematic errors in estimates of catch and bycatch resulting from these situations cannot be eliminated by increasing coverage of the observable fleet. A high non-response rate indicates potential for bias, unless there is good evidence that it is not correlated with the variable of interest, e.g., discarding. It is strongly recommended that records are kept of reasons given for refusals, and that the characteristics of the vessels such as length, main fishing method, port etc. are recorded (see ICES SGPIDS reports [ICES, 2011] for more detailed discussion, and also the Case Studies in Section 3.1). Where vessel census data are available, diagnostic evaluation of vessel characteristics, areas fished, gears used and catch compositions may indicate if access is being prevented to vessels with activities that differ from the fleet as a whole, suggesting a strong potential for bias.

Most of the other problems highlighted above can be resolved by sampling at sea rather than at ports. However, at-sea sampling is costly and generally far fewer trips can be sampled at sea than can be sampled on shore, although the effective sample size for on-shore sampling can be less than the number of fishing trips due to cluster sampling. More highly resolved data are obtained at sea (data by haul; discarded component observed). Self-sampling schemes can increase the at-sea coverage at the expense of data volume (and possibly quality) per trip, but may be the only possibility for sampling small vessels at sea. Remote observation using digital video has been established in the Danish "fully documented fishery" (Kindt-Larsen et al., 2011) as a means of sampling a fleet without the expense of on-board observers, and is being tested in other European fleets. This approach is also promising for evaluating some types of bias in self-sampling programs. Vessels owned or leased by the government may be used to observe near-shore fisheries through a roving survey, particularly to cover small vessels that cannot accommodate observers.

Changes in fishers' behaviour when observed

An additional source of bias in at-sea sampling schemes that is not directly related to the vessel selection method is changes in fishing behaviour when an observer is aboard. For example, biased estimates are likely if fishers avoid areas where bycatch typically is high or change the duration of the trip, length of tow, or other aspects of fishing operations to reduce bycatch when observers are aboard. This form of bias is most likely to occur if fishing regulations, such as bycatch quotas, provide an incentive to change fishing behaviour. The only means of assessing the occurrence and potential magnitude of such a bias would be to compare trip and catch characteristics with observers aboard to characteristics of trips without observers, including for adjacent trips of the same vessel. Diagnostics for identifying significant differences in fishing operations include the areas, times and landings of target species; however, sources of data for such comparisons are generally limited unless there are complete census data from logbooks.

2.8 Raising from sampled vessels to the population

Where a sampling frame has been correctly set up, and the PSUs in each stratum of the frame have been selected randomly and independently, the raising factors for each stratum are simply the fraction of PSUs sampled (e.g. total number of port-day PSUs in an area list frame, or vessel-trips in a vessel list frame, divided by number actually sampled). The sampling design uses sampling fractions (probabilities) based on the expected number of PSUs, whilst the raising uses the actual number of PSUs based on fleet census data for the sampling year, if available. Other raising procedures, using ratio or regression estimators (e.g. based on effort or landings) may also be easily applied depending on quality of fleet-wide census data.

For small-scale fleets with no fleet census data, the total fleet activity data have to be obtained from a separate fleet survey. If there is a known register of vessels, the frame can be set up with vessel - time block PSUs (e.g. 50 vessels with 12 monthly time blocks), and data collected for random PSUs including those with null activity (see Section 2.5.2.1).

In general, the PSU is the first level in hierarchy of sampling units, each representing a cluster of fishing trips, hauls within trips, boxes of fish within hauls etc. (Figure 1). For the overall raising procedure to be unbiased, the selection of samples at each stage should be random, and the raising factors are derived from the sampling fraction at that stage.

Minimisation of bias through sampling design, or at least an ability to identify and quantify biases, is more critical than minimisation of variance (ICES, 2011). Biases could arise due to:

- Raising data without taking into account the sampling design (e.g. lumping samples together without taking into account the different sampling strata and sampling fractions at each stage, or ignoring cluster sampling).
- Biased sampling schemes (e.g. sampling staff using own judgment on which vessels or ports to sample; excessive refusals to take observers on board not accounted for).
- Biases in overall fleet data used in the raising procedure (e.g. numbers of trips; total landings or effort).

These can result in different estimators such as simple random sampling, ratio or regression estimators, or model-based methods, giving different results. Deciding which is least biased may be problematic. For example, if the procedure used to raise discards estimates to the fleet level, based on proportion of trips sampled or on a ratio estimator with landings or effort, is also applied to the landed part of the sampled catches, it may give a systematic bias in fleet raised landings in comparison with official reported landings. Is this due to inaccurate reporting of landings or effort by the fleet, or some bias in the sampling design?

Sampling design, estimators and bias are completely interconnected, and a full treatment of this subject was not possible in WKPICS1 but will be addressed in WKPICS2 in November 2012.

3 Case Studies

This section of the report summarises a range of Case Studies presented at WKPICS to highlight the practical problems encountered in designing and implementing sampling schemes for a range of European small-scale and large-scale fisheries.

We divide the section into three types of fishery sampling schemes:

- At-sea sampling of large-scale fishery catches including discards
- On shore sampling of large scale fishery landings
- Sampling of small-scale fisheries

To ensure an efficient and successful meeting, participants were asked to complete questionnaires prior to the meeting, providing details of the design of their national fishery sampling schemes and the logistical and other difficulties affecting survey design, and several countries were asked to present more detailed Case Studies.

3.1 At-sea sampling schemes for large-scale fisheries

This section is complementary to the reports of the ICES Study Group on Practical Implementation of Discard Sampling Plans (SGPIDS) (ICES 2011, 2012), which should be consulted for detailed reviews of operational issues around the implementation of discard sampling schemes by observers, self-sampling or CCTV.

3.1.1 Case study 1: Observer programme in Kattegat, Denmark (Maria Storr-Paulsen)

Traditionally the Danish observer program allocated observer days at sea by gear group, quarter, and area. Observers could use the same ship for all trips with the same gear group. As a result, relatively few vessels were covered in a year. Vessels were not selected randomly, and refusal rates were not documented.

This case study looked at lessons learned from a new sampling scheme involving:

- Vessel list frame, treating individual vessel trips as PSUs
- Stratification of PSUs by gear group
- Random selection of vessels using a "lucky wheel" – probability of selecting a vessel is weighted by number of trips in previous year.
- Documentation of refusals, and reasons for refusals.

The goal of the new catch sampling scheme is to reduce bias through representative sampling of trips from the fleet, increase precision by sampling more vessels/trips, and improve cost effectiveness. Reasons for "non-response" (not being able to sample catches from a selected trip) were documented as a means of assessing likely bias in achieved sample of vessels/trips (Figure 7).

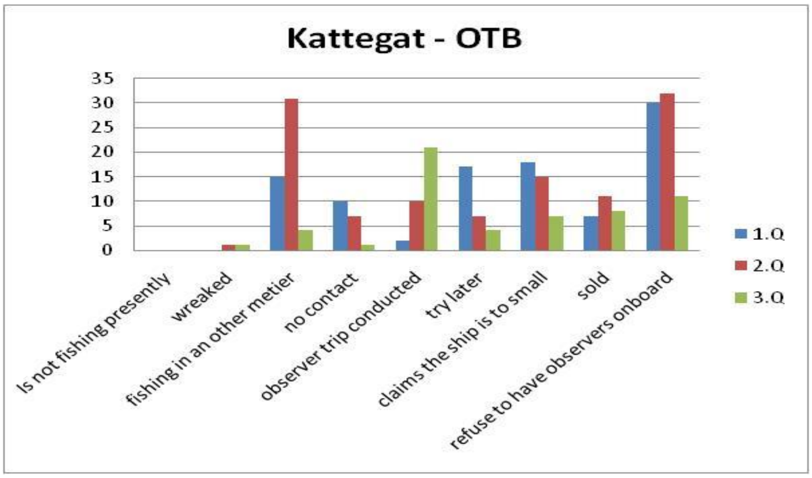


Figure 7. Reasons for refusal to take observer (non-response) for randomly selected trips in Quarters 1 - 3.

Comparisons were made between fishing locations of selected vessels and VMS data from entire fleet, to examine representative selection of trips.

Lessons learned after testing the random vessel/trip selection procedure in 2010 is that it was much more difficult and expensive to get access to sample a trip selected at random, compared with previous approach of sampling the same vessel per gear group. More one-day trips were completed, resulting in fewer days at sea. It was also challenging for observers to contact randomly selected vessels. However, after nearly a year the pool of vessels that accepted observers increased for some areas. The random sampling of vessels/trips highlights the métiers with high refusal rates and gives the fishermen's organization a much larger degree of responsibility. A major challenge is to assess what is an acceptable level of refusal, and how to deal with too high a rate of refusal. It is also not decided how to weight the effort in observer trip between métiers (at present only numbers of trips are used).

3.1.2 Case study 2: Observer program in Sweden (Katja Ringdahl),

Swedish demersal fisheries in the Skagerrak can be grouped into three main fisheries based on the mesh size of the nets: small-mesh (35mm+) Pandalus fishery; Nephrops fishery using 70 mm mesh with sorting grid; other demersal trawlers using 90mm+ mesh. The fleet consists of 140 vessels, with typical trip length of 1-5 days. Vessels participate is several fisheries. The Swedish programme to estimate discards involves 50 observer trips per year, covering 5 fisheries.

- A separate vessel list frame is defined for each fishery, with the PSUs being the individual fishing trips in the fishery
- The number of trips to be sampled for each fishery (frame) is based on the fishing effort in the previous year (days at sea for the contributing vessels)
- A randomised vessel list is produced for each frame, with probability proportional to size (days at sea in previous year), and vessels contacted in order as they appear on the ranked list.
- Vessels that refuse to take observers are not contacted again within that year. Reasons for refusals are tracked.

The main practical issues with the design and implementation of the sampling programme are:

- The sampling frame is a list of vessels based on previous year but vessels are bought and sold frequently.
- A single fishing trip (treated as PSU) may cover two or more of the fisheries, and a contacted vessel in a fishery list frame may be occupied in one of the other fisheries. If this vessel is selected, it represents a trip in a different fishery from the one intended. If not selected, is it similar to a refusal?
- Not all vessels are suitable to carry observers (particular in winter time).
- Refusals are presently not taken into account in estimations. Rates vary between fisheries.
- Some vessels operate for a limited number of days. The probability of sampling these from the vessel list is very low due to the pps selection scheme.
- It is time consuming to contact vessels.
- Possible over-stratification (3 samples/fishery/quarter)

Several questions were posed at WKPICS for future development of the programme. Firstly, how can the sampling frames be made more robust whilst ensuring efficient sampling of the different fisheries? What is the best method to give different vessels different weights in the selection process (trips, days at sea, landings)? How to treat vessels with very low activity?

Although Sweden has defined multiple sampling frames, this sampling scheme appears to be equivalent to a single vessel list frame where the vessels are stratified by predominant fishery. This would allow variable sampling rates per stratum (vessel contacts) to ensure that the estimates for domains of interest (estimates by fishery) are based on a sufficient number of trips to meet precision targets, taking into account any differences in refusal rates between fisheries.

3.1.3 Case study 3: The Norwegian reference Fleet

In 2009, Norwegian vessels landed 2.5 million metric tonnes for a value of NOK 11.3 billion (~2 billion USD). Norway is not part of the EU and therefore does not have to follow the EU DCF. Due to the economic importance of the marine fisheries, the vessel quota system, and the discard ban, Norway spends significant effort on surveillance of the fishery by the Coast Guard and the Directorate of Fisheries, with authorized landing sites and a trip ticket system for all commercial vessels, and VMS and mandatory electronic logbooks for all vessels with length greater or equal to 15 meters. Norway and Russia share the stocks of cod, haddock and capelin in the Barents Sea. Close cooperation between the two countries ensures a rational joint management of these fishery resources. The Fisheries Monitoring Centre (FMC) at the Directorate of Fisheries in Bergen makes sure that position reports and electronic catch and activity reports are received on a regular basis.

Sampling of commercial catches at sea in Norway is conducted by inspectors from the Directorate of Fisheries on board selected vessels and trips, by the Coast Guard, and through the Reference Fleet managed by the Institute of Marine Research (IMR). The IMR also obtains samples from pelagic fisheries through self sampling by the fishers onboard pelagic vessels in accordance with requests from IMR. The IMR also samples commercial catches at landing ports north of 62° N. The use of a comprehensive observer programs for catch sampling of vessels operating in the high seas is not considered practical for Norway because of the intricate coastline, large number of landings sites, and the length of trips. Also, experience from Observer Programs run by NOAA in the US suggests that it would be very difficult to recruit and maintain sufficient staff over time to operate a large observer program in Norway.

A high-seas Reference Fleet was established as an alternative to an Observer Program in 2000 with 17 vessels, and was expanded to 20 vessels in 2012. The breakdown of the Reference Fleet by predominant gear is given in Table 2. In autumn 2005 a similar coastal Reference Fleet was established along the entire Norwegian Coast from Varanger to Oslofjord. This fleet is composed of 20 vessels (mainly gillnetters, 9–15 m long). A public announcement every fourth year opens up bidding for the replacement of the fleet and motivates fishermen involvement. The vessels are selected through a tender process where selection is based on gear type, fishing activity and geography. The objective is to have a Reference Fleet that is representative of the Norwegian fishing fleet. The reference fleet is financed through the quota system.

The sampling "design" represents multi-stage sampling of fish:

(1) The sampling frame comprises the list of vessels in the Reference Fleet. The selection of the fleet is conducted through a tender process with the aim to approximate stratified random sampling. When multiple vessels satisfy all criteria asked for in the tender process, the selection of vessels is based on a random draw. The PSUs are the individual vessels, and individual trips are the secondary sampling units (SSUs).

(2) The vessel PSUs for the coastal Reference Fleet are stratified by nine statistical areas of home ports, predominant gear type, fishing pattern etc. For the high-seas Reference Fleet, vessels are stratified into demersal and pelagic vessels. The demersal RF is also stratified by gear and fishing pattern (e.g. North Sea versus Barents Sea)

(3) Selection procedure for SSUs is by sampling or census of trips for each vessel.

(4) Selection of tertiary sampling units (fishing operations within trips) is by systematic random selection.

(5) Sampling of lower level units involves subsampling of the catches of individual fishing operations, and random sampling of fish to measure or age by trained fishermen (see Allen et al., 2002).

For the coastal Reference Fleet, gillnets are prioritized because the sample size of 18 boats (2 per statistical area) precludes deeper stratification . It is planned to expand the fleet with one vessel of "other gears" in each statistical area.

The relatively small number of vessels in the high-seas Reference Fleet (Table 2) limits the number of factors that can be controlled for, because at least two vessels are required in each stratum.

Crew members onboard the RF vessels are trained to conduct self-sampling following IMR's protocols and are required to record their catch logbooks electronically. On trawlers, Danish seiners and purse seiners they are required to make a complete record (including discards) of each catch. The crew of longliners and gillnetters provide such data for one representative fishing operation per day and in addition record the the total catch per day. The crew on coastal Reference Fleet vessels make a complete record of the entire catch each day.

Biological sampling includes length, otoliths, genetic samples, stomachs, contaminants, tagging etc. The data are recorded electronically and transmitted to the IMR via a satellite link together with the electronic logbooks. This information is continuously added to the IMR's research database. There is also a direct e-mail connection between each vessel and the IMR.

A recent review of the Reference Fleet programme highlighted several concerns:

- Too few vessels may be involved to cover all the métiers in all areas and seasons necessary for stock assessments.
- Vessel catch estimates may not accurately reflect discards and catch of non commercial species.
- Vessel involvement is voluntary, and the vessels selection may therefore introduce bias (some tendency higher landings than the general fleet in some categories).
- Training, quality assurance and quality control which are essential for accurate data reporting is limited due to logistics and budgetary limitations.

Table 2. Numbers of vessels in the high seas Reference Fleet, by predominant gear type.

GEARTYPE	NUMBER OF VESSELS
Factory trawler	2
Fresh fish/freeze trawler	2
Gillnet	3
Longline	3
Combined longline/gillnet	2
Combined danish seine/purse seine	2
Purse seine	2
Pelagic trawl (comb. with purse seine)	2
Industrial trawl	2
Sum	20

Evaluating representativeness

The representativeness of the reference fleet is evaluated by comparing data from the reference fleet with other data sources. In selected statistical areas the species composition of catches, and size and age-composition for selected species (e.g., cod, haddock) obtained from the reference fleet are compared with data from other catch sampling programs. In general, the different sampling platforms provide comparable estimates of catch characteristics, as shown by a comparison of trip-ticket data from the reference fleet and the general fleet (Figure 8).

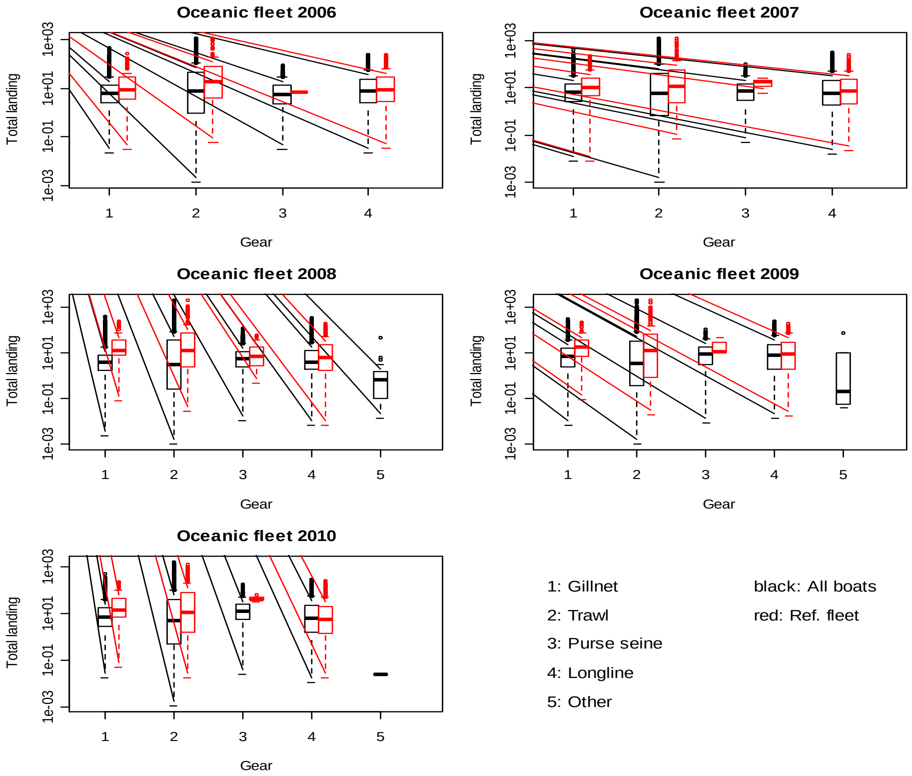


Figure 8. Landings per gear for the high seas (oceanic) Reference Fleet compared with the whole fleet (boxes show 25 percentile, median, and 75 percentile for landings per sales note). Black plots show data from all oceanic boats above 15 m length, while red plots show data from the Reference Fleet.

3.2 On-shore sampling of large-scale fisheries

3.2.1 Case study 4: Port Sampling in England (UK) (Jon Elson)

The port sampling programme was for many years conducted by fishery inspectors working to targets of numbers of fish to measure and age by area, fishery and time period. The programme is now being run by Cefas and has been totally revised to follow sampling survey design recommendations in WKMERGE (ICES 2009).

There are 2445 vessels using 182 landing sites in England. Eleven of the sites are major ports with regular auctions. Sampling staff are dispersed at several locations around the coast to reduce travelling time. The landing sites are a mixture of major ports interspersed with many small sites, including beach haul-out sites, often used by the large fleet of under-10 m vessels. Some types of fishery (e.g. pelagic vessels; beam trawlers) are based on a small selection of major ports whereas the general demersal fleet using otter trawls, nets and lines are widely dispersed. Crustacean (crab, lobster) fisheries are widely dispersed, and some ports are predominantly shellfish ports. Some fisheries are strongly seasonal. There is a complete vessel registry and census data for landings, effort, gear, fishing ground etc. as required by EU logbooks, and sales slips for other vessels not subject to EU logbooks.

The new survey design has the following features:

- PSUs are port-day, with neighbouring minor ports grouped.
- Separate area-list frames are set up covering pelagic fishery ports; beam trawl fishery ports; general demersal ports; and crab/lobster ports.

- PSUs in each frame are stratified by port size: Large; Medium; Small – based on previous years data on species landings; quarter and region. The regional boundaries are specified to best match ICES Divisions and stock boundaries.
- The sampling effort (number of port visits) is distributed across frames and strata using previous year's data, to try and achieve the required sampling effort for fleet metiers.
- The intention is to achieve probability-based sampling using random stratified PSU selection, but approximated using a systematic "bus route" approach. This approach has not yet been fully implemented whilst improved knowledge of sampling needs for minor ports is gathered.
- During port visits, lower level sampling units are selected as: random selection of vessels from the market sales list; random selection of boxes from commercial size categories; all or random selection of fish from boxes. Age material is only taken from a complete length sample. Sampling is a mixture of concurrent and stock-based.
- The number of samples collected by area, quarter, gear, species, is continually monitored against expectations.

The main issues that have arisen are:

- Trips can cut across fishing grounds. A trip is typically assigned to area of primary catch.
- Different gears may be used in the same trip – the landed catch cannot be allocated by gear.
- The entire landing of a species may not be available in one place: they can be split and available at different sites, parts of catch may be retained on board. If it is not possible to source all the catch components, the length data are unusable.
- Some vessels offload directly into lorries and are not accessible (bilateral agreements with other countries are in place for sampling catches transferred from "flag boat" landings in England to ports overseas).
- Some species landings may only be accessible at processors.
- Catches that could be intercepted whilst being landed at some minor ports may actually end up at auctions in major ports – these minor ports therefore may not need to be sampled directly.
- Access to some areas may be closed to samplers.
- In some cases, several vessels may combine their landings prior to sale.
- The time available to sample fish is highly variable.

Current areas for development include reviewing the merging of ports for sampling; identification of minor ports that could be excluded from the frames; greater industry involvement to facilitate sampling; greater intelligence gathering on landing practices around the coast; consideration of the balance between concurrent and stock based sampling.

3.2.2 Case study 5: Demersal Market Sampling in Scotland (UK) (Alastair Pout)

The Scottish demersal catch sampling scheme aims to support ICES stock assessments, the DCF data collection framework, and the Scottish government's data requirements (*discard estimates, cod management plans, real time closures, catch quota schemes, etc)*. The ICES stock assessments are conducted through WGNSSK, WGCSE, WKMIXFISH, and WKHMM for the main commercial species landed in Scotland: cod, haddock, whiting, saithe, monkfish, megrim and hake. The catch sampling scheme for demersal species consists of the demersal market sampling programme and a complementary at-sea observer programme for vessels fishing for demersal fish and *Nephrops* which also provides discard estimates for the above stocks. The market sampling scheme provides estimates of numbers at age by quarter for ICES areas IV, VIa, VIb, or the combined Northern Shelf area according to stock definitions. Additional domains of interest are for various grouped metiers. The features of the onshore sampling scheme are as follows:

- The planning of the market sampling survey is based on the previous year's census data on demersal landings, vessel characteristics, gear, etc. for all ports. Analysis of 2010 log-book/sales notes data from 75,144 trips made by 1,937 vessels showed that 213 vessels and 7,279 trips accounted for 95% of the total annual landings of cod, haddock, whiting, saithe, megrim, monkfish, hake into Scottish ports.
- Based on the census data, six ports out of 25 with demersal landings are identified for inclusion in an area-list sampling frame. The decision of ports to include has been made on practical and budgetary considerations. One of the six ports is excluded as there is no regular market, no facilities for sampling fish and most landings are collected directly by lorries and transported by road. The remaining five ports where sampling was feasible accounted for 76% of trips and 78% of annual demersal landings (in weight) into Scotland in 2010. The sampling frame is thus a matrix of 5 ports × days of the year. The frame suffers from under-coverage due to exclusion of remote, minor ports and the major port that presented sampling difficulties, but allocation of resources to five major ports accounting for almost 80% of landings is considered an appropriate trade-off between under-coverage bias and improved precision by concentrating efforts on major ports rather than wasting resources travelling to minor, very remote ports.
- The 5 ports are grouped into four geographic strata with different sampling rates: Peterhead (1 port – 80 visits); Fraserburgh (1 port – 40 visits), Shetland (2 ports – 36 visits between them), West Coast (1 port – 40 visits).
- A "lattice" sampling design is adopted for the mainland strata (Peterhead, Fraserburgh West Coast), with each stratum being sampled at least once within a standard sampling week.
- The selection of sampling day within a week is dictated by days of the week when there are markets, taking into account the time of market and other practical considerations. In particular, to avoid a fruitless 300 mile round trip, the West Coast stratum is sampled on either the Monday or the Thursday when the main weekly markets occur. The Shetland stratum is covered by a dedicated team based in the Shetland Islands sampling in 36 weeks of the year.

- Within a site-day visit, the sampling is conducted by a team leader and a clerk. The vessels are randomly selected based on alphabetized list of all vessels that are landing on the day. This ensures that trips within metiers will get sampled in proportion to effort by metier in each stratum. Five refusals were documented out of 388 sampled vessels in 2011. Selection of fish species to sample during a port visit is largely left to the discretion of the sampling team leader, with emphasis placed on the main commercial species. Biological sampling includes length-stratified sampling for age.
- During analysis, raising is first by trip, (with the age length key applied at the trip level to generate numbers at age estimates for the trip), and then to the stratum before strata are pooled to obtain estimates for the total catch. Precision of estimates overall and by domains of interest is based on non-parametric bootstrap.

3.2.3 Case Study 6: Port sampling in Iceland (Gudmundur Thordarson)

Iceland is not part of the EU, and has total control of its fisheries, which are a cornerstone of the economy. Due to the ITQ system there is a lot of effort in surveilance of the fishery, with authorized landing sites, VMS and mandatory logbooks. Monitoring and sampling of commercial catches is conducted by inspectors either onboard vessels or located in landing ports. The Marine Research Institute conducts biological sampling of commercial catches for stock assessment from Reykjavik and five branches located around the coast.

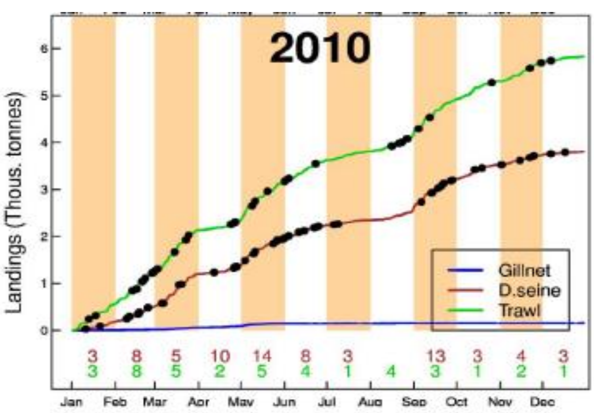
The sampling scheme differs substantially from the Case Studies for other countries in using a scheme that triggers visits to ports according to real-time data on cumulative landings by species and gear as the year progresses. Numbers of samples to be taken per tonne landed are identified by in advance by species and gear. Real time monitoring of catch tonnage then triggers a sampling trip at specified tonnage intervals which vary by fishery and stock. The intention of this scheme is to ensure that the sampling rate is proportional to landings and represents the most efficient use of staff time, so is a pragmatic equivalent to pps sampling though not based on any randomisation of PSUs. The procedure is as follows:

- Landings are monitored in real-time by the sampling software ‘SYNO’ (Connected to the Dept. of Fisheries landings monitoring database)
- SYNO notifies the sampling teams that they should go out and collect a sample.
- Samples are bought from boats/markets at market price and then re-sold, usually at a loss to MRI.
- All measurements are logged into a computer during sampling and sent via the internet to MRI in Reykjavik. Automated systems are also used for sorting species catches at processing plants and on vessels, which record fish weights and log them directly over the internet to the Oracle data base at MRI.

An example for plaice sampling in 2012 is given in Table 3. In general, sampling for most stocks is ‘good’ although the procedures are less clear for smaller stocks, and there are often differences between targets and collection as shown for plaice.

Table 3. Sampling of plaice in Iceland from commercial catches. Tonnage interval is the trigger for sample collection. (The temporal pattern of sample collection is shown in the plot below, where dots are the sampling events.)

GEAR	TONNAGE INTERVAL	CATCHES (TONNES)	SAMPLES GOAL	SAMPLES COLLECTED	PROPORTION
Gillnet	14	93	6	0	0
Danish Seine	33	3647	110	74	0.67
Trawl	18	2021	112	39	0.35



3.3 Sampling small-scale fisheries.

Small-scale fisheries will typically include a large number of small vessels that operates from dispersed landing sites. In general, at-sea sampling by observers is often precluded by the small size of the vessels, requiring on-shore catch sampling, self sampling, and/or interviews for gathering information about catch, catch composition, and effort. Often, neither a complete vessels registry nor a complete list of access points where vessels can be intercepted exists, requiring a separate survey to collect this information.

3.3.1 Case study 7: Small-scale fishery sampling programme in Malta (Francesca Gravino and Eric Muscat)

The fisheries around Malta include small-scale and large-scale fisheries sampled at ports, at sea by observers, by purchase of samples, or by self-reporting schemes. The methods adopted depend on the characteristics of the fisheries and landing practices. The objectives of the sampling schemes are largely focused on the needs of the EU Data Collection Framework, taking into account available resources. For vessels which complete EU logbooks, census data are available at the end of the year to allow the development of raising procedures according to sampling design. However, for the small-scale fleet, such data are not available and a separate survey is needed, which is described below.

Effort and catch survey for small-scale fleet

The small-scale fishery around Malta includes a large fleet of 956 under-10m (LOA) vessels. These comprise 86% of the total fleet, and land around a third of the total catch into Malta (December 2010 data). It operates in coastal regions and as is typical for Mediterranean artisanal fisheries, it has a mixture of full-time and part-time fishers, targets many species and is polyvalent in terms of gear use and switching of gears. Unlike the large-scale fleet, the small-scale fishery does not have exhaustive logbook data, and hence a multivariate Catch Assessment Sampling Survey (CAS) has been devised to collect the necessary data on landings, effort and discards, using questionnaires. The features of the survey are described below:

- The sampling frame is a vessel list frame, in which the PSUs are all vessels less than 10m LOA registered in the Maltese Fishing Fleet Register comprising both active and inactive vessels (EC93/2010)
- Stratification is by quarter, by vessel length (0 – 5.99m and 6.00 – 9.99m) and by Economic segmentation as specified by Appendix III of EC 93/2010. Non active vessels are assigned to a fleet segment based on the list of registered gears specific to every vessel
- The sampling intensity and period of year for sampling is specified for each fleet segment according to the number of vessels, as follows:

SEGMENT	SAMPLE NUMBER	SAMPLING INTENSITY
<5 vessels	Census	All year round
5 – 50	Census	All divided per quarter
51 – 200 vessels	20%	Divided per quarter
> 200	50	Divided per quarter

- For specific gears (under Management plans, very few licences, etc), all vessels having such gears registered are sampled all year round using a census approach
- Individual vessels from segments with up to 50 vessels are selected by census. Stratified random sampling is adopted for segments with >50 vessels. The secondary sampling units are months within vessels, as a monthly questionnaire is used. In practice, for segments with <5 vessels all months are sampled by census; for other segments, skippers complete the questionnaires for all months in selected quarter/s. For segment between 5 and 50 vessels all vessels are sampled by census divided equally and randomly per quarter. For segments between 51 and 200 vessels, 20% of these vessels are randomly selected and sampled divided per quarter. For segments >200 vessels, the same procedure is applied, but 50 vessels are chosen.
- At the beginning of each month the selected vessel owners are given two data sheets, one for catch & discards, and one for effort (gears used; deployment etc.), that they have to fill every week of the month. The surveyors then carry out interviews with selected vessel owners every week either in the port of landing or at home.
- Analysis is straightforward as the PSUs of the frame (vessels) and the SSUs (months selected for sampling) are known and hence the sampling probabilities and raising factors are controlled.

On-board sampling for biological data

On-board sampling is carried out for metiers where discarding takes place and where vessels are able to carry observers. It is also needed when not all the catch is landed for various reasons (sales at sea, own consumption, etc), when the vessel has a tendency to switch gears during same trip (and all catches are then combined together, when a lot of fish (in terms of quantity and value) are caught per trip and the cost is too high to buy a catch and sample in the laboratory OR the large quantities caught make it impractical to sample at the port. An example of a fishery sampled by on-board sampling is the Bottom otter trawl fishery. Sampling design for on-board sampling is as follows:

- Sampling frame is a vessel list. Separate list frames are established for vessels according to registered gear types. PSUs are considered to be trips.
- Vessel owners are chosen at random (from list of vessels that have that gear registered) and contacted to inform them about onboard observations.

Experience has shown that randomness is compromised by avoidance of long trips; reluctance of some vessel owners to take observers onboard; exclusion of vessels that have trips > 1 day but no additional sleeping accommodation for an observer, and exclusion of vessels that do not land in Maltese ports

Port sampling for biological data

Port sampling is adopted for fisheries for which discards need not to be sampled, the vessels are too small to accommodate an observer, vessel owners are reluctant to take observers onboard, or the fishery is not multi-specific (and thus a representative sample per species can be measured at port). An example is the drifting longline fishery targeting large pelagic fish. In some cases, fish samples have to be purchased at the only market (Valletta), for example when catches are overall small (in terms of quantity and value), the fish are highly priced and fishers do not like the idea of having people touching the fish; when fish need to be dissected to collect biological data (otoliths, sex, maturity). The port sampling design is as follows:

- The sampling frame is an area list frame with PSUs = ports x days
- PSUs are selected at random. 2 fishing trips per month for vessels using major metiers identified through the ranking system, targeting species in groups 1, 2 & 3, as specified in Appendix VII of the multiannual Community programme 2011-2013, who cannot be sampled through onboard or market sampling due to the reasons provided above, are randomly sampled at port. Fishermen using the named gears are requested to call 2 hours prior to their arrival at port. The first two calls in the month are then sampled at port.
- At Valletta market (the only fishmarket in Malta), field samplers are present every day and purchase whole catches (or representative samples of whole catches with info on total catch) for biological sampling.

Practical problems encountered include non-response (not all vessel owners call the observers); difficulties in randomised selection from the very large number of small ports that are present in Malta (> 40) with different times of day for unloading fish according to gear, etc., and vessels that do not land all their catches are not sampled as the sample will be biased. A difficulty encountered at Valletta is that some fishers do not land their fish at the market but sell it through direct sales, and thus these are accessible for sampling.

3.3.2 Case study 8: Sampling program for an artisanal fleet (Basque country) (Estanis Mugerza)

The small-scale artisanal fishery in the Basque country is poorly defined and not highlighted for sampling according to the DCF ranking system for fleet metiers. The fleet has increased in the importance, and a survey of the fleet has been needed to improved knowledge of its activities and catches.

As typical for many small scale fisheries, the fleet is polyvalent in terms of gears and target species, has a variety of marketing systems, is seasonal and has high species diversity and variable names for the same species.

Artisanal fleet survey

A survey was conducted of all active skippers at Basque Country fishing ports, using questionnaires designed to compile required information on fishing practices, socio-economics, fish selling channels, equipment etc. Data from 2008-2010 was obtained, and the Fleet Census updated (official active vessels vs. real active vessels). The survey was conducted as described below:

- A logbook was given to each of the skippers of the artisanal fleet. This logbook had to be filled in daily if fishing activities exist. The required data were: catches, gear, effort, fishing location, prices, vessel technical characteristic (GT, Power, total length).

From this survey, nine metiers were identified at the level required by the DCF: four metiers for hook and lines; hand lines targeting finfish; trolling lines targeting large pelagic fishes; set longlines targeting demersal fishes; set longlines targeting deep water species; two metiers for pots and traps (molluscs; crustaceans); three metiers for nets (trammel nets targeting demersal fishes; set gillnet targeting demersal fishes with mesh size smaller than 99 mm; set gillnet targeting demersal fishes with mesh size bigger than 220mm.

It was found that half of the ports have good coverage of sales notes (approx. 95% of landings at those ports). At the rest of the ports, skippers are asked to keep daily logbooks, and the samplers remind skippers to fill in those logbooks by contacting them ever month. Problems with data include the use of different names for the same species in different ports/auctions; some species are landed in mixed groups: e.g. monkfish & black bellied anglerfish, rays, Sparids; difficulties with netters to assign them a metier at level 4 (merge between trammel nets and gillnets)

A problem encountered was definition of effort units. Days at sea was chosen - other units were not possible because number of nets, hooks were the legal ones not necessarily the real ones used.

Identification of a reference fleet is considered to check possible misreporting

Sampling of length compositions

Sampling for length is stratified by gear, area and quarter.

Ports were divided in two categories: 1) Main ports were identified taking into account the number of vessels and landings. These ports cover 90% of the fleet. Samplers made the highest effort in these ports. 2) Secondary ports are the rest of the Basque Country ports were the number of vessels and landings is not relevant. Sampling effort for these ports is once a week.

For vessels, the sampler contact the skippers by mobile phone asking randomly when they arrived and asking permission for sampling, Vessels with positive answer were sampled.

Discards sampling

Taking into account prior studies, only netters (gillnets and trammel nets) are sampled for discards. The procedure is as follows:

- Nine vessels selected (one per selected port)
- A self sampling scheme is used (crew members separate the discards -staff from AZTI then take the discards and trip information at the landing port and analyse them in the lab)

Future work

Based on experiences gained, a goal is to implement a sampling framework of artisanal fisheries that provides good catches and effort estimates that are unbiased and sufficiently precise to be used in stock assessment and fisheries management.

A pilot study on Vessel Monitoring System (GPS, AIS…) is considered for vessels under 15 m total length

4 Glossary[2]

FLEET: A physical group of vessels sharing similar characteristics in terms of technical features and/or major activity.

FISHERY: A group of vessel voyages targeting the same (assemblage of) species and/or stocks, using similar gear, during the same period of the year and within the same area.

FLEET SEGMENT: a group of vessels with the same length class (LOA) and predominant fishing gear during the year, e.g. according to the Appendix III of the EU-DCF. Vessels may have different fishing activities during the reference period, but are classified in only one fleet segment.

MÉTIER: A group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern. The catches for such a sub-population of fishing operations in a fishery (domain) cannot generally be sampled with known probability since a list of PSUs is not available in advance. Estimates of catch characteristic for a métier (domain) are therefore often based on stratification after selection of PSUs (post-stratification.) EU Commission Decision 2008/949/EC (DCF) provides detailed requirements for Member States to collect economic data by fleet segment, and biological data by fleet metier.

MULTI-STAGE SAMPLING: When conducting probability-based multi-stage sampling, a series of consecutive random selections is performed, and groups of the ultimate units being studied (for example specimens of fish) are united to form higher sampling units. An example of multi-stage sampling would be selection of vessels (PSUs), trips, and fishing operations which are ultimately sub-sampled to collect specimens of fish for age-determination.

PRIMARY SAMPLING UNIT (PSU): A sampling unit that is selected in the first stage in multi-stage sampling is called a primary sampling unit.

SAMPLE DESIGN: The totality of instructions, protocols, and rules that govern a sampling method.

SAMPLING FRAME: In statistics, a sampling frame is the list of sampling units or device from which a sample is drawn. The sampling frame comprises all the primary sampling units and any stratification of these, and may be based on a vessel registry or list of ports.

STRATIFICATION: The advance decomposition of a **finite population** of sampling units of size N into k non-overlapping subpopulations (strata) of size N_i.

STRATIFICATION AFTER SELECTION: If a simple random sample is taken from a **finite population** of sampling units of size N the sample may be treated as a stratified sample during the analysis if the post-strata sizes N_i are know. Stratification after selection (post-stratification) is usually applied if the strata to which the selected sampling units belong are only known after the sample is taken. This is often the case

[2] Many of the statistical terms are based on Elsevier's Dictionary of Biometry

for métiers. Standard stratified estimators cannot generally be applied when métiers cuts across strata.

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Annex 1: list of participants

Name	Address	Phone/Fax	Email
Sondre Aanes	Institute of Marine Research P.O. Box 1870 Nordnes 5817 Bergen Norway	Phone +47 55238627 Fax +47 55238687	sondre.aanes@imr.no
Mike Armstrong Chair	Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk United Kingdom	Phone +44 1502 524362 Fax +44 1502 524511	mike.armstrong@cefas.co.uk
Ulrich Berth	Johann Heinrich von Thünen-Institute, Institute for Baltic Sea Fisheries Alter Hafen Süd 2 18069 Rostock Germany	Phone +49 381 811 6128 Fax +49 381 811 6199	ulrich.berth@vti.bund.de
Sofia Carlshamre	Swedish University of Agricultural Sciences Institute of Marine Research P.O. Box 4 SE-453 21 Lysekil Sweden	Phone +46 52318772	sofia.carlshamre@slu.se
Gjert Endre Dingsør	Institute of Marine Research P.O. Box 1870 Nordnes 5817 Bergen Norway		Gjert.endre.dingsoer@imr.no
Jon Elson	Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Lowestoft Laboratory Pakefield Road NR33 0HT Lowestoft Suffolk United Kingdom	Phone +44 1 502 524 243 Fax +44 1 502 524511	jon.elson@cefas.co.uk
Francesca Gravino	Malta Centre for Fisheries Sciences Fort San Lucjan BBG 06 Marsaxlokk Malta	Phone +356 22293326	francesca.gravino@gov.mt
Beatriz Guijarro	Instituto Español de Oceanografía Centro Oceanográfico de Baleares P.O. Box 291 E-07015 Palma de Mallorca Spain		beatriz.guijarro@ba.ieo.es
Alexander Kempf	Johann Heinrich von Thünen-Institute, Institute for Sea Fisheries	Phone +49 40 38905 194	alexander.kempf@vti.bund.de

	Palmaille 9 22767 Hamburg Germany		
Kirsten Birch Håkansson	DTU Aqua - National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 2920 Charlottenlund Denmark		kih@aqua.dtu.dk
Uwe Krumme	Johann Heinrich von Thünen-Institute, Institute for Baltic Sea Fisheries Alter Hafen Süd 2 18069 Rostock Germany		uwe.krumme@vti.bund.de
Alan Lowther	National Oceanic and Atmospheric Administration Fisheries Statistics Division Silver Spring MD United States		alan.lowther@noaa.gov
Estanis Mugerza	AZTI-Tecnalia AZTI Sukarrieta Txatxarramendi ugartea z/g E-48395 Sukarrieta (Bizkaia) Spain	Phone +34 94 6029446	emugerza@azti.es
Eric Muscat	Malta Centre for Fisheries Sciences Fort San Lucjan BBG 06 Marsaxlokk Malta		eric.muscat@gov.mt
Sofie Nimmegeers	Institute for Agricultural and Fisheries Research (ILVO) Ankerstraat 1 8400 Oostende Belgium	Phone +32 59569806 Fax +32 59330629	sofie.nimmegeers@ilvo.vlaanderen.be
Tapani Pakarinen	Finnish Game and Fisheries Research Institute P.O.Box 2 00791 Helsinki Finland	Phone 358205751224 Fax 358205751202	tapani.pakarinen@rktl.fi
Kay Panten	Johann Heinrich von Thünen-Institute, Institute for Sea Fisheries Palmaille 9 22767 Hamburg Germany	Phone +49 4038 905 108 Fax +49 4038 905 263	kay.panten@vti.bund.de
Michael Pennington	Institute of Marine Research P.O. Box 1870 Nordnes 5817 Bergen Norway	Phone +47 55238601	michael.pennington@imr.no
Alastair Pout	Marine Scotland Science Victoria Quay	Phone +44 1224 876544	A.Pout@marlab.ac.uk

	1st floor EH6 6QQ Edinburgh United Kingdom	Fax +44 1224 295533	
Katja Ringdahl	Swedish University of Agricultural Sciences Institute of Marine Research P.O. Box 4 453 21 Lysekil Sweden	Phone (+46) 523-18 753	katja.ringdahl@slu.se
Jose Rodriguez	Instituto Español de Oceanografía Centro Oceanográfico de Santander P.O. Box 240 39004 Santander Cantabria Spain		jose.rodriguez@st.ieo.es
Jon Ruiz Gondra	AZTI-Tecnalia AZTI Sukarrieta Txatxarramendi ugartea z/g E-48395 Sukarrieta (Bizkaia) Spain	Phone +34 9460 29400 Fax +34 9468 70006	jruiz@azti.es
Juan Santos	Instituto Español de Oceanografía Centro Oceanográfico de Vigo P.O. Box 1552 36200 Vigo (Pontevedra) Spain		juan.santos@vi.ieo.es
Marie Storr-Paulsen	DTU Aqua - National Institute of Aquatic Resources Section for Fisheries Advice Charlottenlund Slot Jægersborg Alle 1 2920 Charlottenlund Denmark	Phone +45 3388 3442 Fax +45 3396 3333	msp@aqua.dtu.dk
Gudmundur Thordarson	Marine Research Institute PO Box 1390 121 Reykjavík Iceland	Phone +354 5752000 Fax +354 5752001	gudthor@hafro.is
Sofie Vandemaele	Institute for Agricultural and Fisheries Research Unit Animal Sciences - Fisheries Ankerstraat 1, B-8400 Oostende, Belgium	Tel. + 32 59 56 98 06 (office) / + 32 59 34 22 50 (operator) Fax. + 32 59 33 06 29	Sofie.vandemaele@ilvo.vlaanderen.be
Joël Vigneau	IFREMER Port-en-Bessin Station P.O. Box 32 F-14520 Port-en-Bessin France	Phone +33 231 515 600 Fax +33 231 515 601	joel.vigneau@ifremer.fr
Jon Helge Vølstad Chair	Institute of Marine Research P.O. Box 1870 Nordnes 5817 Bergen , Norway	Phone +47 55238411 Fax +47 55235393	jon.helge.voelstad@imr.no

Annex 2: Agenda

Workshop on practical implementation of statistical sound catch sampling programmes. Bilbao, Spain, 8-10 November 2011

Tuesday November 8

8:30-8:45 Welcome and Logistics - Estanis Mugerza

8:45-9:00 Workshop Objectives – Mike Armstrong

9:00-9:45 Statistical principles of survey sampling applied to catch sampling programs – (Defining sampling frames, defining sampling units, multi-stage sample selection, stratification vs. domains, estimation principles for clustered data) Jon Helge Vølstad

9:45-10:00 Coffee Break

Objective for 10:00 – 15:00: Selection of case studies to highlight different types of catch sampling programmes and their problems

Sampling catches from fishing vessels at sea

10:00-10:30 Marie Storr-Paulsen: Observer sampling programs – case study from Denmark

10:30-11:00 Katja Ringdahl: Observer sampling – case study from Sweden

11:00-11:30 Jon Helge Vølstad: Self-sampling - The Norwegian Reference fleet

Port sampling/market sampling

11:30-12:00 Jon Elson: Port sampling in England:

Lunch 12:00–13:30

13:30-15:00 Case study presentations (continued)

13:30-14:00 Alastair Pout: Port sampling in Scotland

14:00-14:30 Francesca Gravina: Mediterranean fisheries sampling: Case study from Malta.

Sampling small-scale fisheries

14:30-15:00 Estanis Mugerza: market sampling in Spain

Objective for rest of day: develop a scheme to categorise catch sampling programmes in relation to sampling design

15:00-15:15 Outline of process and desired outcomes for rest of meeting (Mike Armstrong)

15:15-17:00 Group discussion (Conveners: Jon Helge Vølstad and Mike Armstrong)

The group discussion will focus on the grouping of catch-sampling programs by objectives and design principles into general categories that will be the focus of the workshop.

Criteria will follow the general structure of the national questionnaires completed by WKPICS members

- Objectives of the catch data collections
- Target fishery/stock/fleet and fleet activities relevant to sampling
- At-sea sampling versus sampling of landed catches
- Type of sampling frame
  - List-based (e.g., list of ports, vessels)
  - Area-frame (e.g., counties, geographic units, sections of a beach etc.)
- Primary sampling units, PSUs (e.g., vessels, trips, ports or other access points)
  - Define reasonable approximations based on case-studies
- Stratification (grouping of PSUs in the planning of the surveys – not afterwards)
- Methods of sample selection (in detail), taking into account available resources
- Domains (e.g., catches taken by a particular gear, in a given statistical area and quarter – precision requirements?)

Wednesday November 9

Objective for morning: Look at additional case studies; continue to develop scheme for categorising catch sampling programmes, identifying main issues and limitations affecting practical implementation of sampling surveys.

8:30 – 9:00 Joël Vigneau: fishery sampling in France.

9:00 - 10:00. Group discussion (Conveners: Jon Helge Vølstad and Mike Armstrong)

10:00-10:15 Coffee Break

10:15-12:00 Group discussion: develop schema for classifying catch-sampling programs by category

Lunch 12:00–14:00

Afternoon objective: Develop guidelines (best-practices) for designing catch sampling programs by category

14:00-14:30 Defining objectives for break out groups (Conveners: Jon Helge Vølstad and Mike Armstrong)

Based on questionnaires, case studies and workshop outcomes so far, each break-out group will be tasked to:

- Develop guidelines on sampling design options for the different categories of catch sampling programmes, taking into account logistical difficulties identified;
- Identify how stratification can be used to achieve desired sample sizes in domains (e.g., métiers)
- Identify appropriate criteria and methods to develop diagnostics of bias issues e.g., bias related to:
    - Completeness of sampling frame
    - Procedures for sample selection, or assumptions
    - Non-response
    - Estimation procedures
    - Provide input to bias score-card (WKACCU)

14:30-17:00 Break-out groups by sampling program category (e.g., At-sea sampling, on-shore-sampling/small-scale)

Thursday, November 10

Morning objective: Summarize outcomes of group discussions, and develop recommendations

8:30-10:00 Reporting from break-out groups (by catch sampling program category)

10:00-10:15 Coffee Break

10:15-12:00 Plenary discussion to develop consensus recommendation on best-practices by category.

Lunch 1200:13:00

13:00-17:00

Outline and work on the WKPICS1 Report

Annex 3: WKPICS2: Terms of Reference for the next meeting

[As revised at PGCCDBS 2012]

WKPICS2; Second Workshop on practical implementation of statistical sound catch sampling programmes.

2011/2/ACOM53. The **Second Workshop on practical implementation of statistical sound catch sampling programmes** (WKPICS2), chaired by Jon Helge Vølstad, Norway, and Mike Armstrong, UK, will meet in ICES HQ, Copenhagen, in 6–9 November 2012, to:

a) On the basis of case studies, examine how national catch sampling programs can be designed and coordinated between countries to meet DCF or other objectives at a regional scale in the most cost-effective way. Develop operational quality assurance indicators for evaluating sampling surveys that can be incorporated in and enhance the WKACCU bias scorecard.

b) Develop guidelines for design-based and model-based data raising and precision estimation, taking account of multi-stage survey design and cluster sampling effects and the need to combine estimates over different sampling programmes within and between countries at a regional or stock level. Consider how national and regional sampling databases could be designed to raise data following best practice.

c) Develop and define quality indicators and levels for onshore and offshore sampling schemes and advise on revisions to the WKACCU score cards to accommodate them.

WKPICS2 will report by 7 December 2012 for the attention of PGCCDBS, RCMs, STECF/SGRN, and ACOM.

List of presentations and working documents

All presentations, Working Documents and national sampling scheme summaries are archived on the WKPICS SharePoint site.