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Workshop on methods for merging metiers for fishery based sampling (WKMERGE)

19–22 January 2010

Copenhagen, Denmark

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CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

WKMERGE was established to assist EU Member States to evaluate the appropriateness of their national sampling schemes for collecting metier-based biological data as required under the EU Data Collection Framework (DCF). The DCF specifies collection of data on discards and length/age composition of catches by fleet metier at the level of gear, target assemblage, mesh band and selectivity devices (DCF Level 6) in defined fishing grounds, with precision estimates at the stock level. Following from recommendations in ICES WKPRECISE (ICES CM 2009/ACOM:40), the Version 2009 of the DCF Guidelines for the submission of National Programme Proposals recognises that highly resolved and temporally dynamic metier definitions are an inefficient basis for stratification schemes. This can lead to over-stratification and problems of under-sampling or non-sampling of strata, and poor control over sampling probabilities. Rather, Member States should specify sampling frames and sample selection schemes with temporally stable strata that are capable of providing sufficient data for the required metiers and fishing grounds. The metiers are treated as domains of interest rather than strata, unless the metier is sufficiently stable over time to act as a stratum with controlled sampling probabilities. Provided the population of vessels or fishing trips in each stratum is sampled representatively at each stage in the sample selection process, estimates by metier may be obtained using post stratification or ratio estimators, provided the number of sampled trips within metiers is sufficient. In this case, the sampled trips within metiers are re-weighted based on information about the distribution of all trips in the population. Hence, the use of post-stratification requires information on all trips in the fishery to adjust the sample weights. When trips cover more than one metier, knowledge on the metier of all hauls of sets within trips would be required for the post-stratification by metier. When planning the sampling programme, the number of trips to sample per metier becomes an expectation based on previous years' fishing activities, not a target, and may alter if the fleets 'activities change over time.

An important role of WKMERGE was to provide training on the design of robust sampling schemes for at-sea and on-shore sampling of fishing vessels to provide data on metier based biological variables. The workshop covered all aspects of sampling design including defining objectives; identifying the population to be sampled and suitable frames for accessing primary sampling units; stratification schemes; sample selection schemes including equal and unequal probability methods, and associated estimation procedures. The use and data-needs of model-based estimators were discussed, including the pros and cons of "quota" sampling for model based and design based estimators. Examples of applying vessel list frames for at-sea sampling and area (access point) frames for on-shore sampling were covered in detail, and methods of combining data from both types of frames are included in the WKMERGE report. Workshop participants provided initial descriptions of their national sampling programmes using a supplied *pro-forma*, and then reviewed these based on the outcomes of the workshop. A slightly revised version of the *pro-forma*, with associated guidelines, is provided in the WKMERGE report to help Member States provide descriptions of their sampling schemes in their DCF National Programme submissions for 2011–2013. WKMERGE dealt primarily with the selection of vessels and fishing trips to sample for metier-related variables and did not address the selection of individual fish to sample for length or age from each trip. This is covered by ICES WKPRECISE.

Methods of optimising sampling schemes to meet multiple objectives were considered, using an example given in a Working Document by France. Statistical proce-

dures for identifying metiers as homogeneous groups of fishing operations (in terms of species and size compositions) were also discussed in the context of "merging of metiers", using an example of multivariate analysis of data from observer trips given in another Working Document by France. Methods for comparing length compositions of species catches as a basis for merging metiers were described in a Working Document from Finland. WKMERGE recommends further development and agreement on appropriate statistical methods e.g. multivariate methods for identifying homogeneous metiers that are stable over time, and are at a resolution relevant to fishery management and capable of being sampled adequately with feasible sampling resources.

A primary focus of WKMERGE was the design of sampling schemes that avoid problems of under-sampled and non-sampled strata or domains requiring imputation of missing data. When imputation is required, it should be done at the analysis stage using expert knowledge of the fisheries. Automated procedures for filling missing entries in databases with data "borrowed" from neighbouring samples or strata should be avoided. A major problem is non-accessibility of vessels for sampling at sea or on shore, as the vessels not available for sampling may have a different catch composition and size frequencies than the accessible vessels. Characteristics of the non-accessible vessels should be recorded to allow retrieval of any auxiliary variables shown to be correlated with discarding or size compositions in the sampled vessels (e.g. gear; mesh; area; trip duration etc.).

1 Introduction

1.1 Terms of reference

2009/2/ACOM40 The **Joint ICES-STECF Workshop on methods for merging fleet metiers for fishery based sampling [WKMERGE]** (Co-Chairs: Mike Armstrong*, UK, and Jon Helge Vølstad*, Norway) will be established and take place at ICES HQ, 19–22 January, to:

a) Review the definition and suitability of the sample frames used by each Member State for collecting data on metier-related biological variables required under the EU Data Collection Framework. The need for consistent approaches between Member States to meet overall objectives will be addressed.

b) Develop guidelines for determining the appropriateness for merging metiers or vessel LOA classes at the national and regional scale.

c) Review and develop probability-based sampling designs (appropriate for the frames defined in ToR a) that will provide the required metier-related biological data. This should be done using case studies that take into account the requirements for reporting bias and precision.

d) Develop guidelines for estimating biological and catch characteristics for collapsed (i.e. combined) metiers in cases of non- or poorly-sampled strata or metiers.

e) Develop guidelines for a consistent approach to documenting the statistical design of sampling schemes for metier-related biological variables in each Member State's National Programme.

WKMERGE will report by 5 February 2010 for attention of PGCCDBS, RCMs, STECF/SGRN; ACOM

SUPPORTING INFORMATION

Priority:	**Essential**
Scientific justification:	This Workshop is essential for the implementation of the EU Data Collection Framework (DCF; Council Regulation (EC) No 199/2008 and EC Decision 2008/949/EC), in particular for the second phase (2011-2013). The DCF requires Member States to collect concurrent length composition data for all or a predefined assemblage of species, simultaneously in the catches or landings of vessels, for nationally important fleet metiers identified using a ranking system according to landings, value or effort. Decision 2008/949/EC states that "*In order to optimise the sampling programmes, the metiers defined in Appendix IV (1 to 5) may be merged. When metiers are merged (vertical merging), statistical evidence shall be brought regarding the homogeneity of the combined metiers. Merging of neighbouring cells corresponding to fleet segments of the vessels (horizontal merging) shall be supported by statistical evidence. Such horizontal merging shall be done primarily by clustering neighbouring vessel LOA classes, independently of the dominant fishing techniques, when appropriate to distinguish different exploitation patterns. Regional agreement on mergers shall be sought at the relevant regional coordination meeting and endorsed by STECF*." The North sea and Eastern Atlantic regional coordination Meeting in 2008 noted that Member States had proposed their own mergers, based on implementation constraints (availability of fisheries statistics, reduction of strata size, etc.) or on a scientific *a priori* grouping (e.g. gear types OTB and PTB, OTM and PTM, etc.). The RCM NS&EA was of the opinion that this way of merging métiers is acceptable given the obligation to have a pragmatic start of the new sampling programmes.

Priority:	**Essential**
	However it was advised that the scientific evidence for métier mergers required by the new DCR needs to be evaluated once the first datasets are available, i.e. from 2010 onwards. It was recommended that the ICES PGCCDBS could be helpful in discussing the appropriate ways of carrying out these scientific analyses. The proposed joint ICES-STECF workshop is required to ensure that Member States are defining fleet metiers in a consistent manner and are adopting the most appropriate methods for identifying metiers to be merged. It is essential that metier definition and merging are done in such a way that the resulting merged metiers can be combined easily across Member States for analysis. The procedures adopted should lead to the optimum stratification of sampling for reducing bias and variance, and should draw on previous experience elsewhere in defining metiers. In addition to providing guidelines for merging of metiers prior to sampling, the Workshop will also provide advice on robust methods for collapsing poorly sampled strata prior to data analysis. To ensure an efficient and successful meeting, participants will be asked to prepare the following material for the meeting: 1. All Member States participants to provide a Working Document describing the basis for national metier definition and merging in 2009&2010; 2. Identified participants to prepare European case studies for examining applications of metier-merging methods. The PGCCDBS will liaise with RCMs to identify suitable case studies. The data for these case studies are to be available at the Workshop in the COST format. 3. Results of relevant metier-merging applications outside of Europe
Resource requirements:	
Participants:	Should include a cross section of end-users including stock assessment scientists, STECF, Commission, and statisticians. Participants should inform ICES secretariat and chairs no later than 15th December 2009 on their intention to attend the WKMERGE. Participants should follow chairs' request and deadlines on data submission and (or) work to be presented. This information will be circulated later by e-mail correspondence.
Secretariat facilities:	
Financial:	None
Linkages to advisory committees:	ACOM
Linkages to other committees or groups:	Expert WGs; PGCCDBS
Linkages to other organizations:	EC – Data Collection Framework; Regional Coordination meetings

1.2 Adoption of the agenda

The list of participants and the adopted agenda are in Annex 1 and 2, respectively. A list of working documents and a compilation of the oral presentations during the workshop are in Annex 3. All the working documents and oral presentations are available from the author(s) or the co-chairs.

1.3 Background for the workshop

WKMERGE addresses the requirements of the EU Data Collection Framework (Council Regulation (EC) No 199/2008 and Commission Decision 2008/949/EC) for Member States to collect metier-based biological data from commercial fisheries. These data are core requirements for fish stock assessments conducted by ICES and for input to mixed fishery models. (The Commission Decision for the 2011-2013 DCF was issued at the time of writing. For convenience the WKMERGE report refers only to Decision 2008/949/EC as the requirements for metier based biological sampling are practically the same other than some changes to species requirements). The workshop was established in response to a recommendation from the 2008 North Sea and Eastern Arctic Regional Coordination Meeting (RCM NS&EA). The RCM had recommended the development of protocols describing the evaluation process and quality checks to be carried out by the RCM on the National Programmes submitted by Member States as well as specifying guidelines for decision making by the RCM aiming at achieving a standard approach for standard situations. The 5th Liaison Committee Meeting (LM) in early 2009 interpreted this as a recommendation to PGCCDBS and PGMED to develop methodologies needed for conducting statistical analysis on merging metiers, between and within countries.

Topic : procedure for decisions on task-sharing			
RCM NS&EA	In order to improve the quality of the harmonisation process and the consistency in decision making, protocols should be established describing the evaluation process and quality checks to be carried out by RCM on the NPs. Also the protocol would specify guidelines for decision making by RCM aiming at achieving a standard approach for standard situations.		
	Follow-up actions needed	*Time frame (Deadline)*	*Follow-up responsibilities*
	Establish guidelines for decisions concerning harmonisation; the same for all RCMs	2009	PGCCDBS/PGMED
LM comment	LM recommends PGCCDBS/PGMED to develop methodologies needed for conducting statistical analysis on merging métiers, between and within countries.		

PGCCDBS 2009 (ICES, 2009a) accordingly developed Terms of References for a joint ICES-STECF Workshop on methods for merging metiers for fishery based sampling. Following the September 2009 ICES Workshop on Methods to Evaluate and Estimate the Precision of Fisheries Data Used for Assessment (WKPRECISE (ICES, 2009b)), it was apparent that the original ToRs for WKMERGE needed to be updated. This was in response to a WKPRECISE recommendation that national fishery sampling schemes should be designed using primary sampling units, sampling frames and stratification that allow control over sampling probabilities. The Commission Decision 2008/949/EC was being interpreted by Member States as imposing the use of fleet metiers at Level 6 (gear_target assemblage_mesh band) as sampling strata, whereas there are many cases where fishing gear choices and target assemblages can vary unpredictably making it difficult to control sampling probabilities. In the worst cases, attempts to fill sampling "quotas" for unpredictable metiers can lead to biased sampling schemes. WKPRECISE recommended that the use of fleet segmentation (groups of vessels defined by predominant fishing technique – see Commission Decision 2008/949/EC Appendix III) to define sampling frames and strata would provide a more statistically robust sampling design than the use of Level 6 metiers, except where there are groups of vessels that operate exclusively in a defined metier. The fleet segmentation was already the basis for designing surveys to collect economic data to meet DCF requirements.

The ToRs for WKMERGE were amended to focus the workshop in providing Member States with clear guidelines on the design of sampling schemes to collect metier-based biological data, treating metiers as domains of interest rather than strata. This concept was acknowledged in the subsequent drafting of revised Guidelines and Standard Tables for Member States to submit their DCF National Programmes for 2011–2013 (STECF SGRN-ECA 2009). From NP 2011-13 onwards, SGRN will consider the sampling intensities in the NP proposal based on the sampling frame (DCF Standard Table III.C.4) to further evaluate MS achievements, and thus consider the numbers of trips to be sampled from metiers (Table III.C.3) as the expected outcome of the defined sampling scheme rather than as targets. This allows for potentially large differences between expected and achieved numbers of samples per metier caused by changes in fleet activities in the sampling year compared with activities in the baseline years used for planning.

WKMERGE may be considered as the fourth in a series of ICES workshops initiated by PGCCDBS that considered the design of fishery sampling schemes to deliver the information on commercial and recreational fishery catches needed by the EU Data Collection Framework, and meeting the needs for implementing the ICES Quality Assurance Framework. The other three workshops were the Workshop on Methods to Evaluate and Estimate the Accuracy of Fisheries Data used for Assessment (WKACCU (ICES, 2008a)), WKPRECISE (ICES, 2009b) and the Workshop on Sampling Methods for Recreational Fisheries (WKSMRF (ICES, 2009c)). Previous ICES workshops dealing with the design of commercial fishery sampling programmes focused on the needs for calculating the precision of estimates of length and age compositions, allowing for factors such as multi-stage cluster sampling, but did not look in detail at the specific issues of designing unbiased schemes, particularly at the fleet level (ICES, 2000, 2005).

2 Why do we need metier-based sampling?

2.1 Fleet based fishery management

Management of fisheries within the EU Common Fisheries Policy (CFP) includes a range of control measures that are targeted at particular sectors of fishing fleets. A major component is direct control of fishing effort (in kW-days) aimed primarily at conservation of cod in the NE Atlantic, with days-at-sea limits specified for different fleet segments, mesh-size bands and by-catch levels, with regional variations (Annex II to Regulation (EC) No 40/2008). A complex set of rules is also given in the EU Technical Conservation Regulations (Council Regulation (EC) No 850/98) linking the use of mesh-size bands in different types of gears with allowable percentage compositions of different target and by catch species. The EC Scientific, Technical and Economic Committee on Fisheries (STECF) conducts annual appraisals of the EU effort management routine in relation to cod conservation, and collates data on landings, effort and discards in fisheries and métiers which are currently affected by fishing effort management schemes defined in Annex II to Regulation (EC) No 40/2008 (STECF, 2008).

The EU Data Collection Framework was revised from 2009 onwards to have a much greater focus on the collection of economic and biological data on a fleet basis, in order to support fleet-based fishery management within the CFP. Council Regulation (EC) No 199/2008 states the requirement for fleet based fishery sampling in the following paragraphs:

Paragraph (6): *Council Regulation (EC) No 1543/2000 of 29 June 2000 establishing a Community framework for the collection and management of the data needed to conduct the common fisheries policy (1) needs to be reviewed in order to take due consideration of a fleet-based approach towards fisheries management, the need to develop an ecosystem approach, the need for improved quality, completeness and broader access to fisheries data, more efficient support for provision of scientific advice and the promotion of cooperation among Member States.*

Paragraph (8): *Data collected for the purposes of scientific evaluation should include information on fleets and their activities, biological data covering catches, including discards, survey information on fish stocks and the environmental impact that may be caused by fisheries on the marine ecosystem. It should also include data explaining price formation and other data which may facilitate an assessment of the economic situation of fishing enterprises, aquaculture and the processing industry, and of employment trends in these sectors.*

The metier-based sampling in the DCF will allow the European Commission to conduct further analysis of data at levels of fleet disaggregation necessary to evaluate specific fishery management measures. For example, an EC call for data in 2010 has requested national data for specified fleet metiers targeting deep-water fish species.

2.2 Defining components of fishing fleets relevant to fleet based fishery management and collection of supporting data

The collection of data to support fleet based fishery management requires unambiguous definitions of the components of the fishing fleets for which data are required. The ICES Study Group for the Development of Fishery-based Forecasts (SGDF; ICES, 2003) provided the following definitions of fleets, fishery and metier:

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.

Metier: A homogeneous subdivision, either of a fishery by vessel type, or of a fleet by voyage type.

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, according to the following definitions:

Fleet segment: a group of vessels with the same length class (LOA) and predominant fishing gear during the year, according to the Appendix III. Vessels may have different fishing activities during the reference period, but might be classified in only one fleet segment.

Metier: 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 DCF concept of a metier is therefore analogous to the metier definition given by ICES SGDF if homogeneity is defined by similarity of exploitation patterns (pattern of fishing mortality at length or age) for species caught. In practice, season is currently not included in the DCF metier codification, although the seasonality of a metier is allowed for in defining required sampling intensities.

An important distinction between fleet and fishery/metier definitions relevant to fishery data collection schemes is that a fleet is a collection of physical entities that can be quantified using a census or sampling scheme, and therefore the size and structure of the fleet can be determined in advance of any activities aimed at sampling the catches. The terms fishery and metier refer to clusters of fishing operations in space and time that are inherently dynamic, and the activities often cannot be quantified until the fishermen involved have already made their operational decisions that define which fishery or metier their trips belong to. With sophisticated reporting and vessel monitoring systems, this can potentially be done in real time. In most other cases, the activities of a fleet may not be fully documented until vessel logbook data are uploaded on a fleet activity database. There are of course vessels that operate entirely within a particular fishery or metier due to the design limitations of the vessels and on-board technology, types of gears owned, license conditions, or simply a preference of the skippers or owners to keep fishing in the same way. For these vessels, the metier is known with some certainty in advance and may be more stable over time.

The latest development on the notion of 'fishery' has been carried out by the FAO FIRMS[1] project, and a list of definitions and examples is given in Annex 4. A few of the FIRMS definitions refer to quantifiable groups of vessels rather than fishing activities, usually where the vessels are unambiguously linked to a particular activity (e.g. industrial fishery).

3 Requirements of the EU Data Collection Framework for metier-based biological sampling data

The EU Data Collection Framework (DCF) requires the collection of economic data by the fleet segments listed in Appendix III of Commission Decision 2008/949/EC, but adopts the fleet metier as the domain of interest for collection of data on quantities discarded and the length and age composition of landings and discards. This links with the idea of a metier comprising trips with similar exploitation patterns.

The DCF requires member states to develop statistically robust sampling schemes to deliver the following types of biological data from commercial fisheries with minimum bias and achieving predefined precision levels. Precision refers to the estimates for individual fish stocks derived from fleet-based sampling schemes, at a national level if a Member State is not contributing to an internationally coordinated sampling programme, or at the international level in the event of coordination:

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1 Fishery Resources Monitoring System, see FIRMS at http://firms.fao.org/firms

- Quarterly length and age compositions of the landings and discards of defined stocks taken by national fleet métiers (after merging) in defined fishing grounds. In most cases the quarterly landings of species by métier are from exhaustive data from EC logbooks and sales notes. Catches by age or length are the primary input to catch-based stock assessment models along with relative abundance indices from surveys and/or fishery CPUE.
- "Concurrent" data on the length composition of landed and discarded fish of all species or a defined subset of species taken together in individual trips of métiers contributing the top 90% of the annual national landings, or value, or fishing effort in each fishing ground. This is needed to predict the effect on co-occurring species of management measures affecting activities of specific fleet métiers.
- Quarterly quantities of organisms discarded from fishing boats in each national métier and fishing ground, for all métiers where >10% of the total catch is discarded. This may include métiers not selected for concurrent length sampling by the metier ranking system. Discards of Group 1 and group 2 species must be the subject of a quarterly estimate of the length distributions when discards of those species represent (on an annual basis), either more than 10 % of the total catches by weight or more than 15 % of the catches in numbers
- Quarterly estimates of recreational fishery catches for a small number of species according to fishing ground.
- Quarterly estimates of mean length and weight at age of fish in the fishery landings and discards in each métier.

The DCF requires Member States to design sampling schemes to achieve <u>target levels of precision</u>. Although length data are to be collected for defined metiers, the target precision for length compositions is at the <u>stock level</u>. The following precision targets for metier based biological sampling (as coefficients of variation of the estimates) are given in Commission Decision 2008/949/EC:

- Quarterly landings length compositions by stock: CV = 12.5% for Group 1&2 species (from metier based concurrent sampling and additional stock-based sampling).
- Quarterly discards length / age compositions: CV = 20%
- Quarterly discard volumes (weights): CV = 20%

In addition to the above data requirements for fishery fleets, the DCF requires the estimation of stock-based biological variables that are best derived from properly designed surveys covering the full range of each stock. These include estimates of growth curves, sex ratio, proportion mature at length/age, and fecundity for stocks according to multi-annual sampling schemes. There may be a need to collect such data from fishery catches if appropriate surveys are not carried out, although WKPRECISE advises against this approach if the fisheries do not provide representative coverage of all relevant components of the stocks (ICES, 2009b).

The fishery data collection activities of EU Member States are coordinated and harmonised through annual meetings of Regional Coordination Meetings (RCMs), and recommendations from these meetings are discussed and elaborated by the annual Liaison Committee meeting comprising ICES, RCM and European Commission representatives. Recommendations related to biological sampling are then transmitted to the annual ICES Planning Group on Commercial Catches, Discards and Biological

Sampling (PGCCDBS) and the equivalent planning group for the Mediterranean (PGMED) which establish work programmes and workshops to improve the quality of fishery data and develop systems for quality assurance of data. PGCCDBS established the workshops WKACCU (ICES, 2008a) and WKPRECISE (ICES, 2009b) to implement the ICES Quality Assurance Framework for data and to support Member States to implement procedures for evaluating bias and precision building on other initiatives such as the EU COST project (http://wwz.ifremer.fr/cost). As end-users of such data, ICES stock assessment Working Groups also pass recommendations to PGCCDBS to address data issues that have arisen. Other ICES Planning Groups exist to coordinate different types of fish stock surveys funded through the DCF.

4 Activities of fishing vessels determining sampling access to catches.

Subsequent sections of the WKMERGE report deal with the identification of target populations, sampling frames and associated primary sampling units. The ability to design a statistically robust sampling scheme depends critically on expert knowledge of how the temporal and spatial activities of fishing vessels determine when and where catches can be accessed for sampling, the fraction of the catches that are accessible, and any constraints that may limit the ability to sample the catches to the extent required. It is also important to know the quality and completeness of any data on fleet activities (e.g. records of gear type, mesh or area fished) that are required for raising sample data to the fleet level.

Aspects of fleet structure and dynamics relevant to the design of sampling schemes include:

1) *The segmentation of the fleet into clusters of vessels with similar dominant fishing methods* (e.g. beam trawlers, demersal otter trawlers and seiners; purse-seiners, shellfish dredgers, polyvalent etc.). This may also include segmentation by vessel LOA class (e.g. 10m and under polyvalent vessels typical in small-scale fisheries). Vessels in different fleet segments are likely to have different fishing and landing patterns.

2) *The distribution of landing sites for each fleet segment*. Harbour facilities, markets and proximity to fishing grounds all affect the distribution of vessels of different fleet segments amongst home ports and landing sites. Large specialised vessels such as pelagic trawlers may be relatively few in number, operate from only a few ports and have few and lengthy trips, whereas small-scale fisheries may comprise thousands of small vessels landing daily at many small harbours. Larger-scale demersal fleet segments such as beam trawlers, otter trawlers, fixed netters, long-liners etc. may also have different geographical patterns of landing amongst ports.

3) *The duration of individual trips within a fleet segment*. Small vessels at sea for a day or less will have a high probability of being accessible for sampling on shore on most days whereas large vessels at sea for several days or weeks will have a lower probability of being sampled on shore on any random day. This may require different sampling schemes for vessels with widely differing trip durations. Further stratification of vessels according to typical duration of trips, or vessel LOA classes if this is correlated with tip duration, may help.

4) *Temporal patterns in landing activities*. The days on which vessels land fish may be linked to the timing of fish markets, or to tidal states affecting the ability to fish. For example, fixed-nets may be shot primarily on neap tides, and the vessels may not be able to fish over spring tides.
5) *Daily landing patterns of different fleet segments or metiers*. It may seldom be the case that all types of vessels at a port land at the same time to the same market. There may be different markets, for example for *Nephrops* and for whitefish. There may even be cases where different components from a single landing are split between different display or storage areas or bypass the market altogether and are transported directly to processors or retailers. This is a particular issue for concurrent sampling (see report of the Joint STECF/ICES Workshop on Implementation Studies on Concurrent Length Sampling (WKISCON (ICES, 2008b)).
6) *Spatial and temporal distribution of catches of individual species and stocks.* Species compositions of catches within a fleet segment may vary substantially between ports, due to the interaction between the spatial patterns of fishing and the spatial distribution of species. The same is true for different size or age classes of individual species. For example, discarding may have strong spatial and temporal trends, for example the smaller vessels in a fleet segment may operate closer inshore on nursery grounds.
7) *Variability in activities of vessels according to domains of interest (e.g. Level 6 metiers) within defined sampling frames and strata*. Landings of vessels within a fleet segment may represent trips by fishing ground (or finer spatial strata), gear type, target species or mesh sizes (i.e. metier level 5 or 6). The occurrence of such trips will vary spatially (between ports) and over time, and knowledge of this is essential for predicting how many trips by fishing ground and metier are likely to be delivered by a given intensity of sampling within each of the sampling frames and strata. If hauls within trips sampled at ports are known to have covered two or more fishing grounds or metiers, it is common practice to exclude such trips from sampling. If this becomes common, it is possible that the sampling scheme should be predominantly based on sampling at sea.
8) *Completeness of data recording at the fleet level*. A major problem can occur if sampling is stratified using variables such as gear codes, fishing ground and mesh size, but the fleet data base used for raising has missing or inaccurate data on these variables. For example, it would be no use stratifying an observer scheme into different types of gillnets, which can be identified accurately at sea, if the fishermen record all their trips using gillnets under a more general gillnet code. Unless the occurrence of sampling trips with different types of gillnet are in direct proportion to their occurrence in the fleet, the scheme will be biased because the sampling probabilities for the more detailed gillnet codes will be unknown.

The particular activities of fleet segments could lead to a requirement for them to have different sampling schemes and primary sampling units (PSUs). In this case, there would be a separate sampling frame for each fleet segment, as the sampling frame comprises all the primary sampling units and any stratification of these. (Currently, the Revised Standard Tables and Guidelines for completing DCF National Programmes, version 2009, imply that there would be a separate sampling frame for each fleet segment.) Some fleet segments may be sufficiently similar in terms of fleet behaviour and accessibility for sampling to have the same PSUs and hence be included within the same sampling frame, although stratification by fleet segment may be advantageous. See Section 5 for a more detailed explanation of sampling frames and strata.

Trip duration is an important aspect for sampling schemes. Random draws of vessels from a vessel list will not result in random samples of trips of all vessels in a stratum, if trip duration varies between vessels. It may in some cases be reasonable to treat trips as the PSUs if the variables of interest are not correlated with trip duration (e.g. if numbers discarded per day at sea was the same, on average, for vessels with different trip duration).

In the case of port sampling, if a sampling frame is defined as a list of access points for sampling clusters of vessels, the trip duration can also have an influence on the sampling design. Vessels at sea for several days or more may tend to land together at markets on specific days of the week, whilst small vessels may land and sell fish daily. If the selected PSUs represent a biased selection (e.g. if port visits coincide only with times when larger vessels with longer trips are landing, and exclude times when other vessels land), they represent only a subset of PSUs and are therefore a separate stratum and PSU definition (e.g. a separate stratum could be defined as all Friday markets in a quarter if there are fleet segments that land only on Fridays). In that case, a separate sampling stratum is necessary to cover all the other PSUs.

5 Designing statistically robust sampling schemes to provide data on fleet metiers or other domains of interest.

This section deals with Terms of Reference (a) *Review the definition and suitability of the sample frames used by each Member State for collecting data on metier-related biological variables required under the EU Data Collection Framework. The need for consistent approaches between Member States to meet overall objectives will be addressed.* and (c) *Review and develop probability-based sampling designs (appropriate for the frames defined in ToR a) that will provide the required metier-related biological data. This should be done using case studies that take into account the requirements for reporting bias and precision*

5.1 Existing guidelines on designing fishery sampling schemes

There are relatively few circumstances where biological data can be collected exhaustively from commercial fisheries, for example though 100% observer coverage. In the vast majority of fisheries some form of sampling survey is needed. The design of sampling surveys to provide estimates or inferences of population variables have a long history in the biological, medical, and social sciences (e.g., Hansen *et al.*, 1953; Kish, 1965; Cochran, 1977; Jessen, 1978; Levy and Lemeshow, 1999; Lehtonen and Pahkinen, 2004). The performance of such surveys is typically evaluated in terms of bias and precision, and the recent ICES Workshops WKACCU (ICES, 2008a) and WKPRECISE (ICES, 2009b) were established to provide guidelines on appropriate metrics and tools for quantifying bias and precision for implementation of the ICES Quality Assurance Framework (Nedreaas *et al.*, 2009).

The WKPRECISE report provides a comprehensive description of the elements of statistically robust sampling schemes for providing estimates of fishery and fish stock variables. These elements include:

- Identifying the target population (e.g., the entire commercial catch of a particular species) and domains of interest (e.g., the catch in an area by a gear type) for which estimates are required.
- Determine if and how the target population can actually be sampled
- If the target population cannot be sampled directly, then a study population may be established to provide access to the target population.
- Defining the primary sampling units (PSUs). When catch sampling is done via a study population, the PSUs would relate to units of the study population that can be selected for sampling (in the first stage).
- Defining sampling frames to provide access to the elements of the population through the PSUs
- Stratification schemes for improving precision
- Selecting PSUs for sampling using probability sampling methods
- Sample size determination

The sampling of commercial catches often involves defining a study-population that is based on a list of vessels, ports, or markets. The sampling plan then may involve a scheme for selecting vessels, ports, or markets and dates when catches can be sampled. Fishing trips may be selected in multiple steps. For commercial fisheries, all the vessels in a fleet are usually known due to licensing arrangements. This is in contrast to unlicensed recreational fisheries where additional surveys are needed to estimate the population of fishermen, for example using telephone surveys. The report of the ICES Workshop on Sampling Methods for Recreational Fisheries (WKSMRF (ICES, 2009c)) contains a detailed description of survey methods for estimating recreational fishery catches, much of which is also relevant for estimation of commercial fishery catches (e.g. discard surveys). Although lists of active vessels usually are available for planning surveys of commercial fisheries, and may be used for selecting vessels for at-sea sampling, it is usually not feasible to compile a list frame of fishing trips for catch sampling since the population of all fishing trips will usually not be known in advance. Therefore, sampling frames are often constructed by identifying ports, markets, or landing sites where fishing trips can be accessed for sampling of catches on selected days.

Representative sampling from a frame of fishing ports/days can be done by selecting random, stratified random or systematic (with random element) samples of ports/ days (the PSUs.) The fishing trips for sampling can then be selected representatively from all the trips within each of these PSUs. This form of sampling of fishery catches is well known as cluster sampling (e.g., Cochran, 1977; Levy and Lemeshow, 1999), where it is likely that the variability within clusters is less than between clusters. The sampling design involves multi-stage sampling where there is a hierarchy of sampling decisions. The sequence of 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 to sample within the cluster; 3) selection of fish to measure or age from the sampled vessels.

Sampling frames can also be based directly on the list of active vessels. Vessels, and trips within vessels, can then be selected for catch sampling according to a specified plan (survey design.) In observer programs, such a list of vessels may often be used as the sampling frame as it is usually necessary to arrange trips in advance. The multi-stage sequence of sampling fish is then: (1) selection of a vessel (the PSU) from all vessels in the list for the sampling frame and stratum, (2) selection of trips to sample for a vessel; (3) selection of fishing operations within trips; (4) sampling of the catches of individual fishing operations; and (5) selection of fish to measure or age (see Allen *et al*., 2002).

These approaches are documented for a number of fishery sampling schemes worldwide. For example, Rago *et al*. (2005) describe standardized survey sampling methods used to estimate bycatch rates of finfish by commercial fisheries in the Northeast of USA. Emphasis is placed on the methods used to define the sampling frame (i.e., the population of commercial fishing trips to be sampled), appropriate stratification, and efficient allocation of sampling effort to these strata. The Food and Agriculture Organization of the UN (FAO) has published a range of technical reports describing good practice for designing fishery sampling schemes. An example is the FAO Fisheries Technical Paper 425: *Sample-Based Fishery Surveys - A Technical Handbook* (FAO, 2002) which discusses several approaches to sampling fisheries to estimate catches, CPUE and other variables.

A range of studies in European fisheries have evaluated the design of discard sampling schemes and the performance of design-based and model-based estimation procedures (e.g. Anon. 1999; Allen, 2009; Allen *et al*., 2001; Borges *et al*., 2004; Cotter *et al*., 2002; ICES, 2007; Rochet *et al*., 2002; Rochet and Trenkel, 2005; Stratoudakis *et al*., 1999 and Vigneau *et al*., 2007).

5.2 Definitions and guidelines for designing sampling schemes to provide fleet based estimates for biological variables

There are a number of important steps that must be followed to plan a survey (such as a sampling scheme for commercial fisheries). The following step-by-step approach is based largely on important aspects of survey planning identified by Sarndal *et al.* (1992) and is adapted from the guidelines for designing recreational fishery surveys given by WKSMRF (ICES, 2009c). The National Research Council of the U.S. provides a thorough review of the NMFS recreational fishery survey, with recommendations on survey designs (National Research Council, 2006).

5.2.1 Defining the objectives

The first step is to specify the objective of the survey. The objectives of a sampling scheme need to be clearly stated before a cost-effective sampling scheme can be designed. A description of objectives should include:

- The target population and domains of interest for which data and estimates are required;
- The likely study population;
- The types of estimates required;
- The desired precision of the estimates.

Unless a fishery is very simple (e.g. a single fishing method catching very few species), there is likely to be a range of different objectives and the optimization of sampling schemes to meet multiple objectives may be very complex (Annex 6: Guerineau and Vigneau, Working Document 2).

5.2.2 The Target Population:

The target population is the population for which information is required, e.g., the commercial catch of a species that is landed in a country. In practice, not all elements in the target population may be accessible for sampling. In such cases, a clearly defined study population should be specified, comprising as much of the target population as possible. For example, the catches by vessels of LOA 10m and under may not be included in an observer program due to lack of space or sleeping quarters. The study population then may be all the catches by vessels greater than 10 m LOA. In such cases, the methods and rationale for extrapolation of information from the study population to the target population should be documented. In some cases, for example where small vessels cannot take observers, other sampling methods such as fisher self-sampling should be explored to avoid the need for imputation or to evaluate the possible biases from imputation.

5.2.3 Specifying Domains and Parameters of Interest

For the target population, the domains (or subpopulations) of interest for which parameter estimates are required should be clearly defined. For example, separate estimates of bycatch and of biological parameters may be requested for a statistical area or for a gear type that could not be specified for each trip in advance.

The DCF currently requires the collection of biological data at level 6 of the metier structure given in Appendix IV of Commission Decision 2008/949/EC. The Level 6 métiers are defined by gear type, target assemblage, mesh size and presence and mesh size of any selectivity devices fitted (in practice the latter are rarely included in the metier definitions given by the Regional Coordination Meetings, as this is not a mandatory reporting requirement on EU logbooks). The metier represents a principal domain of interest for which sampling data are required. It is often the case that the sets of trips that fall in specific metiers can only be identified after the trips have been completed, based on log-books and other sources of information. The trips within a metier may also come from different strata in the sampling plan. When all trips in target population of vessels and trips can be classified into non-overlapping strata, then estimates of catch characteristics, bycatch, and biological parameters may be based on post-stratification of trips. The post-stratification for metiers that cross sample strata involves sample-weight adjustments based on the sampling achieved for the metier in each stratum and the census data (log-book data) (see Section 5.2.8).

The number of metiers for which separate estimates of catch characteristics can be estimated reliably is determined by the number of metiers occurring in the sampling strata and the number of PSUs sampled in each stratum. The sampling plan and number of metiers should be harmonized so that all metiers would be expected to achieve a sufficient number of primary samples (e.g., trips) to support separate estimates of key parameters. This can be achieved by efficient use of historic data on the distributions of trips by metiers from logbooks. The post-hoc merging of metiers should be the last resort.

The concept of "merging of metiers" which led to the formation of WKMERGE originated as a procedure for rationalising the number of DCF Level 6 metiers that can be the target of biological sampling schemes, by combining metiers that have similar selectivity characteristics. The procedure for allocation of individual fishing trips to metiers according to gear, target species assemblage and mesh band, can lead to a very large number of "metiers" being defined by each Member State. The number of such domains would multiply further if stratified into the vessel LOA classes given in Commission Decision 2008/949/EC, Appendix IV. In practice, several metiers and/or vessel LOA classes defined in this way may represent quite similar fishing activities with similar selectivity characteristics. Commission Decision 2008/949/EC therefore allows that:

"In order to optimise the sampling programmes, the métiers may be merged. When métiers are merged (vertical merging), statistical evidence shall be brought regarding the homogeneity of the combined métiers. Merging of neighbouring cells corresponding to fleet segments of the vessels (horizontal merging) shall be supported by statistical evidence. Such horizontal merging shall be done primarily by clustering neighbouring vessel LOA classes, independently of the dominant fishing techniques, when appropriate to distinguish different exploitation patterns. Regional agreement on mergers shall be sought at the relevant regional coordination meeting and endorsed by STECF."

Two approaches for providing statistical evidence for merging metiers or LOA classes could be: (1) an evaluation of the similarity in species and size compositions, fishing grounds etc. of two or more Level 6 metiers and/or LOA classes (from logbook data and existing sampling data), and (2) multivariate analysis to cluster fishing trips into homogeneous units.

An example of the use of multivariate techniques to investigate homogeneity of fishing trips is given in Annex 7 (Vigneau *et al*. WD3) using data for French fleets. Other examples include Davie and Lordan (2009) who applied a combination of factorial and cluster analysis to data on Irish commercial fisheries in the Irish Sea. Examples are also included in the reports of the EU CAFÉ project, and Spain is currently also adopting this approach to identify metiers for its DCF sampling programme.

WKMERGE agrees that multivariate methods may be a useful approach for investigating the extent to which fishing trips can be clustered into groups with similar characteristics, and to allow investigation of what determines such clustering. Such analysis of historical census and catch sampling data can be a very useful approach to defining domains of interest at the metier level that are of use for fishery managers. The domains for sampling schemes should be defined a-priori so that stratification and allocation of sampling effort to strata can be planned to ensure sufficient sample sizes to estimate parameters of interest for domains, with adequate precision. In the interests of international harmonization in the definition of metiers, it is also recommended that the implementation of such methods is harmonised across Member States sharing metiers in a fishing ground.

5.2.4 Defining the sampling frames and primary sampling units

The sampling frame is a list of all individuals or sampling units that can be selected independently with known probability by randomised sampling. The frame may represent the entire population of interest or may be incomplete because not all sampling units are accessible for sampling. In this case it is important to specify the characteristics of the study population (subset of the frame that can be accessed for sampling), and of the non-accessible subset, so that potential bias due to incomplete coverage can be assessed.

The elements (cells) in the sampling frames are the primary sampling units (PSUs) in the sampling plan. A PSU may be a vessel, vessel/trip, port/day, or market/day. The PSUs must completely populate the sampling frame in non-overlapping cells for all elements in the frame population to have a known probability of being sampled, and the sampled units can be given a correct weighting for estimating population values. Incomplete sampling coverage will cause bias if the non-accessible PSUs of the frame have different characteristics than in the sampled population. Examples of sampling frames for fishery sampling are given below:

A complete list of active and non active vessels in the fleets to be sampled.

Member States maintain complete vessel registers for licensed commercial fishing vessels including details of home port, vessel size and power. This is an example of a "direct sampling frame", comprising a list of vessels available for sampling (Table 1).

Table 1. Vessel list frame based on fleet segments and stratified by length and dominant fishing method.

Vessel LOA	Otter trawl	Beam trawl	Gillnets	Lines	Polyvalent
>24m	xxx xxx xxx xxx	xxx xxx xxx xxx xxx xxx xxx			
10-23.9m	xxx xxx xxx xxx xxx xxx xxx xxx xxx	xxx xxx xxx xxx	xxx xxx xxx xxx xxx xxx xxx	xxx xxx xxx xxx	
under 10m	xxx xxx xxx		xxx xxx xxx xxx xxx	xxx xxx xxx xxx xxx xxx xxx	xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx

Vessels are selected at the start of the sampling period (e.g. quarter), and a sample of trips from each vessel is selected during the period (unless all trips can be observed by a permanent observer). In this example, the vessels are the PSUs, and the secondary sampling units are the trips by each vessel in the stratum (i.e. the trips by a vessel are treated as a cluster). Treating the individual trips as the PSUs, and the sampled trips as a simple random samples of PSUs could lead to biased estimates for the stratum; for example the discard estimates from long trips would be given equal weight to the estimates from short trips, whereas in practice there could be many more (or fewer) short trips than long trips in the fleet. The trip could be treated as a PSU if the estimates of the variables of interest are not correlated with trip duration (e.g. if the estimates per trip are discards per unit effort or proportion of catch discarded and these ratios are independent of trip duration). List frames of vessels are not without problems. There can be difficulties in maintaining accurate lists due to vessels being sold or scrapped, new vessels entering the fleet, and vessels relocating temporarily to other areas. This problem applies to the fleet as a whole and to any subdivisions by fleet segment or fishing ground. Vessels occurring only temporarily in a stratum are problematic if selected at random from the vessel list, but are not sampled due to non-availability of observers during the period when the vessels are operating in the stratum. The estimation procedures must account for the effect of this on the raising factors.

Vessel lists should be updated immediately prior to each sampling period (Anon., 1999). All vessels that cannot be sampled (e.g. too small to take observers, or skipper refuses access) and therefore lie outside the list frame should be recorded, so that the accessible and non-accessible vessels can be compared to identify potential bias, or to impute estimates based on vessel characteristics and logbook data.

A complete list of fishing trips.

If it is possible to have accurate knowledge of all the trips by each vessel in a list frame for a forthcoming sampling period, and it is also possible to sample the trips in such a way as to cover all trips representatively, then the list of trips may pragmatically be treated as the sampling frame where the PSUs are the individual trips. When the chance of selecting a trip is approximately equal across all trips in each stratum, then it is reasonable to assume a random sample of trips. This situation might occur for groups of vessels where there are relatively few but very long trips at predictable times of year. For larger fleets with shorter trips of variable duration, the previous year's data could be used to roughly predict the number and pattern of trips in a forthcoming sampling stratum if the pattern is expected to be very similar to the previous year, and form the basis of a random selection of trips to sample. In general, the timing and location of trips are likely to be subject to uncertainty that will lead to poor control of sampling probabilities.

A complete list of access points for sampling

This area frame is an example of an "indirect" frame comprising a list of all ports, harbours or other landing sites that provide access to all landings by the target population of vessels (Figure 1). It is an "indirect" sampling frame because the numbers of vessels and trips are not necessarily known in advance. Rather, the landing sites provide access to clusters of trips by fishing vessels.

	Site 1	Site 2-5	Site 6	Site 7	Site 8-10	Site n
Day 1						
Day 2						
Day 3						
Day 4						
Day 5						
Day 6						
Day 7						
Day 8						
Day 9						
Day 10						
Day 11						
Day 12						
Day n						

Figure 1. Sampling frame comprising a list of locations providing access to clusters of fishing vessels. Primary sampling units in this example are sites or groups of sites on individual sampling days.

Area frames of this type are the *de-facto* sampling frames for most port sampling schemes. The PSUs will have a spatial component (an access point) and a temporal component (a period time over which a visit to the site takes place). The PSU could be a single landing site on a single day, or include a group of neighbouring landing sites and a period of more than one day for sampling these sites. The latter may be appropriate when the sampling sites are located in remote locations involving lengthy travelling time for sampling teams.

The list of PSUs must cover all the trips/landings in space and time in non-overlapping cells. The sampling frame (all the PSUs), and the number of PSUs in any stratification of the frame population, are therefore known and the PSUs can be sampled representatively using random or systematic sampling schemes with known probability. Each PSU represents a cluster of fishing trips that may either be sampled exhaustively, or subject to a further level of trip selection (sub-sampling) to obtain a representative sample of trips within the PSU. An example of an access point survey for a small-scale fishery in Mozambique is given in Section 6 and Annex 5.

A complete list of markets and days when the markets take place (i.e., a matrix of markets and days)

This could also be considered as a list frame that provides access to all catches handled by these markets over time if the markets are predictable. This could be the case if catches are transported directly from several landing sites to a single fish market.

5.2.5 Stratification schemes

Levy and Lemeshaw (1999) note that the concept of simple random sampling is useful for considering sampling theory but is rarely adopted in practice without some form of stratification or inclusion of systematic elements to improve coverage. Stratification of the sampling frame into non-overlapping segments (strata) can be advantageous when there is a need for more homogeneous target populations which will provide more precise estimates or where categorization of the population is needed in order to respond to specific user needs (FAO, 2002). Spatial stratification may also be needed to address logistical issues related to availability of sampling staff in different locations or the cost of sampling in more remote locations. The spatial distribution of different length or age classes of fish could influence stratification – for example small vessels or those with short trip durations may fish closer inshore where a fish nursery occurs.

Stratification of the PSUs may involve the grouping of vessels by size and gear, the grouping of sampling sites by area, or grouping based on information from logbooks. Temporal stratification (e.g., by quarter) may also be employed. Quarterly strata are very common in European waters because of the demand by ICES for stock assessment data disaggregated by quarter for input to databases such as InterCatch. 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). If a stratum is defined by vessel or trip attributes that could change dynamically over time (e.g. DCF Level 6 metiers), the number of PSUs in the stratum in the sampling year could be quite different than in the reference year used for specifying the sampling effort for the different strata. This could lead to inefficient sampling or missing strata. Over-stratified sampling schemes can also lead to zero observations for some strata due to inadequate resources for sampling, resulting in a need for imputation at the analysis stage and potential bias. A combination of both of these problems 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 proportionate allocation of effort and avoidance of missing strata.

As an alternative to defining many strata to cope with heterogeneity in the sampling frame PSUs, a sample selection scheme with probability proportional to size (pps) could be adopted to increase the sampling rate for the larger PSUs (e.g. ports with large fleets, or vessels with track record of large catches or discards) (see Section 5.2.7.1). A pps sampling scheme can also be applied within sampling strata.

The Level 6 metiers for which data are required by the DCF are in some circumstances predictable and stable enough to form the basis for stratification of a frame (or even to act as a separate frame). In other cases, the metier acts as a domain of interest for which the frame and stratum are designed to provide the necessary data by metier. This is the current approach in the Revised Standard Tables and Guidelines for the 2011_13 National DCF Programmes (version 2009). The distribution of trips by metiers in prior years may be used to stratify vessels and ports in order to ensure sampling levels high enough to yield the required sampling effort by metier.

5.2.6 Allocation of sampling effort

Once the possible frames, strata and primary sampling units have been identified, an inventory of available resources in terms of budget, staff, data processing, and sampling equipment should be drawn up. Unless additional resources are available, it is usual that sampling schemes are tailored to make best use of available staff and facilities. Based on existing or new data, the effort required to meet any precision targets can be evaluated and additional resources sought if required.

The overall amount of sampling effort and its distribution between sampling frames (if more than one exists) and sampling strata within the frames will be dictated by the objectives of the sampling scheme. Attaining target precision levels for discard estimates and length/age composition of landings and discards by stock, may require quite complex analysis of existing data to allocate sampling effort. This is particularly the case where the sampling schemes provide data for many stocks.

An example of an optimisation scheme for computing the number of discard sampling trips to meet DCF precision targets for a defined proportion of the stocks is given in Annex 6 (WD 2). Rago *et al.* (2005) describe an extension of Neyman's allocation theorem (Cochran, 1977), which distributes observer trips to strata as a function of their contribution to the total variance, the expected number of observer days per trip, and the probability that a trip will provide information on one or more of the species groups of interest. Miller *at al.,* 2007 evaluate optimisation schemes for observer coverage of the North Pacific Groundfish Observer Programme that are applicable to any sampling design that is stratified with simple random sampling within strata, including multi-stage sampling.

Pending the application of statistical procedures to optimise sampling effort, the available sampling resources may be spread between frames and strata using other metrics. The Commission Decision 2008/949/EC states that

"The sampling intensity shall be proportionate to the relative effort and variability in the catches of that metier. The minimum number of fishing trips to be sampled shall never be less than one fishing trip per month during the fishing season for fishing trips of less than two weeks and one fishing trip per quarter otherwise."

This defines the minimum sampling required for metiers (or merged metiers) listed for sampling in the DCF National Programmes of Member States. The required sampling by frame and stratum in the sampling years (e.g. 2011–2013 for the NP proposals submitted in March 2010) will need to be in accordance with expected outcome by metier meeting the minimum requirements. The predicted outcome of a sampling scheme in terms of numbers of trips sampled per metier can be computed based on the most recent years' (the reference years in the DCF Standard Tables) census data for trips by metier within the defined sampling frames and strata. Adjusting the planned sampling effort by frame and stratum, taking into account the sampling strategy for clusters of trips within individual PSUs, will lead to an expected outcome in terms of trips that would have been sampled per metier by applying the proposed sampling scheme in the reference years. This becomes the expectation for the sampling years. The actual outcomes may differ from the expectations due to changes in fleets and fishing operations. However, if the sampling scheme is representative, the samples by metier should reflect the occurrence of metier trips in the fleet as a whole in the sampling year, and any deviations from expected sampling levels by metier should be explainable by changes in fleet activities.

5.2.7 Selection of primary sampling units

The revised DCF Standard Tables and Guidelines (2009 version) require member States to indicate if the sampling schemes adopted for fleet-based biological sampling fall into one of the following three schemes:

A. Census

B. Probability based sampling (this includes systematic sample selection with a random element)

C. Non-probability based sampling

It would be rare to have census data in the absence of complete observer coverage, for example. Probability based sampling means that the probability of selecting a PSU for sampling is controlled and greater than zero. It does not imply that the sampling scheme needs to be fully randomised, as it would be possible (and possibly more feasible) to select sampling dates, for example, in a more systematic fashion within a stratum, provided this leads to representative (un-biased) sampling (Fig. 2). Systematic sampling schemes, where appropriate, are likely to facilitate planning and be easier to implement than fully randomised schemes. Randomisation would be appropriate for selecting vessels from a list or selecting landings to sample on a quayside during a sampling trip when all the landings are on display. During a port visit, systematic 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 was to be sampled, the first sample should be a random selection of the first five samples.

Non-probability sampling applies to schemes where there is effectively no control over the sampling probabilities, and samples are selected on an opportunistic or ad-hoc basis. Such schemes may produce misleading and biased estimates if treated as if they are probability based, although the bias may be reduced by the expedient of trying to ensure that sampling is spread out over time and space. Model based estimators may be possible with non-probability based sampling, but cannot be expected to rescue a badly designed sampling programme.

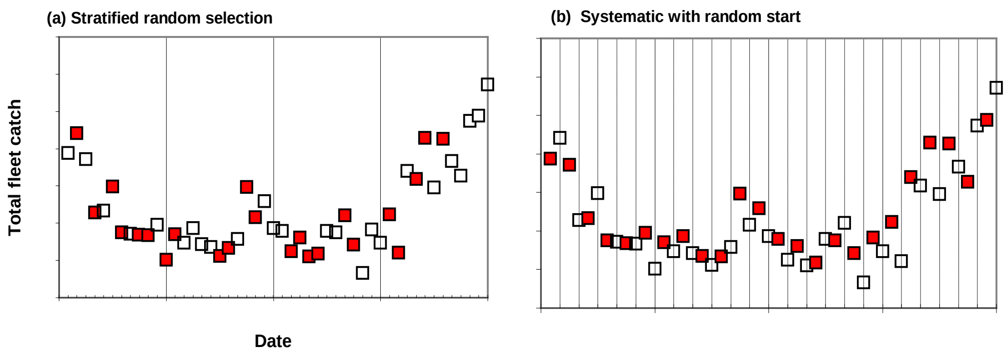


Figure 2. (a) Random sample of weeks to sample within quarterly strata; (b) Systematic selection of every second week. Filled squares are sampled weeks, open squares non-sampled weeks.

Procedures for selecting primary sampling units are described in the following sections, firstly for a scheme involving selection of vessels from a list frame, and secondly for a port sampling scheme involving an area frame comprising lists of access points for sampling clusters of trips. Whatever schemes are chosen, a critical factor is the ability of the sampling staff (which may include contract staff) to easily interpret and correctly implement the sampling instructions. The ability to communicate sampling designs to technical staff or administrators also requires the terminology to be clearly explained: "random selection" may be misinterpreted as something inefficient and lacking in design, whilst "representative sampling" could be interpreted as a need to seek out catches that meet some preconceived notion of a typical catch composition or size frequency.

5.2.7.1 Selection of primary sampling units using a vessel list frame

A vessel list frame should include all relevant attributes of the vessels for defining any stratification, or for assigning prior sampling probabilities based on some measure of "size". Options for selecting PSUs from the list frame are given below.

Stratified random sampling with equal probability.

This is the simplest design-based approach for selecting from the PSUs (vessels) in the list frame covering all vessels expected to operate in any stratum defined by time, area, fleet segment or other characteristics such as vessel LOA or typical trip duration. Vessel lists are available for each sampling frame and stratum, and simple random sampling is used to select vessels for sampling. If the selection of vessels is with replacement, a vessel may be selected two or more times in the random selection process, particularly if the list contains relatively small numbers of vessels (see Fig. 3a). This could be accommodated by selection of multiple secondary sampling units (trips within vessels) to be scheduled at random within the area- time stratum. Alternatively, to maximise the coverage of vessels, selection could be done without replacement so that only one trip per vessel per stratum is sampled. This would be advantageous if the between-vessel variation is greater than the within-vessel variation in the stratum.

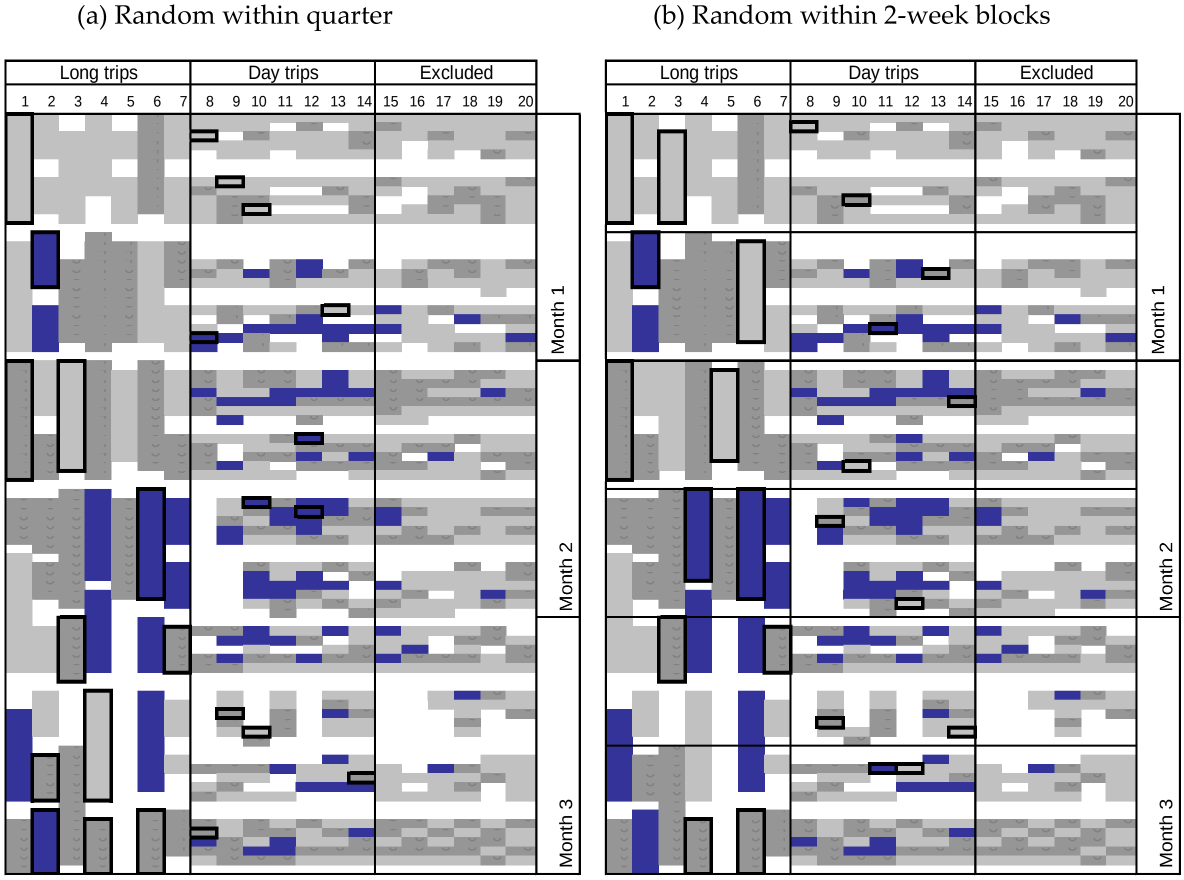


Figure 3. Representation of a vessel list frame used for sampling vessels at sea, with vessels numbered along the top and sampling days down the side. This could be all vessels or a group stratified by fleet segment and/or geographic location. The height of each shaded bar represents the duration of trips of each vessel during a quarter (known after the event), and the vessels are stratified into those with long trips (1-2 weeks), those with day trips, and vessels excluded as too small to carry observers. The shading is to illustrate variability in catch rates between trips (dark = large catch). Sampled trips are outlined in bold. Frame (a) shows the result of random draws of vessels (with replacement) followed by random selection of trips within vessels during the quarter (i.e. a vessel may be sampled more than once in the quarter). Frame (b) uses a lattice-type sampling scheme dividing the quarter into six 2-week blocks and selecting two vessels at random (without replacement) in the "long duration" stratum and two vessels at random (also without replacement) from the "day trips" stratum in each 2-week block. A second-stage random selection of a trip within each vessel is then made.

Stratified systematic sampling with random component

The use of a "lattice" sampling scheme using smaller subdivisions of larger temporal strata (e.g. weekly or fortnightly blocks within quarterly strata), with random selection of vessels within each subdivision, may be useful to avoid large gaps in coverage due to purely random sampling (Figure 3b). Although the subdivisions may appear to be separate strata, they are just a means of taking what would otherwise be a fully random selection of sampling dates and spacing them at more regular intervals. This may be logistically easier to manage than fully randomised sampling.

Unequal probability sampling.

This refers to sampling schemes in which the probability of sampling a vessel is adjusted according to the value of an auxiliary variable x, which is easy or inexpensive to measure and available for the entire population, and which is known *a priori* to be significantly correlated with the variable of interest y (e.g. discard rates). Examples of auxiliary variables could include vessel LOA, engine power, trip duration or quantity of retained fish. Such a scheme is known as sampling with probability proportional to size (pps) where x is the "size" variable. For the example of discard estimates, the sampling is weighted towards vessels contributing most to the discarding (or preferably to vessels contributing most to the overall variance of discards estimates) in the stratum, but the weights (sampling probabilities) are known and are accounted for in the raising procedure using Horvitz-Thompson or Hansen-Hurwitz type estimators (see Annex 9).

Sampling with an intention to apply ratio and regression estimators.

These estimators are also reliant on being able to identify robust and significant linear correlations between the variable to be estimated y and one or more auxiliary variables x. The ratio estimator is in effect a special case of the regression estimator where the intercept is assumed to be zero. An example of ratio estimates are ratios of quantities discarded to quantities retained, or quantities discarded per unit fishing effort. Ratio and regression estimators can be used with probability based sampling schemes. However, if the intention is to apply such approaches or more complex model-based estimators, sampling schemes could be targeted (e.g. using quota sampling) with the objective of providing data that lead to the most accurate linear predictors. For example precision is highest when the mean values of x for the sampled vessels are close to the mean for the population as a whole (an expectation for random sampling), and when data contrast is high enough to allow precise estimates of the slopes of the relationships between x and y. However, there are also opposing views on the merits of quota sampling (see Melnick *et al.*, 1991) and a safe approach is to ensure that the data collection scheme fulfils the requirements of design-based sampling whilst also collecting sufficient data to allow exploring the use of modelling approaches. Some studies (e.g. Melnick *et al.*, 1991) suggest that when the sample sizes are very low, there may be advantages in model based estimators using "quota sampling". In catch sampling programs with very limited sample sizes quota sampling could be used to obtain data covering a range of vessel characteristics that may be correlated with the variables to be estimated. However, care is needed with sample selection if the relationship between x and y varies over time and space within the stratum.

Hirst *et al.* (2004, 2005) provide examples of model-based methods for estimating catch-at-age including Bayesian approaches. The use of auxiliary variables to improve estimation of discards has been investigated in a number of European studies (Allen, 2009; Allen *et al.*, 2001; Borges *et al.*, 2004; Cotter *et al.*, 2002; ICES, 2007; Rochet *et al.*, 2002; Rochet and Trenkel, 2005; Stratoudakis *et al.*, 1999 and Vigneau *et al.*, 2007). The overall conclusions are that the use of auxiliary variables can increase precision. However, ICES (2007) concluded that there were no consistent auxiliary variables for discards estimation usable for all countries, and that a case-by-case evaluation was necessary. A potential problem is that evaluation of the benefits of auxiliary variables and the methods of using them (e.g. pps, ratio and regression estimators) require access to sufficient data collected using well-designed sampling schemes. Exploratory applications of methods to limited data sets can yield significant relationships that are spurious and may fall down as more data are collected. Cotter *et al.* (2002) reviewed the success of a pps scheme applied for estimating discards of English vessels, and concluded that relationships with auxiliary variables detected in historical data may be poor predictors of future discard rates and offered little advantage over equal-probability methods.

A study by Allen (2009) examined different sampling and estimation procedures for estimating discards, including simple random sampling, pps (ppx in Allen's thesis), ratio and regression estimators, and sampling with partial replacement (making use of historical discard rates of a vessel along with current estimates, according to the correlation between the two). Allen's (2009) conclusions for the fleets under study included the following: Select vessels for sampling using equal probability; 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 bias due to non response.

Non-probability methods.

Ad-hoc, opportunistic sampling schemes not based on the statistical approaches described previously will likely be biased and less efficient at meeting the objectives than a suitably optimised probability based scheme. The bias may be reduced if sampling has been deliberately spread out over vessels and time to achieve good coverage of the population. However when there is no control over sample probabilities, the possibility of unbalanced sample allocation and missing strata is increased. Modelling approaches may to some extent improve estimates where sampling is non-representative but has adequate coverage of the strata, providing the relationships between the variables of interest and the auxiliary variables can be estimated with sufficient accuracy. These relationships may be poorly defined when sampling is ad-hoc and unbalanced.

Partial coverage of sampling frames

The exclusion of a substantial fraction of vessels due to being too small to carry observers or due to skippers being otherwise unwilling to carry observers is a serious problem for most of the national sampling schemes reviewed by WKMERGE. The estimates for discarded or retained catches on observed vessels cannot reliably be used to impute values for excluded vessels unless there is evidence that the discards and size composition of catches of the excluded vessels are the same on average as in the observed catches of similar vessels and gears. When a vessel selected at random from a list cannot be sampled by an observer, the refusal should be recorded and the details of the vessel should be obtained. Imputation may be possible if there are auxiliary variables that are correlated with the required estimates in the observed vessels. Self-sampling schemes may be an option for small vessels for which an observer scheme is not possible.

Use of vessel list frames for port sampling

If accurate advance knowledge is available of the vessels due to land at different ports, and the timing of landings, a vessel list frame with random draws could be used to plan a representative sampling scheme based on advance selection of individual vessels to sample at a port or group of ports.

5.2.7.2 Selection of primary sampling units using an area frame

An area frame should include all relevant attributes of the access sites for sampling to allow the definition of any stratification, or for assigning prior sampling probabilities to access points based on some measure of "size". Sampling schemes involving lists of sampling sites providing access to clusters of vessel trips may offer considerable challenges for designing robust sampling schemes (Section 4) due to issues such as timing and location of landings by different fleet sectors.

Key decisions affecting the sampling design are the definition of the PSUs and their stratification in the sampling frames. The PSUs will be defined as a landing site (or group of neighbouring sites) and a time window for the port visit, with all PSUs being non-overlapping area-time cells covering all landings in a frame or stratum. Options for selection of PSUs are given below, with two examples illustrated in Figure 4 (these are nor exhaustive).

Stratified random sampling of PSUs

Stratification (Section 5.2.5) is applied to the great majority of fishery sampling schemes. Defining strata as groups of ports of similar "size" would allow simple random selection of the PSUs in each stratum, with a higher sampling probability in the strata with the largest ports. The example of the sampling scheme for small-scale fisheries in Mozambique (Section 6 and Annex 5, WD4) employs a stratification of sampling sites into "large", "medium" and "small", with a different probability of selecting PSUs (port x day) in each stratum. A theoretical example of such a scheme is also shown in Figure 4. If the selected PSUs represent a biased selection (e.g. if port visits coincide only with times when larger vessels with longer trips are landing, and exclude times when other vessels land), they are representative of only a subset of PSUs. This could form a separate stratum (e.g. all Friday markets in a quarter). In that case, a separate sampling stratum is necessary to cover all the other PSUs.

Stratified systematic sampling with random component

The example of the sampling scheme for small-scale fisheries in Mozambique (Section 6 and Annex 5) uses a systematic lattice sampling scheme where the temporal strata are further subdivided into 1-week blocks. The PSUs (sampling site x day) are selected at random from all the PSUs in each 1-week period. This ensures good temporal coverage whilst retaining an element of randomisation. This approach is also shown in the theoretical example in Figure 4.

Sampling with probability proportional to size (pps)

In pps sampling, the probability of visiting a particular port or cluster of ports in a stratum is adjusted according to an appropriate measure of size such as the expected total landings at the ports or harbours in each PSU, or the numbers of vessels or total effort etc. The disadvantage of pps sampling is the need for more complex statistical methods for computing the estimates, and the possibility that the auxiliary size variables from previous years' data may have changed in the sampling year, leading to reduced efficiency of the scheme. Sample selection using pps can also be applied within any strata.

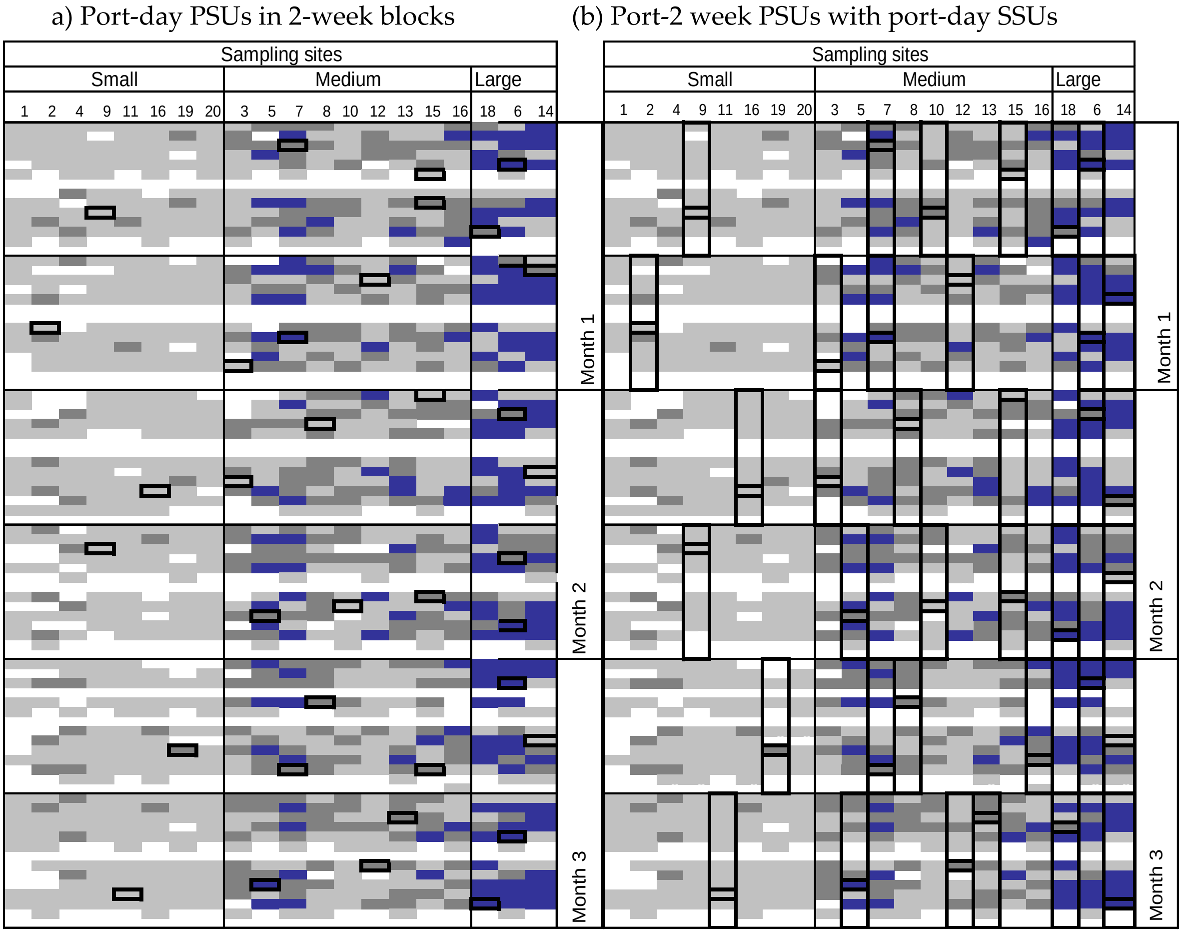


Figure 4. Representation of an area list frame used for port sampling ashore, with sampling sites along the top and sampling days down the side. The sampling sites are stratified in advance into those of "small", "medium" or "large" size (e.g. according to fleet size, quantities landed by species in a previous year). The daily landings are shaded to illustrate variability in the size variable (e.g. total landings, as known after the event; dark = large). The PSUs are defined in Frame (a) as sampling site x day and in Frame (b) as sampling site x 2-week block. In (b), one sampling day is selected at random as a secondary sampling unit (SSU) in each PSU. (Each PSU could comprise groups of neighbouring sampling sites that can be covered in an individual sampling trip). Each PSU comprises a cluster of vessels landings that may be sampled exhaustively or using a representative sample of fishing trips within the cluster. Frames of this type could represent an entire national fleet or represent fishing trips by geographic area or fleet segment Sampled PSUs and SSUs are outlined in bold. Sampling has been planned with one random PSU per 2-week time block for small ports (6 trips per quarter), three random PSUs per 2-week time block for medium ports (18 trips per quarter) and two per 2-week block in large ports (12 trips per quarter). In Frame (a), sampling is with replacement (i.e. a sampling site could be visited more than once), and in Frame (b) without replacement. The sample allocation has been designed to provide roughly the same number of trips per tonne landed in each stratum.

Domains of interest within strata

The trips within a cluster may represent two or more domains of interest (e.g. metiers or fishing grounds). Provided the sampling is effectively random across all trips in the cluster, the occurrence of trips by domain should over time be equivalent to the occurrence in the fleet as a whole. Any requirement to sample a particular domain more intensively than another would require a means of accurately identifying the domain for all the trips in the cluster, at the time of sampling, and applying a higher probability of selecting trips of that domain. The danger of this approach is that the time required to sample those trips could result in the trips from some other domains having a zero probability of being selected, which could lead to some bias. A more subtle problem may occur if the rules for allocating trips to metiers in the census (log book) data cannot easily be applied by the sampling team on site (e.g. if target assemblage is decided by catch value rather than catch weight). In this case the sampling probabilities may turn out different from those planned.

5.2.8 Data processing and estimation

It is critically important that the stratification, and the sample selection method and sampling probabilities at different stages, are accurately reflected in the computational procedures for raising from the samples to the population. Stratum definitions used in the sampling scheme must also be applicable to the available population data used for raising, e.g. in EU logbook data. WKMERGE has focused mainly on the sampling of primary and secondary sampling units – i.e. down to the level of selecting fishing trips from clusters of trips either at access points on shore or representing the trips of individual vessels selected from a list. It is assumed that the procedures for selecting hauls within trips, sampling individual hauls or boxes of fish from a total landing, and selecting fish for length or age determination, are established. Estimation schemes are linked with sampling schemes in the examples in Section 6. Raising procedures for discards estimates are discussed at length in the report of the ICES Workshop on Discard Raising Procedures (ICES, 2007), including comparisons of some unequal probability methods such as ratio estimators.

The estimation of catch statistics and biological parameters for domains that cut across sampling strata requires careful consideration, ensuring that the weighting factors associated with the sample selection in each stratum are represented in the analysis. An example provided by Joël Vigneau to WKMERGE helps to clarify the requirements. The example is for two domains (metiers) M1 and M2 occurring in two sampling strata (North and South), and a third (M3) occurring only in the Northern stratum (Figure 5). The analysis problem is to obtain estimates for the metiers across strata. Table 2 lists some options and their merits.

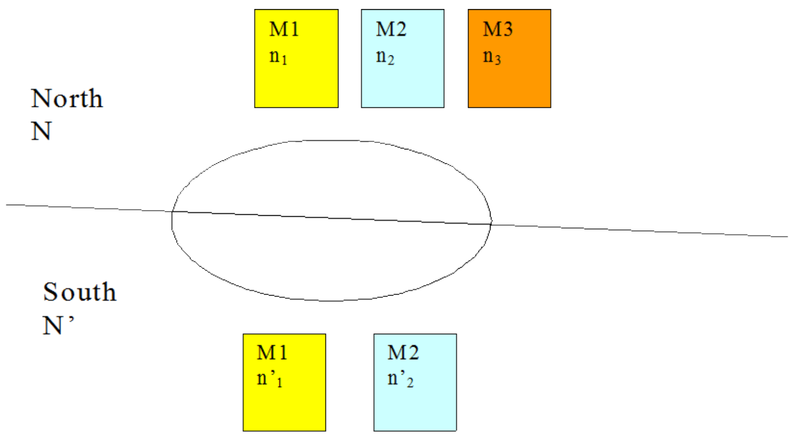


Figure 5. Theoretical example where two domains (metiers) M1 and M2 occur in two sampling strata (North and South), and a third (M3) occurs only in the Northern stratum. The n and n' refer to sample sizes (number of PSUs).

Table 2: Estimation formula for different combinations of metiers and strata, for situations with equal or unequal sampling probabilities in each stratum.

π_i = probability of sampling one unit in strata
x_i^1 = variable collected for unit i in metier 1

	Equi probability of sampling between strata	Raising method	Benefits	Drawbacks
Raising to the population				
1st solution	Yes	$\theta=\frac{N+N'}{(\sum n+\sum n')}(\sum_i x_i+\sum_i x_i')$	May be used to estimate the design effect. N by strata may be unknown	Irrespective of the stratification Likely to be biased
2nd solution	No	$\theta=\frac{N}{(n_1+n_2+n_3)}(\sum_i x_i^1+\sum_i x_i^2+\sum_i x_i^3)$ same calculation for θ' then $\theta=\frac{N}{N+N'}\theta+\frac{N'}{N+N'}\theta'$	Easy to calculate Likely avoiding gaps and poor sampling	Highly reliable on the randomness Accurate only for providing information at the strata level
Raising to the metier (M_1)				
1st solution	Yes	$\theta=\frac{N+N'}{(n_1+n'_1)}(\sum_i x_i^1+\sum_i x_i^1{}')$	Easy to calculate	Difficult to implement a sampling scheme with equiprobability over all population
2nd solution	No	$\theta=\frac{N}{n_1}\sum_i x_i^1+\frac{N'}{n'}\sum_i x_i^1{}'$	Easy to calculate	One domain may have received very poor or no samples
3rd solution	No	$\theta=N\frac{\sum_i x_i^1}{\sum_i \pi_i}+N'\frac{\sum_i x_i^1{}'}{\sum_i \pi_i'}$ (Horvitz-Thomson)		π_i not easy to evaluate
Merging of metier (M_2+M_3)				
1st solution	Yes	$\theta=\frac{N+N'}{(n_2+n_3+n'_2)}(\sum_i x_i^2+\sum_i x_i^3+\sum_i x_i^2{}')$		
2nd solution	No	$\theta=\frac{N}{n_1+n_2}(\sum_i x_i^2+\sum_i x_i^3)+\frac{N'}{n_2'}\sum_i x_i^2{}'$	Easy to calculate	One domain may have received very poor or no samples
3rd solution	No	Horvitz-Thomson		

The most important issue to address when metiers cut across stratum boundaries is ensuring that the selection of sampling units in each stratum provides representative sampling of the component domains (metiers), and that the raising factors for the metiers in each stratum are known exactly. The comments in Table 2 highlight some of the inherent estimation problems when metiers cut across strata. This further emphasizes the problems of over-stratification of sampling schemes, since the problems of missing or under-sampled strata become exacerbated if there is a need for additional estimates for domains that cut across strata.

6 Example application of fishery sampling schemes

6.1 Using an area-frame (indirect frame) to select access points for on-shore sampling

An example from Vølstad *et al.* (in prep) describing the design of a sampling scheme for small-scale artisanal fisheries in Mozambique is provided as a working document in Annex 5. It serves as a good example of how probability based sampling can be applied using an indirect area frame comprising lists of access points for sampling clusters of trips. The methods could be adapted to the majority of port sampling situations in European countries. Some of the main design aspects are summarised below.

Design of the sampling scheme

The **objectives** of the scheme are to obtain precise and unbiased estimates of total catch and effort, catch composition by species and size, and other important characteristics of the coastal small-scale fisheries in a district or province over time.

The **target population** in this case is all catches made by fishermen using beach seines, lines and gillnets along the coast of Mozambique. This is an artisanal fishery involving 70 000 fishermen fishing mostly at 658 coastal locations falling within a number of geopolitical strata.

The **sampling frame** is an area frame comprising a list of all sampling centres (access points for sampling) together with the information needed for setting up a probability based sampling scheme. The Mozambique fishery involves day trips, and hence the sampling frame comprises a lattice of **primary sampling units** (PSU) defined as sampling centre and day.

The **stratification** of the PSUs in the frame has four spatial levels of strata (Figure 6a). The Levels 1–3 are spatial strata, whilst Level 4 clusters sampling centres into "small", "medium" and "large" based on the amount of fishing activity. A time stratification by month is also adopted. The clustering of sampling centres by size permits the use of simple random sampling with sampling probabilities for each stratum adjusted according to the "size" variable, rather than sampling with probability proportional to size across all centres in an area / month stratum. For each PSU randomly selected from the sampling frame, the gears were stratified by type (seines, gillnets, and hand-lines). In most provinces, the survey only covers daytime fishing. In some areas where night fishing accounts for a significant component of the total catch, daytime (6:00 to 18:00 hours) and night (18:00 to 6:00 hours) strata were defined; with catch and effort sampling being conducted independently in each stratum. This temporal stratification was necessary because the effort, catch rates, and species composition differ significantly between day and night.

The **sampling scheme** is described by Vølstad *et al.* (Annex 5) as multi-stage lattice sampling, and the different stages of **sample selection** are as follows:

First stage sampling

The sampling frame is used in the first stage sampling as a mechanism for selecting a stratified random sample of fishing centres over time. To ensure good temporal coverage in each stratum, **restricted random sampling** (Jessen, 1978) is used. This involves selecting a fixed number of PSUs, at random, every week, in each of the level 1–3 spatial strata (Figure 6b). In each stratum, sampling is typically conducted on three randomly selected days per week, at three different sites. For seven sampling centres over seven days, this represents a probability of 3/49 of sampling any centre on any day. This design ensures that the probability of visiting any particular fishing centre at any particular day is equal within each geographic stratum. Strictly, this sampling scheme involves weekly temporal strata. In the analysis, however, these strata are pooled to monthly or quarterly temporal strata.

Second stage sampling

Second stage sampling is the selection of samples within a selected PSU. During a sampling trip for a selected PSU, the first task is to conduct a census of the number of active and passive fishing units by type (beach-seine, hand-line, or gillnet). The active fishing units in a PSU are then stratified by type. The field staff conducts the **second stage sampling** by selecting a random subsample of at least two active fishing units from each type of gear (Figure 6c). For these secondary sampling units, data are collected on catch in weight and numbers by species, and the size composition for selected species. Some socio-economic and meteorological data are also collected for each PSU. Note that the stratification of the PSU by gear type is done based on the on-site census and that all gears in the PSU are sampled with known probability. This is not equivalent to **quota based sampling** where a target is set for the number of trips to sample by gear type (or metier in the European context) in each stratum. Quota based sampling could lead to some gears not being sampled from a selected PSU either because too much time is spent sampling a particular gear to meet a quota, or if the quota is filled. When this occurs, the probability of sampling some gears in the PSU become zero.

Third-stage sampling

For the beach seine example in Figure 6c, a third stage of sampling occurs where a random selection of individual sets is made. (For port sampling schemes where vessels are landing catches aggregated over all hauls in a trip, this third stage would not be possible. However, for at-sea sampling schemes where not all hauls can be sampled due to time constraints, a third sampling level to select hauls within trips would be required.)

Fourth stage sampling

Subsampling the catches from a haul or set to collect data on length or age compositions represents a fourth stage of sampling.

Data analysis

The data analysis for the Mozambique fishery recognises the spatial and temporal stratification scheme and the multi-stage sampling design within strata. With reference to Figure 6c, the procedure for raising follows exactly the reverse of the sequence for the 4-stage sampling:

i) Raise from the stage 4 subsample taken from each set selected for sampling to the total catch for the set;

ii) Raise from the stage 3 sampled sets to all sets made during the day by the selected fisherman (equivalent to raising from the hauls within trips to the total trip on a fishing vessel);

iii) Raise from the fishermen selected at stage 2 to the total number of fishermen obtained from the census carried out at the sampling centre on the sampling day during the second stage (equivalent to raising from vessels sampled randomly during a port visit to all vessels landing during the period of the visit). This represents the total for the cluster of fishermen (or vessels) in the selected PSU.

iv) Raise from the PSUs sampled at Stage 1 to the total PSUs in the geographic stratum

v) Sum the raised stratum estimates to obtain the total for the sampling frame.

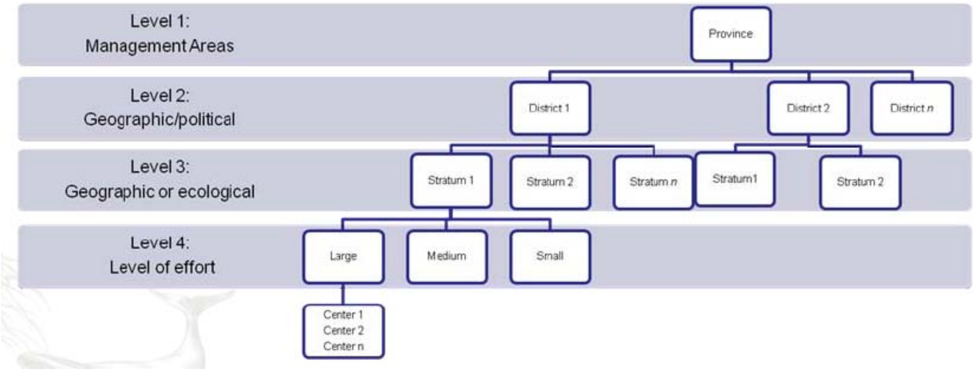
The PSUs sampled in a month are treated as random selections from all the PSUs in the month/ area/gear stratum. The weekly blocks, with three random PSUs per week, are pooled to monthly (4-week) strata. The weekly sampling was employed for scheduling purposes, and ensured that sampling was spread in time.

By adhering to the stages of sampling specified in the sampling scheme, the sampling probabilities required for the weighting factors are known at each stage, and the analysis correctly accounts for cluster sampling effects. A more detailed explanation of the Mozambique fishery sampling scheme is given in Annex 5 together with the formulae used for variance estimation.

Extension to European fisheries

Many European Member States have a diverse range of landing sites that may differ in their usage by fleet segments and also differ in the patterns of landing over periods of days or even within days. The situation is therefore analogous to the Mozambique example, differing only in scale and detail. Small-scale fisheries can be relatively important – for example the 10m and under segment of the English fishing fleet dominates the fleet numerically and landings are made daily at hundreds of sites including vessels hauled out on beaches. The steps taken in designing the Mozambique sampling scheme could therefore be adapted to almost any port sampling situation in Europe.

(a) Stratification by area and “size” of fishing centres



(b) Selection of Stage 1 PSUs in a 4-week temporal stratum with weekly subdivisions.

	Month 1													
	Week 1							Week 2						
Centre	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1			x											
2									x					
3														
4						x								
5												x		
6										x				
7				x										

(c) Sampling of catches on a selected day at a selected fishing centre (PSU stage 1)

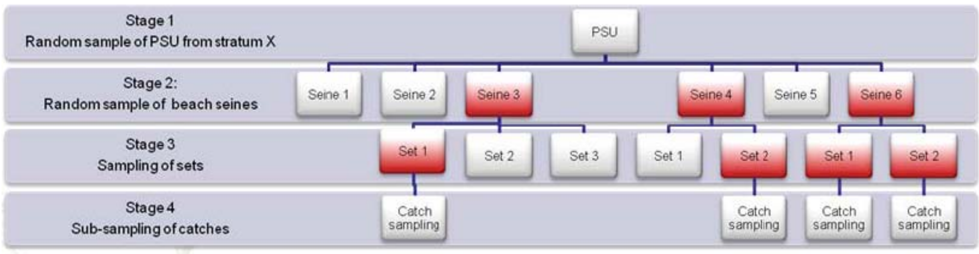


Figure 6. Stages in the design of an access-point sampling survey for small-scale fisheries in Mozambique.

6.2 Using a vessel list frame (direct frame) to select vessels for at-sea sampling

The way a fishery is structured and operates is the same whether the catches are sampled at sea or on shore. The goal of sampling is the same (e.g. estimation of length and age structure of catches; developing CPUE series; but in this case excluding data on discards). However, the use of a vessel list frame is typically more appropriate for at-sea sampling due to the need to arrange trips in advance.

The **target population** remains the same – all catches made by vessels using a variety of gears during the period for which aggregated data are required. A difference with port sampling is that a larger fraction of the population of vessels may not be accessible for sampling due to the vessels not being able to carry observers, skippers refusing to take observers, or the vessels landing in remote locations for which a decision has been made that it is too difficult or costly to sample.

The **sampling frame** is a regularly updated list of all the vessels that have a probability of being sampled. These may be restricted to the vessels only of the country carrying out the sampling unless there is a bilateral arrangement. The **primary sampling unit** may be the vessel. Auxiliary data, such as recent year's fishing effort or catches, vessel size or power, should be collated for each vessel to allow the use of pps or ratio/regression estimators or other model based estimators if required. In the NE USA observer programme described by Rago *et al.* (2005), the fishing trip is considered as the PSU rather than the vessel. The catch samples from the observed trips are assumed to provide random, independent data to estimate the variables of interest for each stratum. In the Rago *et al.* scheme, trip duration is used as a stratification scheme, and the variables of interest appear to be mainly ratios (ratio of discards to kept fish, or discards per unit effort). Hence the effect of variable trip duration might be reduced.

Theoretically it would also be possible to use the same type of sampling scheme used for port sampling, using an **area frame** and port-day type PSUs, to select trips for at-sea catch-sampling. This would involve:

1) Selecting ports/days (PSUs) within suitable strata,

2) Determining the number of vessels that are due to depart from the selected port and day or group of days (based on advance knowledge or a census on the day), and

3) For the selected port and days, selecting trips at random for observing at sea.

This selection scheme would allow control over the selection probabilities of trips, at least approximately, although in practice the knowledge of which vessels are due to depart from a port on a given day or days may be uncertain, and resources could be wasted if refusals to board vessels are not known in advance of the trip. A refusal may be more likely if the skipper has not been contacted in advance to arrange the trip. Accurate recording of departure dates for all individual vessels at the fleet level (e.g. from EU logbooks) would be required to allow the calculation of raising factors. In principle the landing date could be used in which case the sampled trips are assumed to be a random selection of trips by all vessels in the stratum landing on that day or group of days.

The **stratification** for selecting vessels and trips for at-sea sampling may be by fleet segment to help optimise sample levels for domains of interest such as metiers, and by time period (e.g. quarter). In this case it is necessary to allocate all vessels to fleet segments according to their dominant fishing activity (or to polyvalent if there is no dominant activity) and one or more groups of vessel LOA classes. Stratification by **area** could be done on the basis of lists of vessels associated with clusters of ports, if the departure and landing ports are sufficiently predictable. For the Mozambique small scale fishery, and probably most other small scale fisheries, fishermen and vessels are likely to be very restricted in their mobility between harbours and fishing grounds. Fairly accurate lists of vessels could therefore be available for defined stretches of coastline, and sampling probabilities can be well controlled. The observer scheme for demersal fisheries in NE USA described by Rago *et al*. (2005) uses this form of area stratification. However if vessels move unpredictably between geographic strata, which is more common for larger vessels fishing well away from the home port and landing in distant ports for periods of time, maintaining an accurate list of vessels for port groups could be difficult. Stratifying by **fishing ground** is considered below in the context of PSU selection.

The **sampling scheme** for a list-frame could follow any of the approaches outlined in Section 5.2.7.1. Multi-stage sampling (Allen *et al.*, 2002) will again be needed:

First stage sampling scheme

When the PSU is the vessel, the first stage is a selection of vessels to sample from all the vessels in the list frame for each stratum. The sample selection could use **simple random sampling** or sampling with **probability proportional to size** (an approach currently used by Sweden). If all trips of all the vessels are known in advance, it could be possible to use vessel trips as PSUs and to sample these at random within the strata or any temporal subdivisions used in a lattice scheme. There may be circumstances where a pps scheme used with vessels as PSUs leads to an approximately equal probability of sampling individual trips from all trips made by the fleet. In this case, the trips may pragmatically be treated as the primary sampling units in the estimation process.

Care needs to be taken if using ratio or regression estimators, or if more complex model based estimators are planned, as the relationship between discard rates or size/age composition and any auxiliary "size" variables such as quantity of retained fish, vessel LOA or power, trip duration etc. may be weak or could alter between the reference and sampling years (Cotter *et al*., 2002).

In practice, selection of vessels is usually arranged sufficiently in advance of a trip to make arrangements with the skipper. Refusals to take an observer must be recorded and the details of the vessel noted so that any auxiliary variables for that vessel can be retrieved to assist with imputation at the analysis stage.

A requirement for achieving sampling levels for individual fishing grounds could result in an attempt to use fishing grounds as strata rather than stratifying vessels according to geographic groups of ports. In this case, skippers of randomly selected vessels are asked what fishing grounds their forthcoming trips will take place in, and any other details such as fishing gear to be used or target species. Based on current achievements against a list of target numbers of trips per fishing ground per fleet segment and temporal stratum, a trip may be accepted or rejected. The total number of trips by each vessel in each fishing ground will not be known in advance, and the sampling scheme will probably set targets according to the number of trips in a previous year or the same quarter in the previous year. Hence the sampling probabilities are only forecasts and could alter dramatically (e.g. if fuel costs prevent vessels going to more distant fishing grounds). This is a form of **quota sampling** – which could result in poor control over sampling probabilities unless the distribution of fleet activities between fishing grounds remains stable over time.

Second stage sampling

If the PSU is the vessel, not the trip, then all the trips of that vessel in each sampling stratum become the secondary sampling units (see Figure 3). When a vessel is selected, a trip must also be selected from the list of possible trips of that vessel in the sampling stratum. If the vessel has day-trips, a random day could be chosen in advance (with some flexibility in timing to allow for weather etc.). Similarly, if the vessel is at sea for two weeks at a time, and fishes only on neap tides, a random month could be selected and a trip arranged for a suitable boarding day. A problem is that random selection of time periods can lead to trips on two or more selected vessels overlapping in time. This is compounded if too many spatial or gear strata are defined (an argument for minimising any stratification). Unless enough observers are available to cover overlapping trips, the timing has to be altered to avoid overlap. An approach adopted in England is to sample the vessels in the order of the random numbers allocated in the selection process, and spread the trips over the time stratum. The use of a lattice-type design with restricted random sampling (see Section 6.1 and Figure 3b) may help in managing the use of staff time for sampling.

Third stage sampling

The third stage sampling at sea is the selection of hauls to sample within trips. Cluster effects could lead to little gain in precision from sampling more than a certain fraction of hauls unless the vessel is moving between strata or domains.

Fourth stage sampling

The fourth stage is subsampling of individual hauls. Where there is a single observer, the method of subsampling catches may need to be relatively simple, but there are numerous potential sources of bias depending on the way in which the catch is presented for sampling and the time available. Accurate recording of raising factors at the haul subsampling level is essential as this is a potentially large source of error.

Data analysis

As with area-frame sampling, the data analysis for list-frame sampling must recognises the stratification scheme and the multi-stage sampling design within strata. The procedure for raising follows exactly the reverse of the sequence for the multi-stage sampling. For schemes where the vessel is the PSU, the following procedure would be used:

i) Raise from the stage 4 subsample from each sampled haul to the total catch for the haul;

ii) Raise from the stage 3 sampled hauls on a trip to all hauls made during the trip.

iii) Raise from the stage 2 sample (trip within vessel) to all trips made by that vessel in the sampling stratum. If the vessel is sampled two or more times, the estimates for the sampled trips should be combined before raising to the stratum. This represents the total for the cluster of trips in the selected stage 1 PSU (vessel) for the stratum.

iv) Raise from the PSUs (vessels) sampled at stage 1 to all the vessels in each stratum v) Combine the raised stratum estimates using appropriate strata weights to obtain estimates of catch characteristics for the total catch across strata (for the overall sampling frame.) Strata sizes can be total number of PSUs in the strata, or census data on total landings or effort.

If the PSU is defined as a trip (e.g. if the sampling frame is stratified according to expected average trip duration of each vessel, or if the required estimates are not correlated with trip duration), stage (iii) above can be omitted and stage (iv) involves raising from the trips (PSUs) sampled at stage 1 to the total number of trips in the strata. The strata sizes when combining estimates across strata would then be number of trips in the strata.

When estimating length compositions of retained fish from at-sea sampling, the raising factors at all stages should be derived using the total weight of retained fish for each species. However, if there is a possibility that logbook data on landings could be inaccurate, other raising factors from the sampled vessels to the fleets could be used (e.g. fishing effort). Various raising factors for discards estimates are discussed in ICES (2007), including ratio estimators such as ratio of discards to retained fish or discards per unit effort.

A number of issues need to be considered. Firstly a vessel could occur in more than one geographic stratum during a quarter, for example if it moves to a more distant port for an extended period part way through the quarter. In an unbiased, probability based scheme, the occurrence of selected vessels with this behaviour should be in proportion to their occurrence in the population of vessels in the list frame. If a primary domain of interest is to have estimates by **fishing ground**, representative sampling of vessels without any area stratification (or stratification by port groups) should also lead to sampled trips tending towards the same distribution across fishing grounds as in the population of vessels in the list frame. On the other hand, if an attempt is made to stratify sampling by fishing ground – a problem arises if the census data (e.g. EU logbooks) cannot adequately split the trips by vessels between fishing grounds (e.g. if the skipper allocates the whole trip to one ground despite hauls occurring in two or more grounds).

Discard raising procedures are considered in more detail in ICES (2007).

6.3 Combining estimates from different sampling frames

It is possible that data on length compositions of retained (landed) fish are obtained from a combination of samples collected at sea and on shore. However, if the at-sea samples and on-shore samples are collected using different sampling schemes (e.g. using a vessel list frame for at-sea sampling and an area frame for on-shore sampling), different estimation procedures are needed for each scheme.

One approach could be to produce separate estimates of the length composition of retained fish from each sampling scheme, and to combine the estimate using weighting factors. Appropriate weighting factors could be the inverse of the variance of the length composition estimates, or more simply the effective sample size from each scheme calculated taking into account the cluster sampling effects. The combined length frequency would then be raised to the best estimate of the landed weight for the fleet segment, quarter, area etc.

If data are to be combined in this way, the sampling schemes should be stratified in a way that allows estimation of lengths compositions for comparable strata. Before combining data from different schemes, an indicator of the accuracy of each sampling scheme should be conducted using the approaches given by WKACCU (ICES, 2008a).

7 Suitability of the sample frames used by each Member State for collecting data on metier-related biological variables required under the EU Data Collection Framework

This section addresses ToR (a) *Review the definition and suitability of the sample frames used by each Member State for collecting data on metier-related biological variables required under the EU Data Collection Framework. The need for consistent approaches between Member States to meet overall objectives will be addressed*

Attendees at WKMERGE were requested to bring to the meeting information on the design of their fleet based sampling schemes for collection of biological variables. A *pro-forma* was supplied to ensure consistent information from each Member State. The submissions were reviewed during the workshop to determine the extent to which the sampling frames, stratification schemes, allocation of sampling effort and sample selection methods conformed to the ideals for statistically robust, minimum bias sampling. After discussion and clarification, the *pro formas* were re-drafted and are available on the WKMERGE Sharepoint site. These do not represent all Member States.

The exercise was extremely useful for focusing on the basic sampling principles outlined above and helped WKMERGE attendees to understand the concepts of sampling frames, primary sampling units, strata and sample selection schemes for which descriptions are required in the National DCF Programmes of each member State. The exercise also highlighted a number of shortcomings in national sampling programmes. One of the main issues arising was incomplete coverage of target populations, both in terms of shore-based sampling sites and to a greater extent the exclusion of vessels from at-sea sampling schemes for various reasons.

8 Guidelines for a consistent approach to documenting the statistical design of sampling schemes for metier-related biological variables in each Member State's National Programme.

This section addresses ToR (e) *Develop guidelines for a consistent approach to documenting the statistical design of sampling schemes for metier-related biological variables in each Member State's National Programme*.

Commission Decision 2008/949/EC requires Member States to include in their National Programme submissions a description of the sampling schemes adopted for collecting métier-based biological variables. The Revised DCF Guidelines version 2009 (2011-13 NP) Sections III.C.1(c)–(e) and III.C.2 refer to the information required.

Based on discussions around the Pro-formas completed by WKMERGE attendees, a modified version with guidelines is included in Annex 10. This is recommended by WKMERGE as a suitable format for providing a minimum sufficient description of national sampling schemes for fleet-based biological variables, for inclusion in the DCF National Programmes for Member States to be submitted for 2011-13 and subsequent DCF periods. Refer to Section 5.2 for a full explanation of the information required.

9 Guidelines for determining the appropriateness for merging metiers or vessel LOA classes at the national and regional scale.

9.1 Defining metiers as domains of interest

WKMERGE recommends that the merging concept is more applicable to a-priori defining domains of interest e.g. metiers that are stable in time. This is distinct from establishing optimal stratification for sampling in order to provide the domain data. Sampling programmes at sea and on shore should follow the guidelines given in this report for defining sampling frames, primary and subsidiary sampling units, stratification schemes and sample selection schemes. The sampling design should be adapted to ensure that sufficient data are obtained, in a representative manner, to cover the metiers for which data are required, and too meet any requirements for precision of estimates or minimum sampling rates by metier.

The definition of metiers at level 6 in the DCF metier matrix (Commission Decision 2008/949/EC Appendix IV) as gear_target assemblage_mesh_band_selective device_device mesh, by fishing ground, can lead to very large numbers of metiers appearing post-hoc in national fleet activity databases. The DCF rules allowing vertical merging of metiers and/or merging of vessel LOA classes can allow groups of level 6 metiers to be collapsed into larger units on the basis that the merged metiers still represent homogeneous clusters of fishing operations of relevance to evaluation and implementation of fleet-based management measures. As discussed in Section 2.2, homogeneity is defined in this context as fishing operations with similar target assemblage and selectivity patterns.

The number of domains (metiers) for which data are required is a critical factor in determining the intensity and distribution of sampling across frames and strata. Merging metiers provides a means of reducing the number of domains for which data are needed. However, if this leads to a sampling programme providing only the minimum sampling needed for the merged metier, data extractions for finer-level metier definitions will suffer from very low sample sizes and instances of missing data within strata. Substantial additional sampling, at much greater cost, may be needed to provide adequate data for highly-resolved metiers.

Working Document 3 (Vigneau *et al*; Annex 7) notes that the identification of metier may be done following three approaches described by Marchal (2008): input-based, output-based and combined methods. Input-based methods make use of existing records of the technical features of fishing trips, usually available in fishers' logbooks (gear, mesh size, fishing ground, season) or are built on direct interviews with stakeholders. Output-based methods assume that catch profiles perfectly reflect fishing intention. Metiers can be identified by direct visual inspection using principal components analysis or automatically through a hierarchical cluster analysis algorithm. Combined methods categorize metiers by clustering catch profiles (outputs), then relating these clusters to fishing trip characteristics (inputs) using multivariate analysis. Vigneau *et al* (Working Document 3) uses the combined approach applied to fishing trips sampled at sea. This has the advantage over landings-based methods (e.g. Davie and Lordan, 2009) in using data on retained and discarded trips, but the very small sample size compared with fleet census based on EU logbooks is clearly a major limitation for applying multivariate techniques such as cluster analysis. Vigneau *et al* (Working Document 3) concluded that the scientific evidence to combine domains is as relevant as bringing scientific evidence to combine strata. The number of samples falling in combined domains will be more numerous than in distinct domains. *A posteriori* analysis would be required to evaluate differences between metiers within a domain.

Working Document 4 (Annex 8) utilises several statistical methods (equivalence trials, generalized regression neural network, and Bayes Meta classifier) to compare exploitation patterns (fish length distributions) between two gear types (midwater trawlers OTM, and midwater pair-trawlers PTM) used for small pelagic fish in Finland. Such approaches are useful for determining if differences between length compositions are meaningful or occur by chance. In the example given in WD 4, differences in length compositions were determined as chance occurrences, providing evidence that vessels using OTM and PTM for small pelagics can be treated as belonging to a single metier for sampling and analysis.

WKMERGE recommends further development and agreement of statistical methods e.g. multivariate methods for identifying homogeneous metiers that are stable over time and relevant to fishery management. The methods used in Working Documents 3 and 4 can serve as guidelines for doing such analysis. Any scientific evidence brought for grouping metiers should be discussed at DCF Regional Coordination Meetings for international agreement.

10 Develop guidelines for estimating biological and catch characteristics for collapsed (i.e. combined) metiers in cases of non- or poorly-sampled strata or metiers.

Over-stratified sampling designs and/or expectations from users to receive data on a much more detailed level than the available resources justify can result in undersampled or non-sampled strata. This is even more problematic for domains within strata. Excluding the missing strata from the analysis will lead to an unknown bias. Poorly sampled strata are also problematic if there are insufficient samples to estimate variance. A commonly used solution is to impute values for the missing data based on similar data from neighbouring spatio-temporal strata, or use other approaches such as modelling to predict values based on auxiliary variables available for all strata or domains (e.g. from census logbook data). The equivalent problem in fish stock surveys (e.g. missing or poorly sampled strata due to bad weather or the vessel breaking down) could be addressed using spatial modelling techniques such as General Additive Models to predict the catch rates in missing strata. The success of this depends on the spatial distribution pattern remaining stable over time. Potential biases caused by such imputation techniques should be evaluated.

Methods for imputation of "missing data" in fishery sampling programmes are frequently used both at a national and at an international level. A potentially major problem occurs if data "borrowed" from other strata are put into a database as if they are real observations. In some cases such imputation may be automated inside databases (e.g. automated search routines to locate nearest samples). Unless such data are clearly referenced in the database as imputations and can be excluded from analyses, it would be difficult to assess the quality of the data and to distinguish data from actual observations rather than imputation. This practice would also restrict the use of the data, for example it would not be possible to statistically compare catch composition in trawls with and without selection panels if data have been borrowed between those cells.

All imputation should be done at the data analysis stage, using data that represent actual observations. Only then can the biases due to missing data be properly evaluated (see ICES WKACCU (ICES, 2008a)). Procedures for imputation at the analysis stage require expert knowledge on the characteristics of the domains. A cautionary tale on the use of ill-informed imputation techniques is from the Danish and Swedish demersal trawl fisheries in the Kattegat. These could be considered quite similar but are governed with different national management systems. In one year Danish discard data were missing in one quarter, and single-species discard rates (kg discards per kg landed weight) from the Swedish fishery were applied to the Danish landings figures. Unfortunately it was prohibited to land cod in Sweden during this period resulting in a discard rate of 99%. The Swedish fishery was characterised by low effort and low landings while the Danish one was going on as usual. As a consequence of using the Swedish discard rate on the Danish landing figures the Danish cod discards was estimated to be 12 000 tonnes (at the time SSB was estimated to approximately 2000 tonnes.

WKMERGE makes the following recommendations regarding imputation:

- Sampling programmes should be designed in a robust way avoiding over-stratification, minimising the risk of empty cells.
- Data users should be informed on the level of resolution of domains (metiers) for which robust data can be expected given the available resources for data collection.
- Automated imputation of missing data in databases should be avoided. If it is carried out, all imputed data must be clearly referenced in the database so that they can be excluded from any analyses, and the imputation methods clearly documented.
- Expert knowledge of the fisheries is needed when designing imputation methods for data analysis.
- Extreme caution should be taken in borrowing data from a metier sampled by one country to impute values for the same, but non-sampled, metier of another country. Different management measures operating in different countries exploiting the same stocks could lead to quite different catch compositions, for example different discard rates due to country-specific quota uptake, market forces, fish avoidance measures or other differences in activities in the same metier.

11 Concluding remarks and recommendations

The proposals for sampling schemes given in WKMERGE are intended for demonstrating the principles behind statistically robust fishery sampling schemes but should not be considered as exhaustive. Other unbiased approaches achieving the same goals are possible and may be more appropriate for particular national circumstances.

The key features of good sampling schemes for at-sea and shore based sampling include:

- Use robust statistical designs rather than ad-hoc, opportunistic sampling
- Use sampling frames that maximise the coverage of the target population

- Fully document all non-accessible population elements and reasons for non-accessibility
- Use stratification that is stable over time allowing controlled sample probabilities
- Treat potentially unstable fleet components such as Level 6 metiers as domains
- Avoid over-stratification – better to have representative, optimised sampling of fewer strata than to have under-sampled and missing strata requiring imputation
- Ensure that the variables for designing sampling strata are represented exhaustively in the fleet census data used for calculating raising factors
- If domains cut across strata, ensure that accurate weights for raising the samples from the domains to the fleet level in each stratum can be obtained
- Include systematic sampling (with random elements) where appropriate to improve temporal coverage and allow more efficient use of staff time
- Use predominantly design-based sampling schemes even if planning to use model-based approaches.
- Avoid unequal probability methods such as probability-proportional-to-size if the correlation with the auxiliary variables is likely to be unstable over time
- Ensure vessel list frames are updated immediately prior to the vessel selection period.
- Do not assume that a random selection of vessel PSUs from a list frame is equivalent to a random selection of trips within a stratum, if trip duration is skewed within the population of vessels in the stratum (e.g. more vessels with short trips)
- Ensure that sampling schemes are easy to interpret and implement, for example by contract staff with limited knowledge of sampling theory

A number of recommendations are given in the report, and these are summarised in Annex 11, with an indication of who should follow up the recommendations.

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Annex 2: Agenda

Joint ICES-STECF Workshop on methods for merging fleet metiers for fishery based sampling [WKMERGE] (Co-Chairs: Mike Armstrong, UK, and Jon Helge Vølstad, Norway)

Location: ICES Copenhagen

Dates: 19 – 22 January 2010

Meeting start time: 09:30 Tuesday, 19 January

Meeting end time: 12:00 Friday, 22 January

Draft Agenda (original agenda – modified as meeting progressed)

Tuesday 19th January:

Background information and theoretical aspects

1) General introductions

2) Overview of requirements for metier-based biological variables (Mike Armstrong)

3) Defining metiers and allocating individual trips to metiers (includes ToR (b))

- Identifying clusters of fishing trips that have catches with similar biological characteristics, using multivariate methods – (Ifremer presentation)
- What other statistical methods can be used to demonstrate that two or more fleet metiers, or two or more vessel LOA groups, are sufficiently "homogeneous" to allow merging into larger combined metiers for sampling or analysis? (Jon Helge Vølstad)
- Round table presentation - National approaches to merging metiers

4) Design of sampling schemes for metier based biological sampling, drawing on WKACCU and WKPRECISE reports (Jon Helge Vølstad) (ToRs (a) – (c)).

5) Analysis of metier-based biological sampling data (Jon Helge)

- Conditions for post-hoc collapsing of metiers, LOA classes or other sampling strata in the event of undersampling; estimating precision of estimates from collapsed metiers / strata. (ToR (d))
- Other relevant aspects

6) Identify case studies for examination on Wednesday.

Wednesday 20th January

Morning

7) Presentation and discussion of national sampling schemes focussing on the appropriateness of the objectives, sampling frames and sample selection process in relation to ToRs (a) and (c), based on "pro-forma" reports.

8) Agree schedule for text drafting

Afternoon

9) Afternoon: Drafting of text including ToR (e).

Thursday 21st January

Morning

9) Review of drafted text so far; continued text drafting.

Afternoon

10) Continued drafting of text. Plenary at end of day to review progress.

Friday 22nd January

Morning

11) Review of remaining text

12) Responsibilities and deadlines for post-Workshop completion of report.

Annex 3: List of presentations and working documents

Presentation by: Mike Armstrong: Introductory material and background information for WKMERGE

Working Document 1 & Presentation by Jon Helge Vølstad. *Probability-based survey techniques for monitoring catch and effort in the Coastal small-scale fisheries in Mozambique*. Vølstad, J.H., A. P. Baloi; P. Santana Afonso; N. de Premegi; and J. Meisfjord

Working Document 2 & presentation by Jöel Vigneau: *Looking for a methodology for drawing a discards sampling plan*: Lise Guerineau, Joël Vigneau

Working Document 3 & presentation by Jöel Vigneau: *Test case on differentiating metiers based on their catch composition*. Joël Vigneau, Mathieu Merzereaud, Lise Guerineau, Christian Dintheer.

Presentation by Jöel Vigneau: Formulae for combining metier data across sampling strata.

Presentations of national sampling programmes using *pro-forma*:

Spain	LuciaZarauz
Sweden	Katja Ringdahl
Scotland	Alastair Pout
Denmark	Henrik degel
Latvia	Ivi Sics
France	Joël Vigneau
Germany:	Ulrich Berth
Malta	Francesca Gravino
England	Mike Armstrong
Netherlands	Stijn Bierman
Belgium	Els Torreele

Annex 4: FAO fleet definitions from FIRMS project

The latest development on the notion of 'fishery' has been carried out by the FAO FIRMS[2] project. The project intends to make a worldwide inventory of fisheries, and had to face the issue that the concept of a fishery encompasses an inherent complexity also referred as “multifaceted”, due to the various perspectives/perceptions people have on fisheries. The definition that the FIRMS partners agreed, quoted from the document Fisheries Inventory: Methods and Guidelines (FAO, 2009) is the following:

Fishery: “A Fishery is an activity leading to the harvesting of fish, within the boundaries of a defined area. The fishery concept fundamentally gathers indication of human fishing activity, including from economic, management, biological/environmental and technological viewpoints (FIRMS 2006, modified from FAO glossary of fisheries)”.

With this definition, fisheries may be described following three approaches:

1) A Fishery Resource approach refers to elements of natural aquatic resources (biotic element) which can be legally caught by fishing. Examples include:

- "Deep-sea shrimp fishery", where reference is made to the resources of shrimps in deep-sea waters off Angola;
- “Shrimp and groundfish fishery – Gulf of Paria”, where reference is made to the resources of shrimps and groundfish in gulf of Paria, in Trinidad and Tobago waters

2) A Jurisdictional approach emphasises geopolitical and institutional boundaries which provide legitimacy for development of management systems. It describes the set of governing rules agreed within a recognized legal framework for the management of a fishery or group of fisheries. For example:

- “Commonwealth fisheries” (Australia), where reference is made to Australian fisheries operated within Australian Commonwealth waters and managed at federal level (as opposed to those occurring within state territorial waters and managed at state level);
- “Alaska fisheries”, where reference is made to the USA Alaskan fisheries operated within the NPFMC management system;
- "Municipal fishery - Philippines", where reference is made to the Philippines fisheries occurring within a jurisdiction area of a 15-km coastal waters strip, and managed by local municipal and city government under municipal management systems.

3) A Production System approach identifies homogeneous segments of the means of production (e.g. vessel type, fleet segments, or fishers’ communities) including through consideration of their enterprise or livelihood strategies, and focuses on the description of their socioeconomic aspects. For example:

- "Coastal trawlers - Italian Adriatic coast", where reference is made to the fleet of coastal trawlers based in the various ports of the Italian Adriatic coast and operating according to the same enterprise strategies;

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[2] Fishery Resources Monitoring System, see FIRMS at http://firms.fao.org/firms

- “Family-scale fishing and rice field fisheries”, where reference is made to household communities in Cambodia basing their subsistence strategies on mixed fishing and rice culture activities.

In addition of the three fundamental approaches, other main approaches can be derived by combining these fundamental ones:

1) A Fishery Management Unit approach highlights those harvested fishery resources under management considerations. A fishery management unit evolves from a resource focus, while taking into account the jurisdiction within which the resource is managed, e.g:

- "Toothfish – South Georgia Maritime Zone", where reference is made to the harvested toothfish resources under CCAMLR-South Africa joint management responsibilities.

2) A fishing activity or metier approach stresses the fishing activity component and identifies classes of fishing activity implemented by a fishing fleet or fishermen community. This approach is positioned at the crossroads of the production system approach and the resource. For example:

- "Offshore flatfish trammel netting", which refers to fishing activities using trammel nets for catching flatfish in offshore waters of the French continental shelf.

3) An access rights approach identifies means of production authorized to operate within a jurisdiction, for example:

- "European industrial fisheries", where reference is made to the European fishing fleet authorized to operate in Senegalese waters under the Senegal-EU fisheries agreement.

Annex 5: Working Document 1: Probability-based survey techniques for monitoring catch and effort in the Coastal small-scale fisheries in Mozambique

Probability-based survey techniques for monitoring catch and effort in the Coastal small-scale fisheries in Mozambique

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Abstract

Catch and effort data form an important, and often the only, source of data for fish stock assessment and management in developing countries. Population parameters and management quantities important for stock assessment are often estimated by fitting production models to standardized series of catch-per-unit-effort. Such basic information is notoriously hard to obtain for small-scale fisheries because of spatial and temporal variability in effort, the numerous landing sites, and limited access to landings sites for biological data collections. In this paper we present probability-based survey sampling methods for the monitoring of the small-scale fisheries in Mozambique. The access point survey implemented is an on-site intercept design that supports estimation of monthly and annual catch and effort and other key statistics for the coastal fisheries in a geographic area. Estimates of catch and effort, with associated relative standard errors, for beach seine fisheries in two provinces are used to illustrate the applicability of the methodology. The flexible survey design is now used to monitor small-scale fisheries in all provinces of Mozambique. We also present an alternative method for obtaining approximate estimates of the variance of total catch for a region when the coverage of fishing centres is incomplete. An estimate of the proportion of days each gear is fished by month is first used to adjust effort based on census data on total number of gears. The adjusted effort is then combined with estimates of CPUE to estimate catch. Results suggest that the estimation of effort from a frame survey alone would introduce substantial bias of variable magnitude because fishing activity depends on weather conditions and socio-economic factors.

1. Introduction

Mozambique is a developing country in southeast Africa, with one of the world's lowest GDPs and per capita income. Yet, Mozambique has potentially extensive fisheries resources that could contribute not only to an improvement in GDP but to enhance the socio-economic plight of many in its large population (~18 million). For many years, the offshore industrial prawn fisheries have been a key component of export for foreign exchange earnings and national income. However, the small-scale coastal fishery, largely driven by an artisanal sector, contributes significantly to the informal economy, especially at the local level, and is a major source of protein for coastal residents. Small-scale fisheries take place throughout the extensive coastline (2780 km) at different levels of fishing effort, with yearly landings that account for the largest part of domestic fish consumption (Charlier 1995).

In a 2002 census conducted by the Institute for Development of Small-scale Fisheries (IDPPE), it was estimated that approximately 70,000 fishers were involved in the artisanal fisheries in Mozambique, with a majority of the effort associated with 658 fishing centres (IDPPE 2002). This represents an increase of about 10,000 fishers since the 1996 census. Despite the importance of the coastal marine resources to a large sector of Mozambique's population, little information was available for assessing the sustainability of the small-scale fisheries, or the characteristics of their landings, before the implementation of the current monitoring survey.

Rational decisions concerning future management and development of the small-scale fisheries in a province or district require reliable data on catch and effort. Population parameters and management quantities important for stock assessment can be estimated by fitting production models to standardized series of catch-per-unit-effort (Xiao 1998). However, such basic information is notoriously hard to obtain for small-scale fisheries (Pauly and Mines 1982; Munro 1983). Many studies of artisanal fisheries rely on a census of landing sites at some intervals in time, combined with regular sampling of effort and landings from a small subset of fishing centres (e.g., Stomatopoulos 2002) that often are selected ad-hoc. In the census of landing sites, often referred to as a frame survey (Caddy and Bazigos, 1985), the number of vessels (by type), fishing gears, and fishers are typically recorded. The total effort (boat days) for a time period is estimated by adjusting the potential number of boat days for the expected activity level. Total catch over a time period is then estimated by extrapolating mean catch-per-unit-effort (CPUE) from the intercept samples to the estimated effort. Such estimates of total catch may be subject to bias when estimates of fishing effort, CPUE, and composition of the landings estimates are based on sampling through time in a few centres chosen ad-hoc. Probability-based sampling provides an alternative approach for assessment and monitoring of artisanal fisheries (e.g., Solana-Sansores and Arreguín-Sánchez, 1990). In this paper we present a probability-based multi-stage survey that is used to monitor the small-scale fisheries in Mozambique, where the sampling frame is a matrix of landing sites and days. The fishery concerned operates from beaches, or in near coastal waters (generally within 5 km), and is dominated by beach seines, hand-lines, and gillnets deployed by a mixed fleet of vessels less than 10 m in size. Vessels usually conduct daily fishing trips using one type of gear, but in some cases multiple gears are employed simultaneously. The vast majority of fishing trips can be accessed for sampling at a finite list of fishing centres along the coast.

The overall goal of this study was to develop survey methods that support precise and unbiased estimates of total catch and effort, catch composition by species and size, and other important characteristics of the coastal small-scale fisheries in a management unit (district or province) over time. The access-point survey presented here is an on-site; intercept design (Hayne, 1991; Pollock *et al*., 1994; Vølstad *et al*., 2006), similar to survey designs used for estimating catch and effort in recreational fisheries in many developed countries. The survey has been implemented in all coastal provinces in Mozambique (Figure 1) with various level of sampling cover of the major components of the small-scale fisheries. Yearly estimates of catch and effort for beach seine fisheries from 1997 to 2003 are presented for Inhambane Bay, where the sampling frame covers nearly all the landing sites, and for one district (Angoche) with incomplete sampling coverage.

2. Methods

2.1. The sampling frame

The sampling frame was derived from a map of fishing centres (landing sites) in the study area, using comprehensive information from the 1996 atlas of the artisanal fishery (IDPPE, 1996) and the 2002 national census conducted by the Institute of Small Scale Fisheries (IDPPE, 2004). We used lattice sampling (Jessen, 1978) to schedule the sampling of fishing centres over time. The sampling frame was created by designating days as columns, and fishing centres as rows. Fishing centres were stratified geographically, by management unit, by size, and based on ecological considerations (Figure 2). The primary sampling units (PSUs) are the combination of days and fishing centres (Figure 3). Management of the small-scale fisheries in Mozambique is done on a provincial or district level. In the stratification of fishing centres within a district, we took into account available resources for field operations, distances between fishing centres, and traveling times necessary to visit them. Fishing centres within a district are generally grouped into geographic strata that can be covered by one sampling crew. Large fishing centres that cannot be covered by one crew are designated as separate strata, and further divided into zones (substrata) that can be covered by one crew each. Some geographic strata were sub-stratified by other characteristics, such as expected activity-level and type of gears used.

Assume that a geographic stratum h in a district contains F_h fishing centres. We are interested in estimates of total catch, effort, and the composition of the landings across all centres for a time period of D days; temporal strata of one month are used to improve the estimates of yearly catch and effort. The sampling frame for scheduling representative sampling over time and space is the lattice of $N_h = F_h \times D$ primary sampling units (PSUs). For each PSU randomly selected from the sampling frame, the gears were stratified by type (seines, gillnets, and hand-lines). We initially stratified the fishing days into weekdays and weekend days because we expected significant differences in daily effort. Results from the survey, however, indicated that the mean daily effort were similar between weekends and weekend days. Thus, we abandoned this temporal stratification for simplicity.

In most provinces, the survey only covers daytime fishing. In areas such as Maputo Bay and Inhambane Bay, however, where night fishing accounts for a significant component of the total catch, daytime (6:00 to 18:00 hours) and night (18:00 to 6:00 hours) strata were defined; with catch and effort sampling being conducted independently in each stratum. This temporal stratification was necessary because the effort, catch rates, and species composition differ significantly between day and night.

2.2. Multi-stage lattice sampling

The objective of the monitoring survey is to collect data on catch, effort, and biological characteristics that are representative for the total catch over a time period (e.g., monthly or yearly). This was achieved through spatial and temporal stratification and multiple stages of selection:

<u>In the first stage</u>, we used the sampling frame as a mechanism for selecting a stratified random sample of fishing centres over time. To ensure good temporal coverage

in each stratum, we used restricted random sampling (Jessen 1978), with sampling of fishing centres scheduled on random days during each calendar week from each stratum. This design ensures that the probability of visiting any particular fishing centre at any particular day is equal within each geographic stratum. For each week, sampling is typically conducted on three randomly selected days within each stratum.

In the second stage, a census of the number of active and passive fishing units by type (beach-seine, hand-line, or gillnet) is conducted for each PSU. The active fishing units in a PSU are then stratified by type. The field staff conducts the second stage sampling by selecting a random subsample of at least two active fishing units from each type of gear. For these secondary sampling units, data are collected on catch in weight and numbers by species, and the size composition for selected species. Some socio-economic and meteorological data are also collected for each PSU. Examples of multi-stage sampling designs are in Figures 4a, and 4b.

Within a primary sampling unit it is generally advantageous to sample dominant gears more frequently than gears with less fishing effort and catch. In practice, however, the sampling effort within each PSU is determined by logistics. When only one crew is available, the sample sizes within a day will largely be fixed. The allocation of sampling effort among gears within a PSU, however, might be based on their relative importance, with more samples allocated to the gear that catches most fish. At a minimum, two subsamples are collected from each gear to support the estimation of variance components.

2.3. Field data collections

Local agents contracted by the National Institute of Fisheries Research (IIP) in Mozambique collect field data. The agents generally live in the neighborhood of the fishing centre(s) they cover, to minimize travel cost and facilitate access. At each selected PSU, the agents record total number of active and passive gears, and then collect catch samples from a representative sample of fishing units for each type of gear (Figure 4 a,b). The procedures for subsampling of individual catches generally follow methods described in Gulland (1969), Pauly (1983), Sparre and Venema (1992), and Anon. (1999), adapted to local fishing practices on a case-by-case basis. Number of fish and total weight by species is recorded for each catch; size composition is recorded for a limited number of species. Samples of catches are generally conducted from completed fishing trips, with exception for some beach seine fisheries, where samples are collected for a subsample of all sets.

2.4. Quality Control

A rigorous quality control (QC) system is implemented by IIP at all levels, following recommendations in Pollock *et al.* (1994). The QC begins with training of the agents, and extends through regular visits in the field by IIP biologists to monitor their performance, checks of field data, data entry, and analysis. The database used for storage and reporting includes numerous checks to identify input data that are out of range. The QC of field collections and data entry includes three levels: (1) A biologist visits with each agent in the field once per month during the implementation of sampling in a stratum, and once every two months thereafter; (2) A meeting with all field agents in a province, held once per year to ensure consistent data collection; and (3) A national meeting between IIP supervisors and provincial coordinators of field collections, held once every two years to ensure consistency among provinces.

2.5. Estimating total catch

Complete sampling coverage

When the sampling frame (lattice consisting of fishing centres and days) includes all fishing centres in a region, the total catch can be estimated without bias from the stratified random samples of PSUs using standard design-based methods (Cochran, 1977; Jessen, 1978). For stratum h, assume that a simple random sample of n_h primary sampling units (PSUs) is selected from the complete list of N_h units in the sampling frame. Further, let M_{hi} denote the total number of active fishing units of a particular type recorded in a census within the i th PSU. In most cases, catch data from completed fishing tips are collected for each gear type from a representative subsample m_i of the active fishing units. For seine fisheries conducted directly from the beach, however, the total catch for a fishing unit during a sampling day is typically estimated by extrapolating the mean catch for a subsample of sets to all sets completed by the fishing unit during that day. In the following estimating equations c_{hij} represents the total catch for unit j of a gear type sampled from the active units in the PSU ($j = 1, \ldots, m_{hi}$), either observed directly or estimated. Let $\hat{C}_{hi}$ be an estimate of the total catch for all fishing units of a particular type (e.g., seines) for PSU i, obtained by extrapolating the mean catch per unit for the m_{hi} units in the sample to all active units M_{hi}. An estimator for total catch in the geographic stratum h is then obtained by extrapolating the mean catch per PSU to all units in the sampling frame,

$$\hat{C}_h = \frac{N_h}{n_h} \sum_{i=1}^{n_h} \hat{C}_{hi} \qquad (1).$$

An estimator for the variance of (1) is:

$$v\left(\hat{C}_h\right) = \frac{1}{n_h - 1} \left\{ \frac{N_h^2}{n_h} (1 - f_h) \sum_{i=1}^{n_h} \left(M_{hi} \bar{c}_{hi} - \frac{\hat{C}_h}{N_h} \right)^2 \right\} + \frac{N_h}{n_h} \sum_{i=1}^{n_h} M_{hi}^2 (1 - f_{hi}) \frac{s_{hi}^2}{m_{hi}} \qquad (2)$$

where $\bar{c}_{hi}$ is the mean catch of the m_{hi} fishing units sampled in PSU i in stratum h, $f_h = n_h / N_h$ is the sampling fraction of PSUs, $f_{hi} = m_{hi} / M_{hi}$ is the sampling fraction of active fishing units within the i^{th} PSU, and

$$s_{hi}^2 = \frac{1}{m_{hi} - 1} \sum_{j=1}^{m_{hi}} \left(c_{hij} - \bar{c}_{hi} \right)^2$$

is the estimated (population) variance in catches between fishing units within PSU i (Cochran 1977, pp. 300-303; Wolter 1985). The relative standard error (RSE) of the estimated total catch in stratum h is $\sqrt{v(\hat{C}_h)} / \hat{C}_h$ (Jessen 1978). The above equations can be extended to estimate total catch for all fishing gears in stratum h by using standard stratified estimators to obtain estimates of total catch across gears within each PSU. When only a small fraction of PSUs (< 10%) is sampled, it should be noted that the variance of (1) can be computed from primary sample values only (see Cochran, 1977, p. 279; Særndal *et al.*, 1992), thus greatly simplifying the estimator (2). In this case, it can safely be assumed that sampling of PSUs is conducted with replacement, eliminating the need for a finite population correction factor at the first stage as used in equation (2).

An estimator for the total catch across all strata ($h = 1,..., L$) in a district (or province) is

$$\hat{C} = \sum_{h=1}^{L} \hat{C}_h \qquad (3),$$

where $\hat{C}_h$ is the estimated total catch in the h^{th} stratum (1). An estimator for the variance of (3) is

$$v\left(\hat{C}\right) = \sum_{h=1}^{L} v\left(\hat{C}_h\right) \qquad (4).$$

Equations (1) to (4) can also be used to estimate catch for a particular species, using samples of catch composition to estimate proportions of each species for individual trips. These proportions are used to restrict the input data for each trip to catch for a species of interest before applying the above catch equations.

Incomplete sampling coverage

It is not feasible to include all fishing centres in every district in the sampling frame because of limited access, and other logistical constraints. In some cases, a model-based method might be used to provide an estimate of total catch for centres where no catch samples are collected. The frame survey (census) conducted by IDPPE at regular intervals in Mozambique may be used in conjunction with information from the probability-based lattice survey to obtain approximate estimates of total catch for centres outside the frame in many regions. When the centres outside the sampling frame for a region are intermingled with centres in the frame, we believe that it is reasonable to apply the CPUE estimates from the survey to the centres outside the sampling frame. Estimates of the activity level, as measured by the 'boat activity coefficient' (Stomatopoulos, 2002), furthermore, can be used in conjunction with census data on the number of boats per fishing centre to obtain estimates of effort for groups of fishing centres outside the sampling frame. In the probability-based survey, the total number of active (M_{hi}) and passive (M''_{hi}) fishing gears is recorded for each PSU i in stratum h. This information can be used to estimate the proportion of boats (fishing units) that are active (fishing) during a typical fishing day in each month ($\hat{p}_h$). Assume that a total of M'_h gears of a specific type were recorded for fishing centres outside the sampling frame, but within the same geographic region as stratum h. Let $\hat{E}'_h$ be an estimate of total effort during D fishing days for fishing centres outside the sampling frame in stratum h, and let $\hat{R}_h$ be an estimate of the catch rate overall, or for a species of interest. An estimator for regional total catch for the centres outside the frame in stratum h is

$$\hat{C}'_h = \hat{E}'_h \times \hat{R}_h \qquad (5),$$

with approximate variance

$$v\left(\hat{C}_h'\right) = \hat{E}_h'^2 \times v\left(\hat{R}_h\right) + \hat{R}_h^2 \times v\left(\hat{E}_h'\right) - v\left(\hat{E}_h'\right) \times v\left(\hat{R}_h\right). \qquad (6)$$

The catch rate and its variance is estimated by equations (14) and (15), and the effort is estimated by

$$\hat{E}_h' = p_h \times M_h' \times D \qquad (7)$$

with variance

$$v\left(\hat{E}_h'\right) = \left(M_h' \times D\right)^2 \times v\left(\hat{p}_h\right) \qquad (8)$$

where

$$\hat{p}_h = \frac{\sum_{i=1}^{n_h} M_{hi}}{\sum_{i=1}^{n_h} \left(M_{hi} + M_{hi}''\right)} \qquad (9)$$

is the boat activity coefficient estimated from the probability-based sampling of fishing centres over time. The variance of (9) is estimated by the jackknife method (deleting one PSU at a time), or by Taylor approximation (Pollock *et al.*, 1994). The activity coefficient generally varies seasonally because of changes in weather conditions, and for socio-economic reasons such as religious ceremonies and migration of effort between strata. Thus, the above adjustment is necessary to obtain accurate estimates of effort for each stratum.

An estimate of total catch over time across all fishing centres in a region with incomplete coverage is the sum of the estimated catch for the centres covered in the survey ($\hat{C}_h$) and the imputed catch ($\hat{C}_h'$) for centres outside the sampling frame. The approximate variance of the total catch is the sum of the respective variances.

2.6. Size composition of total catch of a species

Representative estimates of size composition of the total catch for a particular species can be obtained by using the above catch estimators successively, with numbers caught by size class as input data. Samples of catch composition are first used to estimate the proportion of fish by size for each trip observed. The proportions are then applied to generate catch in numbers by size class for each trip. The size composition of small pelagic species is measured in 0.5 cm intervals, while 1 cm intervals are used for larger fish.

2.7. Estimating Effort

Estimates of the total effort for a specific fishing unit during a time period (i.e., number of active fishing days across all beach seines during a month or a year) in stratum *h* is based on the data from the sample of n_h primary sampling units from the lattice of landing sites and days. Let M_{ih} be the total number of active fishing units of a particular type (e.g., seines) in PSU i within stratum h. An estimator of the total effort for this gear across all landing sites and days in stratum h is

$$\hat{E}_h = \frac{N_h}{n_h} \sum_{i=1}^{n_h} M_{ih} \qquad (10)$$

with variance

$$v\left(\hat{E}_h\right) = N_h^2\left(1 - f_h\right)\frac{s_h^{\ 2}}{n_h} \tag{11}$$

where

$$s_h^{\ 2} = \frac{1}{n_h - 1}\sum_{i=1}^{n_h}\left(M_{hi} - \overline{M}_h\right)^2$$

and $\overline{M}_h$ is the mean number of active fishing units for the observed PSUs in stratum h. Total effort is obtained by summing over all strata

$$\hat{E} = \sum_{h=1}^{L}\hat{E}_h \tag{12},$$

with variance

$$\mathrm{v}(\hat{E}) = \sum_{h=1}^{L}\mathrm{v}(\hat{E}_h) \tag{13}.$$

2.8. Estimating Catch-per-unit-effort

The catch-per-unit-effort (CPUE) within a stratum h is estimated as the ratio of total catch and effort

$$\hat{R}_h = \frac{\hat{C}_h}{\hat{E}_h}. \tag{14}$$

This estimator for catch rate is equivalent to the ratio of means method, and is appropriate for complete trip data (Pollock *et al.*, 1994, p. 221). The variance of (14) can be estimated by a Taylor series approximation (e.g., Seber 1982, Chapter 2; Pollock *et al.*, 1994, p. 229). However, since the sample size n_h is small in each spatiotemporal stratum (~ 12 PSUs per month), we use the jackknife estimate of CPUE, and its standard error (Cochran, 1977; Efron and Gong, 1983). The jackknife estimator of the variance of (14) is

$$v\left(\hat{R}_h\right) = \frac{\left(n_h - 1\right)}{n_h}\sum_{i=1}^{n_h}\left(R_{(hi)} - R_{(h\cdot)}\right)^2 \tag{15}$$

where

$$R_{(\mathrm{hi})} = \frac{\sum_{i\neq j} M_{hi}\overline{c}_{hi}}{\sum_{i\neq j} M_{hi}}$$

is the CPUE deleting the *i*th observation from the n_h selected PSUs and

$$\hat{R}_{h\cdot} = \sum_{i=1}^{n_h}\frac{R_{(hi)}}{n_h}$$

is the jackknife estimator of R_h. This approach holds for estimating R and its standard error within each stratum. To take into account the stratification of PSUs we used the combined ratio estimator (Cochran 1977, p. 165; Wolter 1985, p. 175) to estimate R across strata

$$\hat{R} = \frac{\sum_{h=1}^{L} \hat{C}_h}{\sum_{h=1}^{L} \hat{E}_h}. \qquad (16)$$

This complex estimator is necessary because the proportion of effort in each stratum is unknown. The estimation of variance of $\hat{R}$ is also more complicated for stratified sampling. An estimate of R and its variance across strata is obtained by the jackknife method described by Wolter (1985; p. 174–183).

3. Examples

The probability-based lattice survey described in this paper has currently been implemented in five coastal provinces in Mozambique. As an example of the performance of the survey we present yearly catch and effort estimates from 1997 to 2003 for the beach seine fisheries in the Inhambane Bay and for the district of Angoche in the Nampula Province (Figures 5–13). The sampling frame covers all significant fishing centres in Inhambane Bay, while the coverage in Angoche is less than 100% for logistical and economic reasons. Different approaches are used for stratifying fishing centres in the two provinces.

3.1. Yearly catch and effort in the Inhambane Bay

The Inhambane Bay is a shallow estuary covering an estimated 200–250 km^2 of sandy bottom and seagrass beds. Channels separated by sandbanks that are exposed at low tide characterize the bottom topography. The Inhambane Bay fishery is a chief supplier of fish to the population of the Inhambane Province. Beach seine is by far the most important gear category with respect yield.

All registered fishing centres with beach seine fishing activity were stratified into three groups by size as measured by number of beach seines: large ($\geq$ 25 seines); medium (10–25 seines) and small (< 10 seines). During the pilot phase (1997) a sampling effort of 9 shifts per month was allocated to the daytime (6:00 to 18:00) beach seine fishery, evenly distributed among the three strata (randomly selected days). From 1998, the weekend days were excluded from the sampling frame for practical reasons. Results from 1997 showed that the effort during weekends were no different from the weekday effort. The 17 fishing centres currently included in the sampling frame (1 large, 4 medium, and 12 small) cover 95% of beach seines registered in the area. Sampling effort from 1998 to 2003 includes 3 random days per week in each stratum.

The beach seine fishermen throughout the Inhambane Bay land their catches during low tide. For each selected primary sampling unit (day/location), a team of data collectors covers the entire landing period. A representative sample of landings was obtained by first selecting a vessel at random from the group of vessels that arrives first on the beach, and then systematically selecting the next vessel that arrives after the sampling of a landing is completed. Estimated total yearly catch (tons) of fish and shellfish by family for the beach seine fishery in Inhambane Bay are provided in Table 1. Effort and yield estimates for the Inhambane Bay fishery was rather stable (Figures 5–9) with the exceptions of the high catch estimate for 1997 (see above) and the high effort estimates at the beginning of the time series. In southern Afrika, the level of mobility of fishers is considerable and it is much more influenced by economic factors external to the sector than by investment-driven changes (Jul-Larsen *et al*., 2003). It is therefore possible that the period from 1996–1998 with drought conditions (as reflected in Lake Kariba lake levels presented by Kolding *et al*., 2003), created poor living conditions for the people engaged in the agricultural sector, provoking a shift in work force from farming to fishing and that this effect is being reflected in the high levels of fishing effort in 1997–1998.

3.2. Yearly catch and effort in Angoche, Nampula

The district of Angoche is located in the Nampula province in northern Mozambique (Figure 1). More than 8000 fishers participate in the small-scale fisheries in this district alone (IDPPE 2002). Based on the 2002 census data, a total of 473 beach seines were engaged in fishing in Angoche, and 336 of these operated from fishing centres that are included in the survey frame employed in this study. Over 70% of all fishing boats in Angoche employed beach seines. Most of the beach seining in this district is conducted within 100 to 250 m from the shore, and in some cases out to 650 m. In the estuaries, the beach seines are typically set within a distance of between 40 to 70 m from the shore. The wings have a stretched mesh size from 24 to 48 mm. A total of 316 beach seines use mosquito nets as liners for the central part of the seine, and hence the catches include a high percentage of larvae and juvenile fish.

Estimates of effort, catch, and cpue for the beach seine fishery in Angoche are in Figures 10-12. Estimated total yearly catch (tons) of fish and shellfish by family for the beach seine fishery in the district of Angoche, Nampula Province are provided in table 2. The yearly effort in the beach seine fishery in Angoche showed a significant declining trend ($p<0.05$) from 1997 to 2003 (Figure 10), based on Kendal's s test (Gilbert, 1987; Hirsch *et al*., 1982). Imputed catch represented 20% to 35% of the total yearly catch by beach seines in the Angoche district (Figure 11). Catch per unit effort (kg/boat day) for the beach seine fishery in Angoche, Moma was highly variable from month to month, and yearly (Figures 12–13).

4. Discussion and Conclusions

Representative catch and effort sampling of small-scale fisheries through time in a large geographic region is difficult to achieve. The reason is that an accurate sampling frame (list of active fishing units) is not available prior to the scheduling of field sampling. Information from previous frame surveys is useful for identifying important landing sites, but generally does not provide accurate information on the number of active fishing units on any given day. Temporal variability in effort results from changes in tidal conditions and the weather, migration of fishers between fishing centres, and because of socioeconomic factors. The landing sites for small-scale fisheries along the coast of Mozambique are generally highly clustered in space; a significant part of the total catch in a province or district is typically landed in fishing centres with relatively good public access and infra structure which allows handling of the catches. This is taken into account in the survey design.

Probability sampling has several advantages over ad-hoc surveys. In addition to producing unbiased estimates of catch, effort, and other key parameters, the precision in such estimates can be quantified. Sample surveys are cost-effective, and the underlying theory is well developed and documented. The on-site survey methods implemented in Mozambique provides reliable estimate of yearly catch and effort, and thus can be a useful tool for managing the small scale fisheries in many districts or provinces for example by regulating effort. Since no fisheries independent surveys is conducted of the near-shore fisheries resources, the estimates of CPUE over time may be used as a proxy of stock size. Because of the wide spatial and temporal distribution of effort, and minimal changes in fish When implementing a survey in a new district, it is recommended that the number of samples per stratum be allocated proportionally to strata sizes (A_h), approximated by the number of fishing units recorded in the most recent census. When estimates of catches and their spatiotemporal variances (s_h^2) becomes available from the survey, the survey may be optimized by allocating samples proportionally as $n_h \propto A_h s_h^2$ (Cochran, 1977). In practice, other factors such as travel time may be important to consider for achieving minimum variance in estimated total catch for a fixed cost.

The imputed estimates of total catch for fishing centres with no sampling coverage only holds under the key assumption that survey estimates of average usage rate and catch per unit effort apply to fishing centres outside the frame. Thus, imputations should generally be limited to centres that are proximate to those included in the survey, with similar fisheries characteristics, and to areas with similar resources.

Alternative methods that combine effort surveys with on-site surveys of catch rates are widely used in developed countries, but have limited applicability in Mozambique. Aerial surveys, however, may be used effectively for estimating daily effort in small geographic areas, such as the National Park established near the Bazaruto archipelago. Results from the probability-based access survey presented here strongly suggest that the estimation of effort directly from a frame survey (census) only can introduce significant bias because the proportions of all gears actively fishing varies over time.

Acknowledgment

We are grateful for financial assistance from the Norwegian Agency for Development Cooperation (NORAD) and the International Fund for Agricultural Development (IFAD). We thank Dr. Jean Louis Kromer and Ms. Angelica Dengo for their assistance with the implementation of the initial surveys, Mr. Roberto Morreno and Mr. Xavier Manussa for their database programming support, and all the dedicated staff that has participated in the field data collections. The Mozambican Institute for the Development of Small-scale Fisheries (IDPPE) provided logistical support with the implementation of the survey methods.

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Table 1. Estimated total yearly catch (tons) of fish and shellfish by family for the beach seine fishery in Inhambane Bay.

	YEAR						
Family	1997	1998	1999	2000	2001	2002	2003
Carangidae	275.2	367.1	513.5	481.3	380.2	534.1	368.4
Clupeidae	1,902.8	113.5	472.1	403.6	228.6	447.9	184.5
Gerreidae	108.7	103.7	89.9	59.6	52.4	66.2	79.2
Lethrinidae	44.2	50.7	31.0	34.2	66.8	37.9	43.2
Portunidae	217.5	219.2	120.3	92.7	55.6	102.9	69.6
Scaridae	56.4	71.1	69.3	25.6	66.6	28.4	152.9
Scombridae	60.5	32.2	64.2	142.5	82.6	158.1	142.3
Siganidae	92.8	39.8	49.6	43.1	100.8	47.8	28.0
Sillagnidade	120.3	69.5	81.4	56.1	65.1	62.2	230.7
Sphyrnidae	46.9	35.4	55.1	60.6	29.0	67.2	29.8
Teraponidae	117.9	61.3	59.3	19.3	58.0	21.4	45.2
Teuthoidae	35.0	52.6	46.3	15.6	55.6	17.3	10.5
Others	319.7	363.0	387.3	423.3	371.0	469.7	387.7
Total	3,397.9	1,579.1	2,039.4	1,857.4	1,612.4	2,061.2	1,771.9

Table 2. Estimated total yearly catch (tons) of fish and shellfish by family for the beach seine fishery in the district of Angoche, Nampula Province, including imputed catch for fishing centres outside the sampling frame.

	YEAR						
Family	1997	1998	1999	2000	2001	2002	2003
Engraulidae	793.6	4723.8	784.4	259.7	478.5	1205.6	684.4
Clupeidae	387.4	306.2	276.0	364.1	35.6	334.2	388.3
Leiognathidae	171.5	109.4	178.9	451.7	127.8	115.8	404.5
Haemulidae	168.5	156.4	220.4	1006.2	138.3	118.3	145.7
Belonidae	0.4	1.0	0.0	9.1	8.6	0.7	793.8
Larvas	494.7	817.7	452.1	198.0	131.6	206.8	175.8
Mullidae	142.4	146.8	349.3	224.7	84.4	50.4	154.7
Scombridae	683.3	1431.9	1942.8	1472.4	252.7	415.4	171.0
Sillaginidae	104.8	519.2	481.7	277.3	40.9	83.3	293.7
Carangidae	622.1	155.5	1056.3	1020.7	212.2	275.1	630.9
Others	707.2	1229.4	1299.9	2333.1	584.5	694.0	933.2
Total	4275.8	9597.2	7041.7	7617.0	2095.1	3499.6	4776.1

Figure 1. Map of study area, with number of fishing centres per district

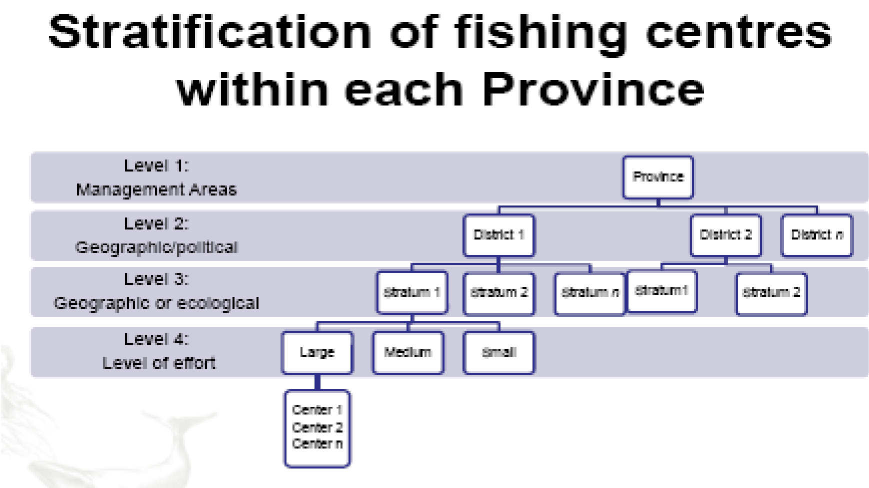
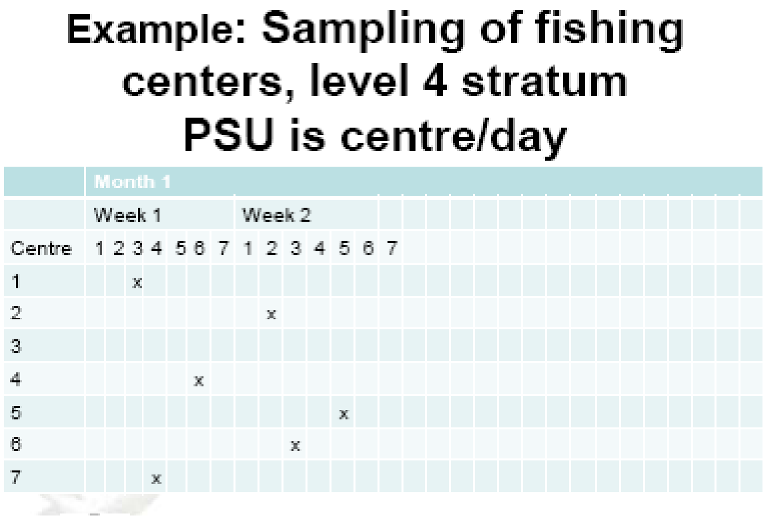


Figure 2. Stratification of fishing centres within each province.



Centre	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1			x											
2									x					
3														
4						x								
5												x		
6										x				
7				x										

Figure 3. Primary sampling units ate fishing centres/days. Selected centres for sampling are marked with 'X'.

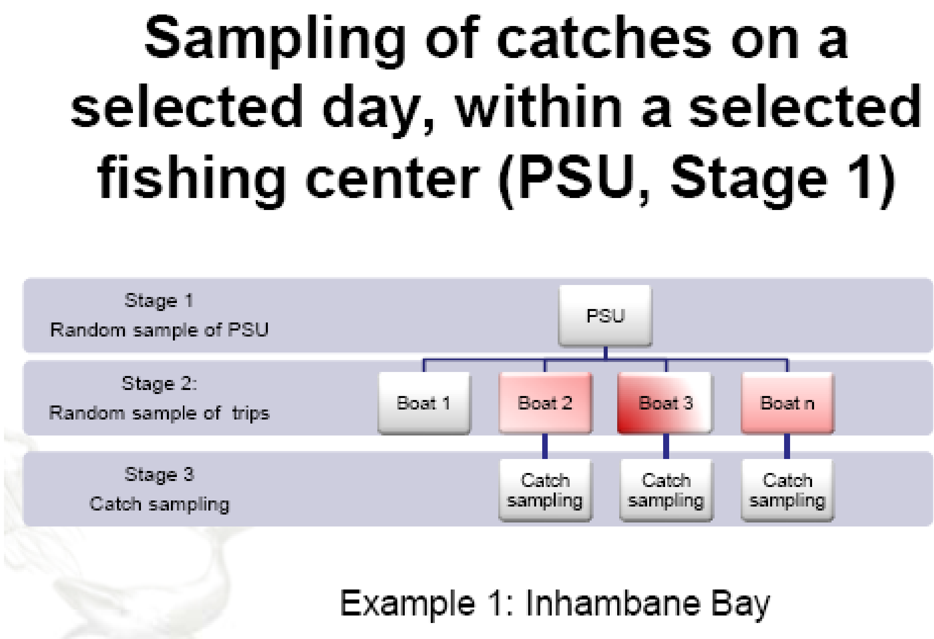


Figure 4a. Illustration of the survey design employed in Inhambane Bay for sampling fishing trips. Primary sampling units are selected in the first stage from the lattice of fishing centres and days. A sub-sample of fishing trips is the selected from each PSU in the second stage.

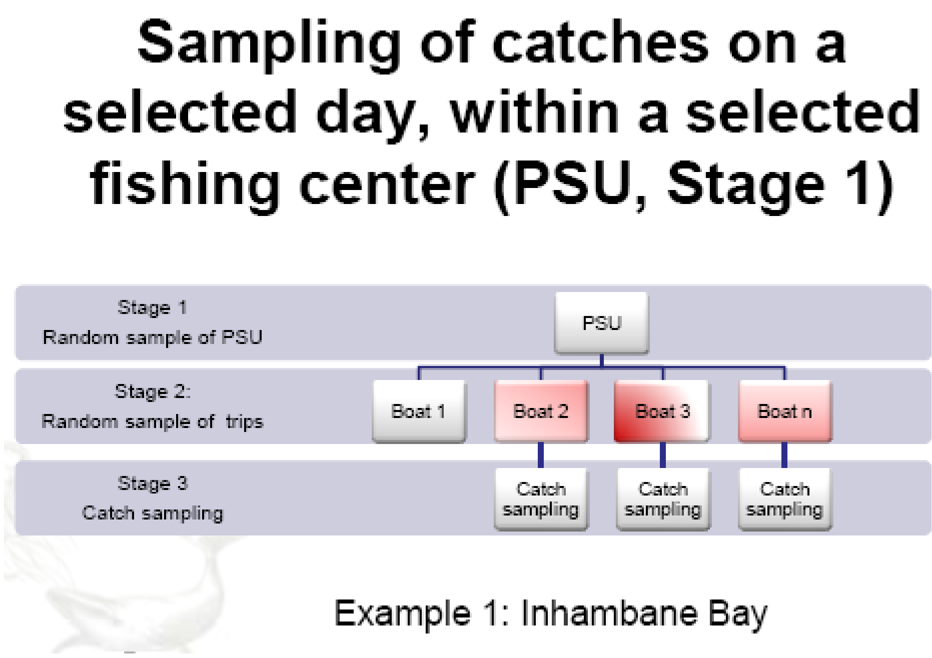


Figure 4b. Illustration of the multi-stage survey design employed in Angoche District in the Nampula Province to sample catches from beach seine fishery. Primary sampling units are selected in the first stage from the lattice of fishing centres and days. A sub-sample of beach seines (Secondary Sampling Units, SSU) is the selected from each PSU in the second stage. For each beach seine, a sub-sample of sets is selected for catch-sampling.

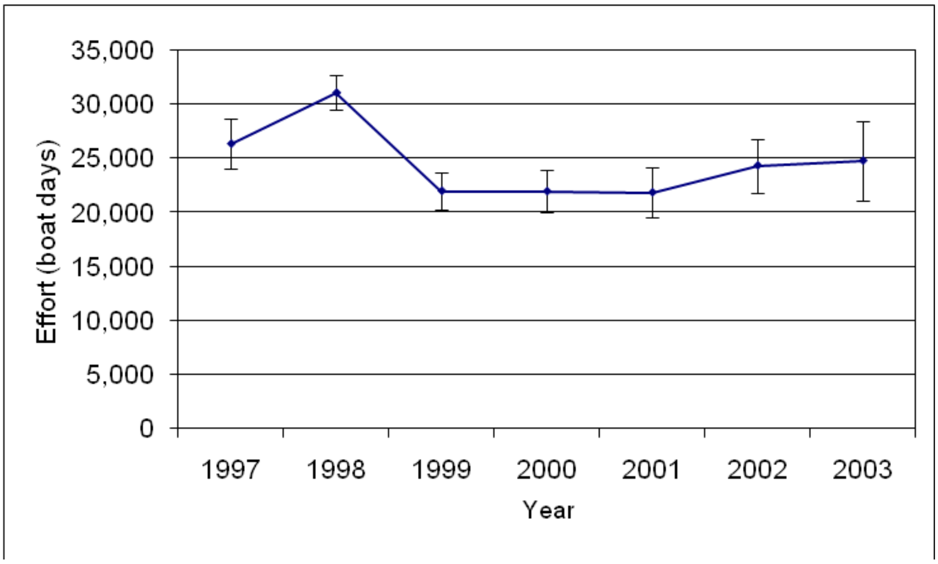


Figure 5. Estimated yearly total effort (number of boat days) for the beach seine fishery in Inhambane Bay. Error bars represent 95% confidence intervals.

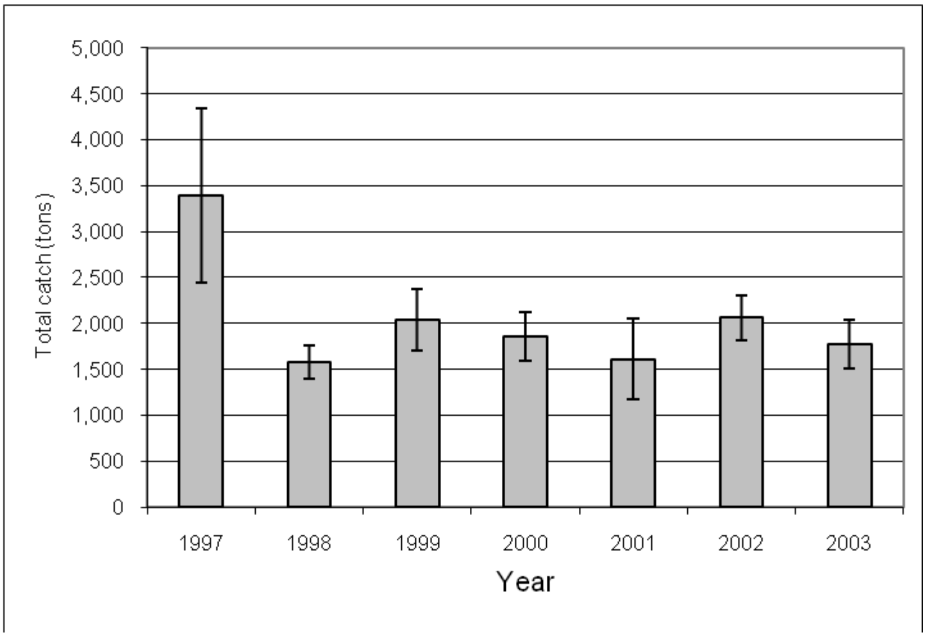


Figure 6. Estimated yearly total catch for the beach seine fishery in Inhambane Bay. Error bars represent 95% confidence intervals.

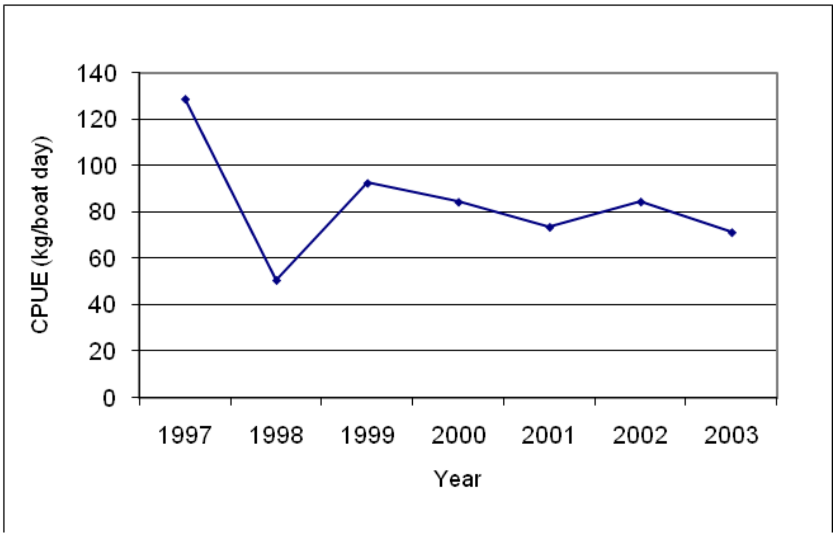


Figure 7. Yearly estimated catch per unit effort (kg/boat day) for the beach seine fishery in Inhambane Bay.

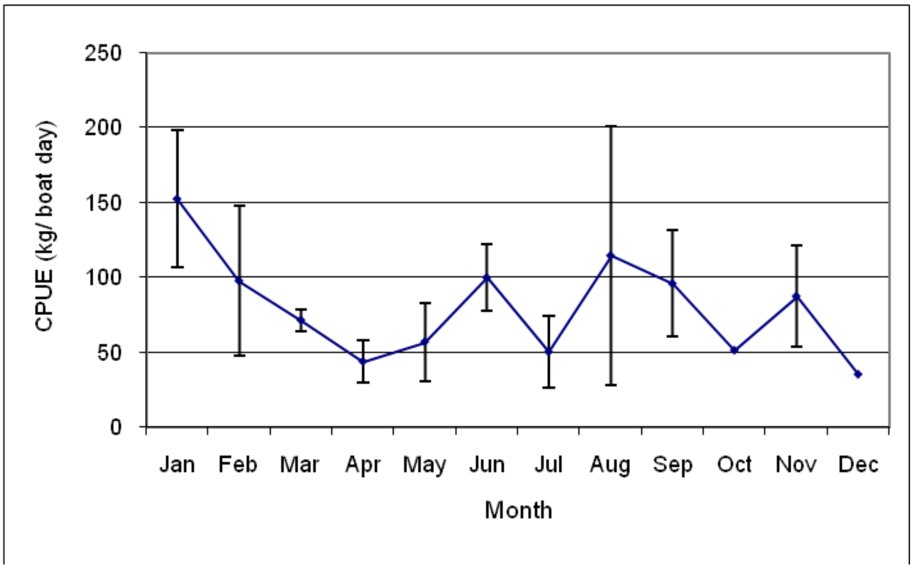


Figure 8. Estimated monthly catch per unit effort (kg/boat day) for the beach seine fishery in Inhambane Bay during 2002. Error bars represent 95% confidence intervals.

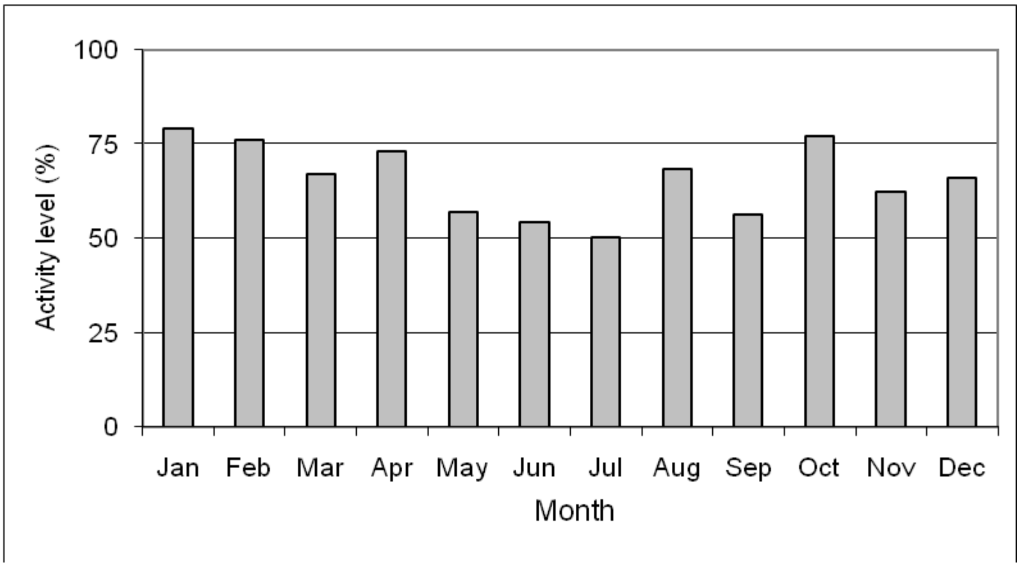


Figure 9. Estimated proportion of boats actively fishing on an average day for the beach seine fishery in Inhambane Bay during 2002.

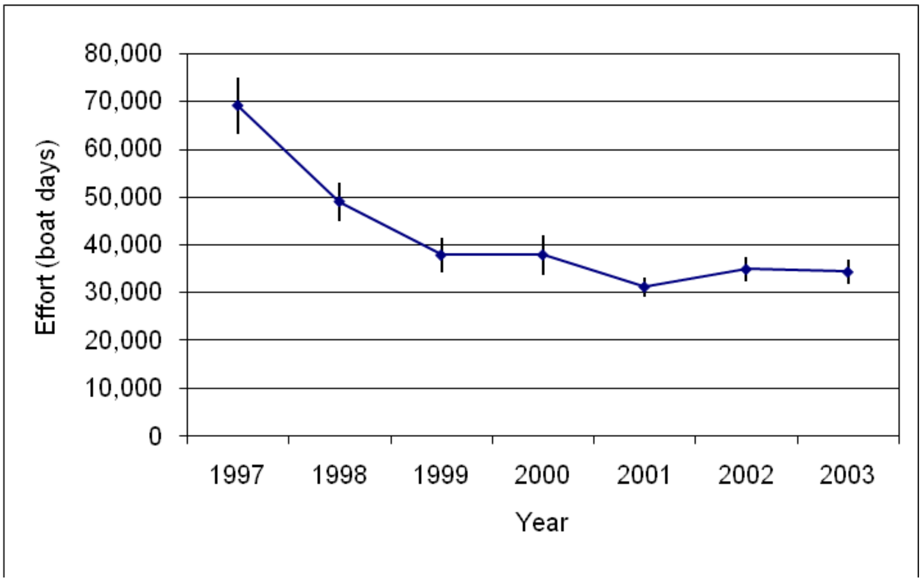


Figure 10. Estimated yearly total effort (number of boat days) for the beach seine fishery in the district of Angoche, Nampula Province. Error bars represent 95% confidence intervals. Kendal's test for trend show a significant decline in effort (p<.05).

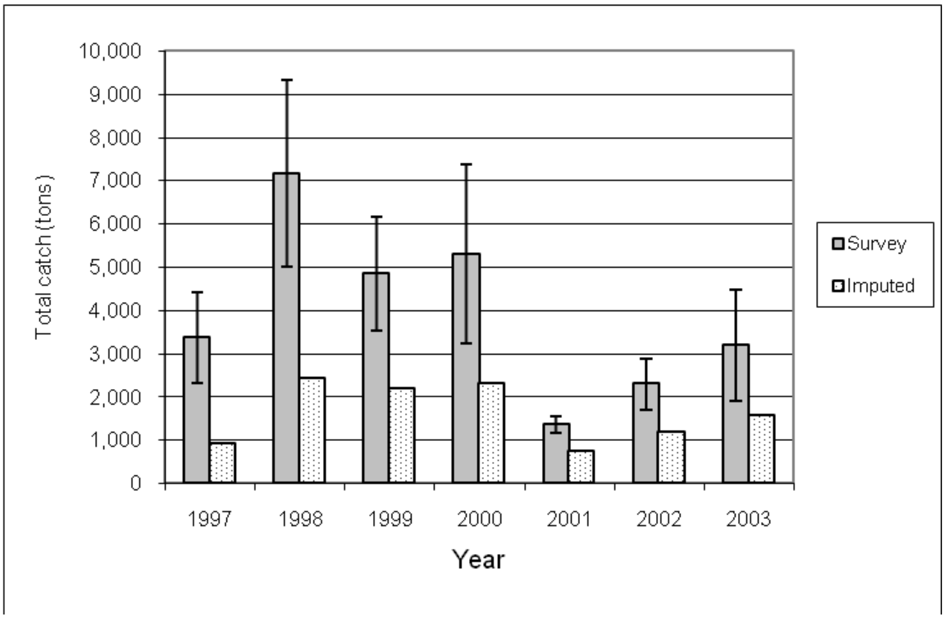


Figure 11. Estimated yearly total catch for the beach seine fishery in Angoche, Nampula for fishing centres in covered in the survey, and imputed total catch for centres outside the sampling frame. Error bars for the survey estimate represent 95% confidence intervals.

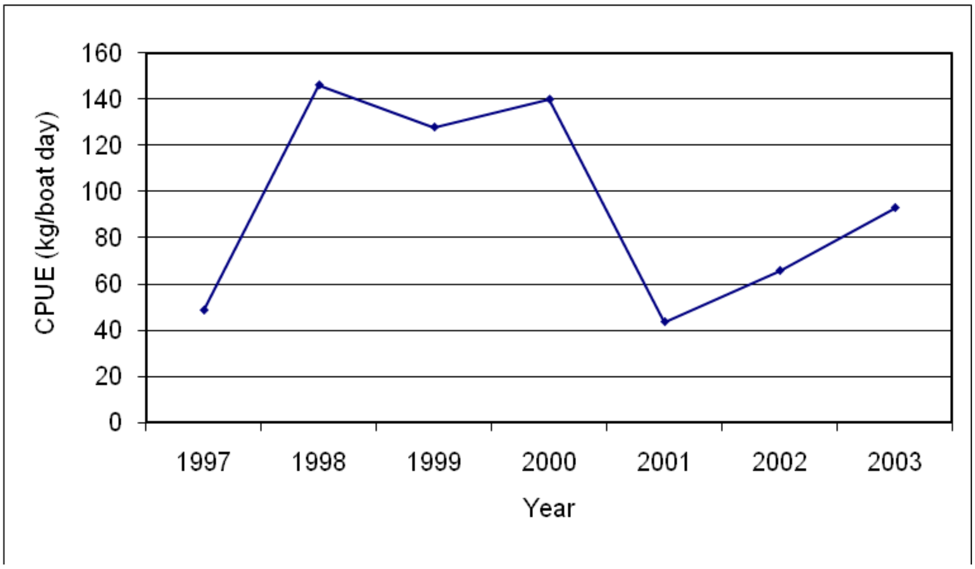


Figure 12. Yearly estimated catch per unit effort (kg/boat day) for the beach seine fishery in Angoche, Moma.

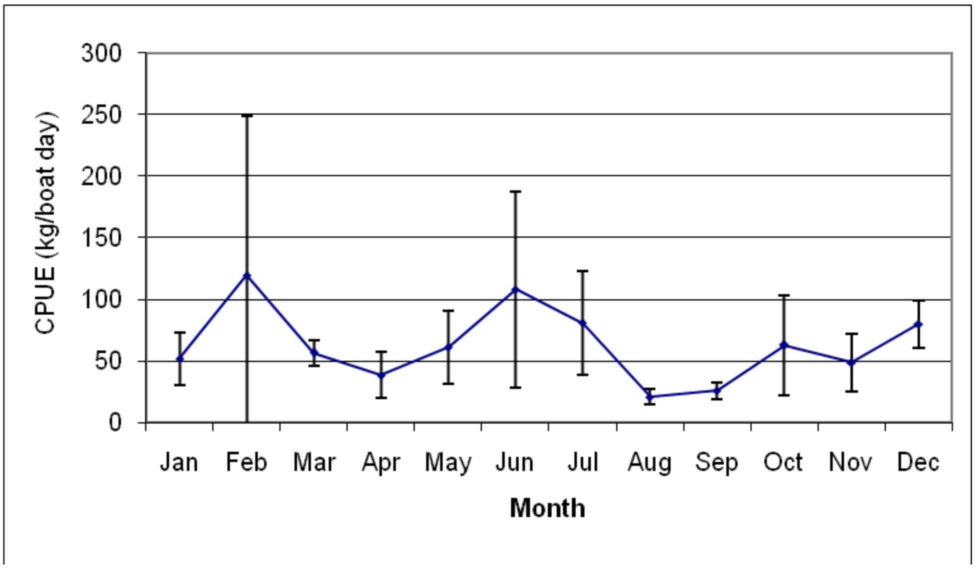


Figure 13. Estimated monthly catch per unit effort (kg/boat day) for the beach seine fishery in Angoche during 2002. Error bars represent 95% confidence intervals.

Annex 6: Working Document 2: Looking for a methodology for drawing a discards sampling plan: WD to WKMERGE (Lise Guerineau and Jöel Vigneau, Ifremer)

Looking for a methodology for drawing a discards sampling plan

Contribution to ICES WKMERGE

Lise Guerineau, Joël Vigneau

Introduction

Drawing a sampling plan in order to achieve multi-varibles objectives is a complex issue. The objective of this document is to try to find a method for optimising the number of samples to allocate by strata, including the variability of the discards estimates and the coverage of as many species as possible. The other challenge is to try to respect as much as possible the DCF requirements in terms of precision objectives, sampling coverage, …).

Material

Effort data

Effort data, in terms of number of trips, are used for raising the discards sampled to the population. The stratification used is the DCF metier level 5, which is the level omitting the mesh size and the selective device. The source of information are the logbooks and other declarative forms (monthly forms for less than 10 m vessels). The allocation of trips to metiers is done following the RCM recommendations.

Selection of metiers

The metiers selected for sampling are those retained by the ranking system.

Method

The issue is to allocate sufficient samples to estimate discards in each of the selected strata. We will look for a number of trips to sample, by metier level 5, fishing grounds and quarter, leading to a precision of +/- 40% for all species, on the volume of discards variable.

Here are the steps followed:

1) Ranking system to determine the strata for the sampling programme

2) Preparation of the dataset: list of species where an estimate is required, and filter of the observed samples.

3) Restriction of the list of species by eliminating those representing less than 10% of discards and filtering those under a certain weight (threshold related to the fishing ground). A list of retained species is then retained by fishing ground.

4) For each of the fishing ground, the discards are estimated for each of the retained species, with a criterion of a minimal number of trips sampled in a stratum. A table like the one below is drawn;

time	space	technical	Ammodytidae	Aspitrigla cuculus	Cancer pagurus	…
all	NSEC	GTR_DEF	0	0	11737.41	
all	NSEC	OTB_DEF	11737.41	172839.03	0	
all	NSEC	OTB_MOL	250.63	542056.63	0	
all	NSEC	OTB_SPF	263.13	428482.81	0	

5) The non-null cells of the table are the values used for calculating the minimal number of trips to sample, with the following formula: $n = \frac{N}{1 + \frac{NL^2}{4CV^2}}$

N = total number of trips in the population
L = relative precision required by the DCF (40%)
CV = empirical coefficient of variation

6) In order to satisfy the precision criteria, the maximum number of trips for each area and metier should be taken. This number is likely to be much too high. The quantile method will be used to choose the number of trips:

a) quantile=0 : the precision of 40% will be guaranteed for 1 species

b) quantile = 50%. the precision of 40% will be guaranteed for 50% of the species

c) quantile = 100% the precision of 40% will be guaranteed for all the species.

Results

Figure 1 shows that, at first stance, 34 species were selected for having discards representing more than 10% of the total catch per weight. From these 34 species, 32 were kept for having a significant total discards weight estimation.

Figure 2 shows different graphs representing different metiers and quarters. The y-axis of the graphs represent the number of trips to sample in order to reach a precision of +/-40% and the x-axis represent the percentiles of the number of species. For example, the top left graph (GTR_DEF, Q1) shows a linear trend, meaning that the more trips you sample the more species will reach the objectives of precision. To cover 100% of the species with a precision at least equal to +/-40%, 200 trips should be needed to sample.

The top right graph (GTR_DEF, Q2) tells a different story. A trade-off is displayed at 40 trips where around 50% of the species are covered with the required precision. This means that it would be very costly to increase the number of trips after that point (very few extra species are covered as and when increasing the sampling effort).

The benefits of these graphs is in the existence of these trade-offs, showing where is the optimum in term of cost-efficiency of discards sampling. The method does not prioritise one species from the others, but it would be possible to plot on the graphs where are situated some of the key species.

It must be added also that the DCF does not require a target precision by metier and quarter for discards (as shown in figure 2), but only by quarter all metiers combined. The further allocation of the optimal number of samples per quarter, into metiers or strata, should be done using a Neyman allocation scheme.

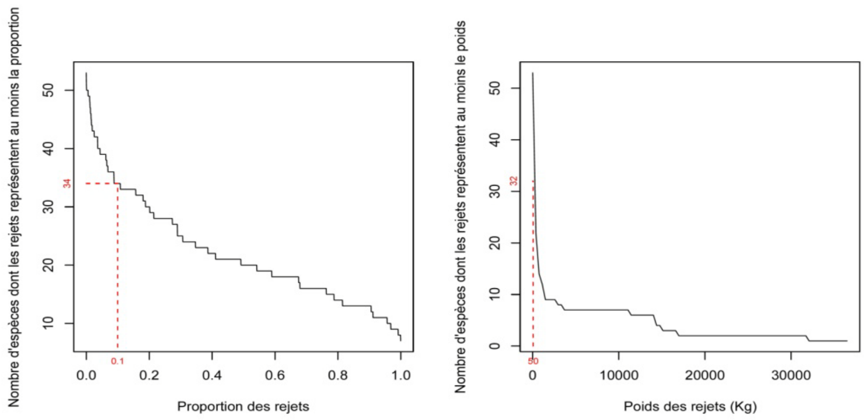


Figure 1. Selection of the threshold for filtering the number of species

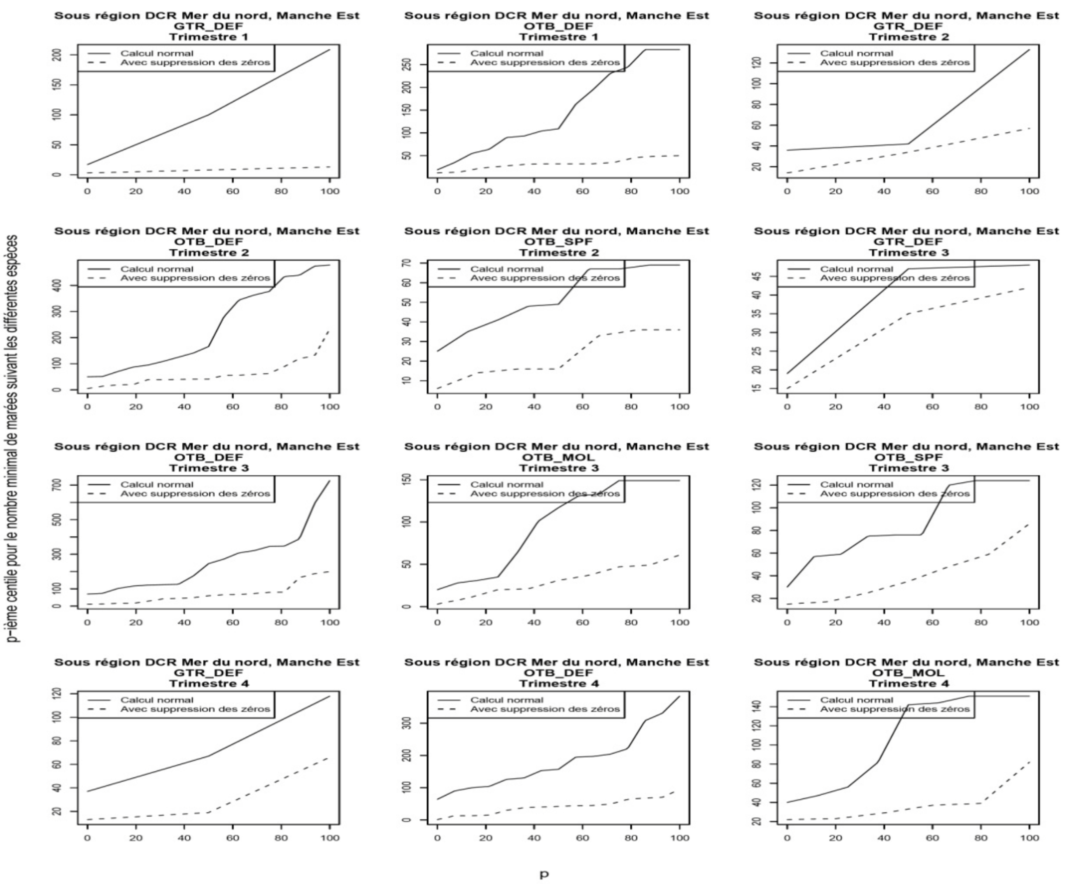


Figure 2. Centiles of the optimum number of trips to sample

Annex 7: Working Document 3: Test case on differentiating metiers, based on their catches

Working document for the ICES WKMERGE

Joël Vigneau[a], Mathieu Merzereaud[b], Lise Guerineau[c], Christian Dintheer[c]

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Introduction

Based on the work done by the ICES Study Group on the Development of Fishery-based Forecasts (SGDFF, ICES, 2004), the first expert meeting (EC., 2005) held in preparation of the DCF (EC, 2008) and reflecting on fleet fishery based sampling defined the metier as being *a group of fishing trips targeting the same (assemblage of) species, using similar gear, during the same period of the year and/or within the same area*. The experts already supplemented the definition with a statement that *appropriate aggregations of fishing activity types are the basis for biological sampling in the ICES area*. The STECF/SGRN held a meeting in 2006 (EC., 2006) to set up the future data collection framework and proposed that *for assessment and management purposes, fishing effort, quantities landed and discarded, removals by species, together with their length and/or age distributions, may have to be reported for each individual cell in the métier matrix. However, this does not mean that the collection of discard or length composition data too needs to be organised for each cell in the matrix separately. If genuinely applied, the merger of cells in the métier matrices for the collection of discard and/or length composition data can help reducing the workload and thus make the DCR less labour-intensive and less costly (compared to the obligation to sample all individual cells in the matrices), without however impairing the quality of the end-products*. The DCF regulation that followed these scientific forum and that came into force in the beginning of 2009, has provisions for merging metiers, provided that scientific evidence is brought (EC, 2008, chapter III, section B1.2.1). It is with the objective of defining what should be the guidelines for such scientific evidence that the ICES PGCCDBS (ICES, 2009) proposed the WKMERGE workshop.

The identification of metier may be done following three approaches as recalled by Marchal (2008), i.e. the input-based, the output-based and the combined methods. Input-based methods make use of existing records of the technical features of fishing trips, usually available in fishers' logbooks (gear, mesh size, fishing ground, season) or are built on direct interviews with stakeholders. Output-based methods assumes that catch profiles perfectly reflect fishing intention. Metiers can be identified by direct visual inspection using principal components analysis or automatically through a hierarchical cluster analysis algorithm. Combined methods categorize metiers by clustering catch profiles (outputs), then relating these clusters to fishing trip characteristics (inputs) using multivariate analysis. In this paper, we are going to use the combined approach, and try to go a little further with fishing trips which have been sampled at sea.

The current work consists on an analysis of three metiers, as defined by the DCF and further agreed within the RCMs, in order to quantify their degree of differences and similarities in terms of catch and discards profiles, and length structure of their catches. These three metiers, are operating on the same fishing ground at the same period, so that the perceived differences will only come from the inherent ability of the metier to catch different species assemblages and/or different length structures, and consequently different discarding patterns. In summary, and including the notion of space and time, we can propose that two metiers will be considered different if they have different exploitation patterns. Indeed, the exploitation pattern as defined in FAO glossary is *the distribution of fishing mortality over the age (or length) composition of the fish population. It is determined by the type of fishing gear, area and seasonal distribution of fishing, and the growth and migration of the fish*.

Material and methods

20 sampled trips in ICES division VIIIa during the second quarter of 2009 will be the basis for the analysis. The metiers are known, as they are defined on-board from interview with the master of the sampled vessel. The datasets represent 3 combinations of gear and target species: Otter trawl targeting demersal fish (OTB_DEF), otter trawl targeting crustaceans (OTB_CRU) and twin trawl targeting crustaceans (OTT_CRU), plus some having a selective device (4th item of the naming convention, 0 = no selective device, 1= ??, 2 = grid), potentially representing 7 metiers as shown in the table 1 below. The information available per metier is given in Table 1.

Table 1: Description of the test case dataset

Metier name	No Trips sampled	No hauls sampled	No species discarded	No species retained	No fish measured for discards	No fish measured in the retained part
OTT_CRU_70_0_0	1	3	25	23	184	366
OTT_CRU_70_2_0	5	41	44	28	2705	1234
OTT_CRU_80_0_0	4	15	48	39	1035	1512
OTT_CRU_80_2_0	3	12	41	18	885	988
OTT_CRU_85_2_0	1	15	28	15	837	624
OTB_CRU_80_2_0	2	15	34	14	574	534
OTB_DEF_70_0_0	3	12	40	25	668	435
OTB_DEF_90_0_0	1	7	16	8	133	143

Differences in the catch and discards composition

A cluster analysis has been performed on the total number of species caught and discarded by each of the trips. The idea is to measure an Euclidian distance between each of the trips based on their relative catches per species. A small distance will be an indicator of similarity between the catch composition of 2 trips, whereas a large distance will be an indicator of dissimilarity. The clusters obtained will allow the grouping of similar trips, hence potentially displaying homogeneous metiers.

All catches (retained and discarded parts) were raised to the sampled trips using COST[3] software packages.

[3] http://wwz.ifremer.fr/cost

The catch composition matrix has been transformed into proportion of each species by number. By doing so, we give the same importance to each of the species caught, independently of its intrinsic value, in other words, we don't give an extra weight to the targeted species. The reason is to focus on the catch composition as a whole, without *a priori*.

Different clustering algorithms will provide different results on the same data. The same clustering algorithm may give also different results depending on arbitrary initial condition. Ward's method says that the distance between two clusters, A and B, is how much the sum of squares will increase when we merge them. With hierarchical clustering, the sum of squares starts out at zero (because every point is in its own cluster) and then grows as we merge clusters. Ward's method keeps this growth as small as possible[4]. This is convenient when we think that the sum of squares should be small, which is the case here. Different methods have been used, and the Ward method displays approximately the same picture as the "complete" method, which provides a distance of the farthest points in each cluster.

Length structure of the catches

The choice of methods is vast regarding the comparison of length structures. It should be said here that if two length structures are significantly different, any method should clearly display this information. The problem here was that we have more than 100 species caught in total, and a fairly important within metier heterogeneity. The methods had to adapt to this context, and try to display as much information as possible.

The first method used was the delta plot provided by the COST software, and based on a work by Vigneau and Mahevas (2007). The delta plot was used only on the hake (*Merluccius merluccius*) length structures, as this was the most numerous species measured by every sampled trips. Following Vigneau and Mahevas (2007) advice, only the first half of the length structures was taken to give the focus on the differences in the smaller length classes.

In order to dig further, and try to account for more species, an analysis on the selectivity ogives was performed. This study made use of the L50 estimates, which is the length under which lies 50% of the catches. A L50 was estimated for every species caught by all sampled trips, after a filter was applied on the number of length measured, at a trip level, for all species. Species where less than 6 length classes were available were rejected from the analysis. The L50 is species specific, as a large fish (e.g. cod, hake) will have a larger L50 than a small fish (e.g. *Nephrops*, pout), so the values of the L50 were normalised within species and across sampled trips. Another filter was then applied on the number of trips with a L50 value, and every species caught by less than 3 trips were rejected. The final comparison makes use of 9 species, with normalised L50 combined.

[4] Free press. Distances between Clustering, Hierarchical Clustering. 36-350, Data Mining. 14 September 2009

Results

Differences in the catch composition

Table 2 :Catch profiles in term of proportion of the number of fish caught for the 20 sampled trips

	Nephrops norvegicus	Merluccius merluccius	Trisopterus luscus	Trachurus trachurus	Merlangius merlangus	Munida intermedia	Arnoglossus spp	Micromesistius poutassou	Solea solea	Sepia spp	Others
OTB_DEF_70_0_0	0.00	**0.53**	0.15	0.01	0.19	0.00	0.00	0.00	0.00	0.00	0.12
OTB_DEF_70_0_0	0.00	0.06	0.00	**0.55**	0.00	0.00	0.00	0.00	0.00	0.00	0.39
OTB_DEF_70_0_0	0.00	0.10	0.72	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.06
OTB_DEF_90_0_0	0.00	0.17	0.31	0.01	0.12	0.00	0.06	0.00	0.05	0.06	0.22
OTB_CRU_80_2_0	**0.76**	0.13	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.03
OTB_CRU_80_2_0	**0.58**	0.19	0.06	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.11
OTT_CRU_70_0_0	**0.86**	0.11	NA	0.00	0.00	NA	0.00	NA	0.00	0.00	0.03
OTT_CRU_70_2_0	0.41	0.29	0.01	0.00	0.00	0.00	0.07	0.00	0.00	0.01	0.20
OTT_CRU_70_2_0	**0.78**	0.07	0.07	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.07
OTT_CRU_70_2_0	**0.51**	0.37	0.02	0.00	0.00	0.00	0.04	0.03	0.00	0.01	0.02
OTT_CRU_70_2_0	**0.70**	0.15	0.02	0.02	0.00	0.00	0.05	0.02	0.00	0.00	0.05
OTT_CRU_70_2_0	0.39	0.22	0.03	0.01	0.00	0.00	0.08	0.06	0.02	0.02	0.17
OTT_CRU_80_0_0	**0.95**	0.03	0.00	0.00	0.00	NA	0.00	0.00	0.00	0.00	0.01
OTT_CRU_80_0_0	**0.54**	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.04
OTT_CRU_80_0_0	**0.94**	0.03	0.00	0.00	0.00	0.00	0.00	NA	0.00	0.00	0.03
OTT_CRU_80_0_0	**0.94**	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
OTT_CRU_80_2_0	0.41	0.07	0.01	0.04	0.00	0.43	0.01	0.00	0.00	0.00	0.03
OTT_CRU_80_2_0	**0.93**	0.06	0.00	0.00	0.00	NA	0.00	NA	0.00	0.00	0.01
OTT_CRU_80_2_0	**0.83**	0.09	0.02	0.00	0.01	NA	0.01	0.01	0.00	0.00	0.03
OTT_CRU_85_2_0	**0.63**	0.27	0.03	0.00	0.00	NA	0.01	0.02	0.00	0.00	0.03

Table 2 shows the catch profiles of the 20 sampled trips. The catch profile is the proportion of the species caught by number, per trip, for the total top 10 species. An a priori postulate would consider merging all occurrences of OTT_CRU and OTB_CRU and keep OTB_DEF separate for sampling purpose. The objective of this study is to assess whether this is correct to do or not.

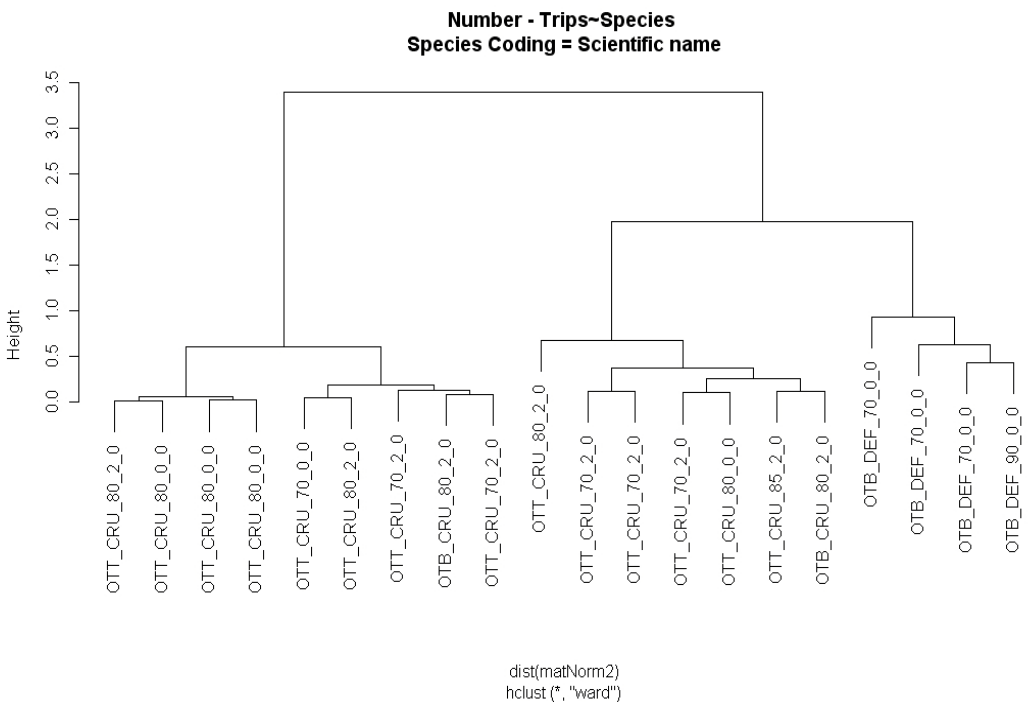

Figure 1: Metier clustering using Ward distance method.

The result is displayed in figure 1. The first information is that the trawlers targeting demersal fish are well discriminated from the trawlers targeting crustaceans. The second information, confirming the starting postulate, is that the OTB_CRU and OTT_CRU are confounded in the same clusters. The more tricky clustering is the split of the trawlers targeting crustaceans as soon as the first division, even before dividing into trawlers targeting demersal and the others. This means that some other effects than the targeted species assemblage impacts the catches. Given that the dataset is based on one ICES division and one quarter, it could be that the area and time operates on a finer granulometry. Figure 2 displays more information on each sampled trip, i.e. the latitude label of the ICES rectangle and the fishing week. The clustering of metiers targeting crustaceans shows now a North-June against South-April/May dichotomy, emphasizing the importance of the time and spatial component of the metier description.

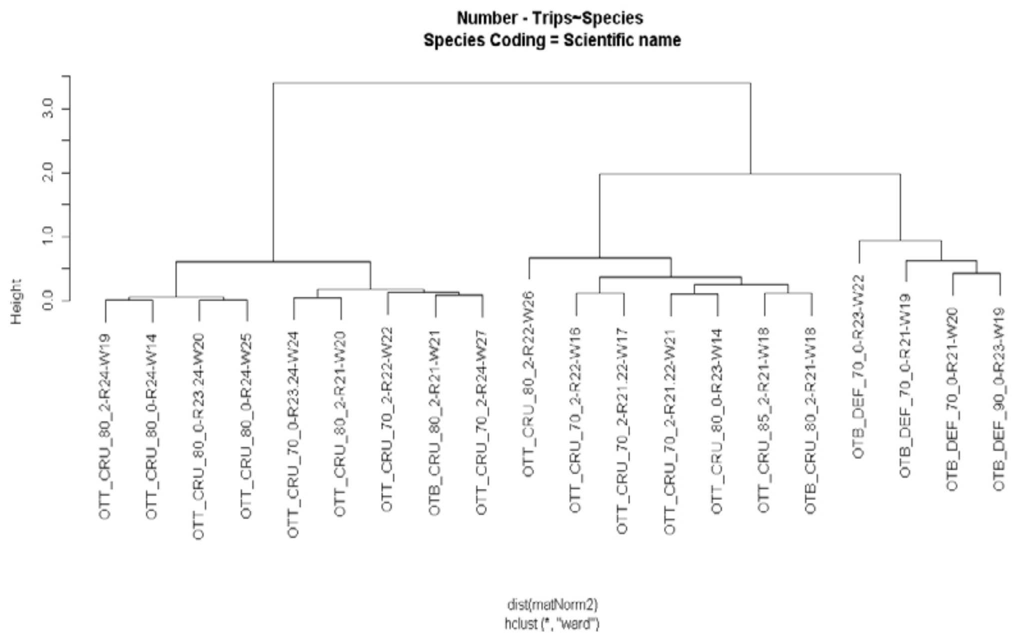

Figure 2: Metier + rectangle + week clustering using Ward distance.

Differences in the discards composition

Table 3 shows the discard profiles of the 20 sampled trips. The discard profile is the proportion of the species caught by number, per trip, for the total top 10 species. Vaues larger than 0.5 were emboldened.

The Figure 3, resulting from the clustering is difficult to interpret. The trawlers targeting demersal are all on the left, but discriminated at the second level, and clustered together with a trawler targeting crustacean. The first split discriminates 5 trips from all the others, with the fact that they all have a selective grid, they all target crustaceans in the first half of the quarter. The problem is that metiers having this particular feature are also found in the second cluster.

From table 3, we can see that none of the trawlers targeting demersal, discard *Nephrops*, but the troubles come from the discarding behaviours of all other species, which shows at first glance, erratic figures. More work would be needed to evaluate properly the differences and similarities between sampled trips in this case. In other words, apart from the very different discarding behaviour on *Nephrops* by trawlers targeting demersal and trawlers targeting crustaceans, little can be said on the impact on selective grid, shape of the trawl, or fine-scale time and space component on discarding in general.

Table 3 :Discard profiles in term of proportion of the number of fish discarded for the 20 sampled trips

	Nephrops norvegicus	Merluccius merluccius	Trisopterus luscus	Trachurus trachurus	Munida intermedia	Merlangius merlangus	Arnoglossus spp	Micromesistius poutassou	Argentina sphyraena	Sepia spp	Divers
OTB_DEF_70_0_0	0.00	0.46	0.21	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.10
OTT_CRU_80_2_0	**0.90**	0.10	0.00	0.00	NA	0.00	0.00			0.00	0.00
OTT_CRU_70_0_0	**0.79**	0.19	NA	0.00	NA	0.00	0.00			0.00	0.02
OTT_CRU_70_2_0	0.16	0.63	0.04	0.00	0.00	0.00	0.07	0.05	0.01	0.01	0.03
OTT_CRU_70_2_0	**0.61**	0.20	0.02	0.01	0.00	0.00	0.06	0.02	0.01	0.00	0.05
OTB_DEF_90_0_0	0.00	0.07	0.35	0.01	0.00	0.14	0.07	0.00	0.00	0.07	0.30
OTT_CRU_70_2_0	0.23	0.25	0.04	0.02	0.00	0.00	0.11	0.08	0.06	0.03	0.18
OTT_CRU_80_0_0	**0.91**	0.09	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.01
OTT_CRU_85_2_0	0.47	0.39	0.05	0.00		0.00	0.02	0.03	0.00	0.00	0.04
OTB_DEF_70_0_0	0.00	0.06	0.77	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.05
OTT_CRU_80_2_0	**0.75**	0.13	0.03	0.00		0.01	0.01	0.01	0.01	0.00	0.04
OTT_CRU_80_0_0	**0.92**	0.07		0.00		0.00	0.00	0.00		0.00	0.01
OTB_CRU_80_2_0	0.38	0.28	0.09	0.02	0.01	0.03	0.02	0.01	0.00	0.00	0.16
OTT_CRU_80_0_0	**0.52**	0.45	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.03
OTT_CRU_80_0_0	**0.91**	0.04	0.00	0.00	0.00	0.00	0.00			0.00	0.04
OTB_CRU_80_2_0	**0.58**	0.19	0.09	0.04	0.00	0.00	0.00	0.00	0.00	0.04	0.06
OTT_CRU_70_2_0	0.16	0.40	0.02	0.00	0.00	0.00	0.10	0.00	0.09	0.02	0.21
OTB_DEF_70_0_0	0.00	0.03	0.00	**0.58**	0.00	0.00	0.00	0.00	0.00	0.00	0.38
OTT_CRU_80_2_0	0.24	0.09	0.01	0.03	0.58	0.00	0.01	0.01	0.00	0.00	0.03
OTT_CRU_70_2_0	**0.72**	0.09	0.09	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.08

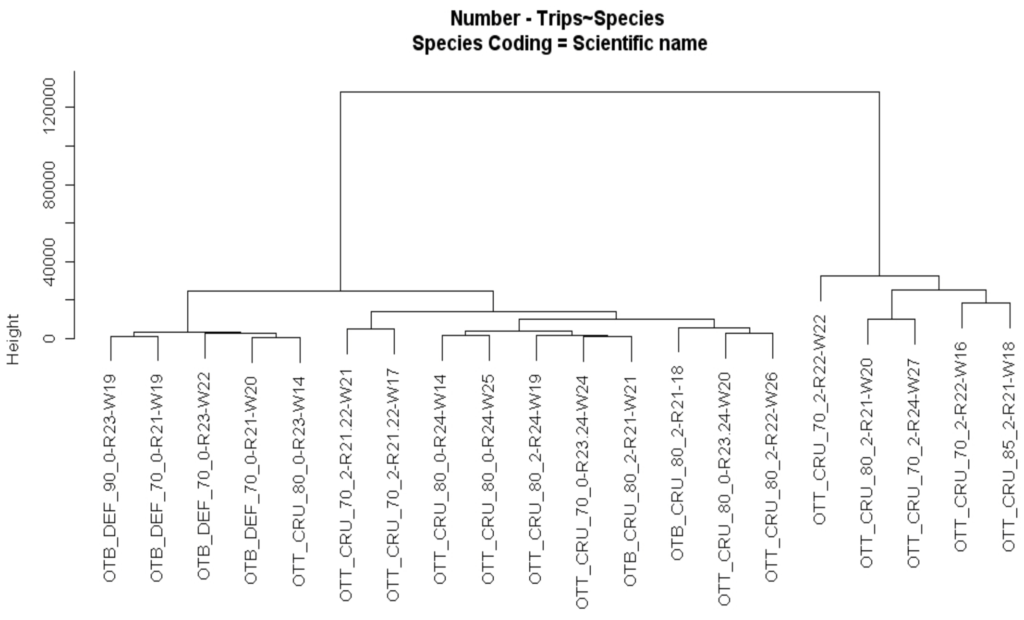

Figure 3: Discards per Metier clustering using Ward distance method.

Length structures

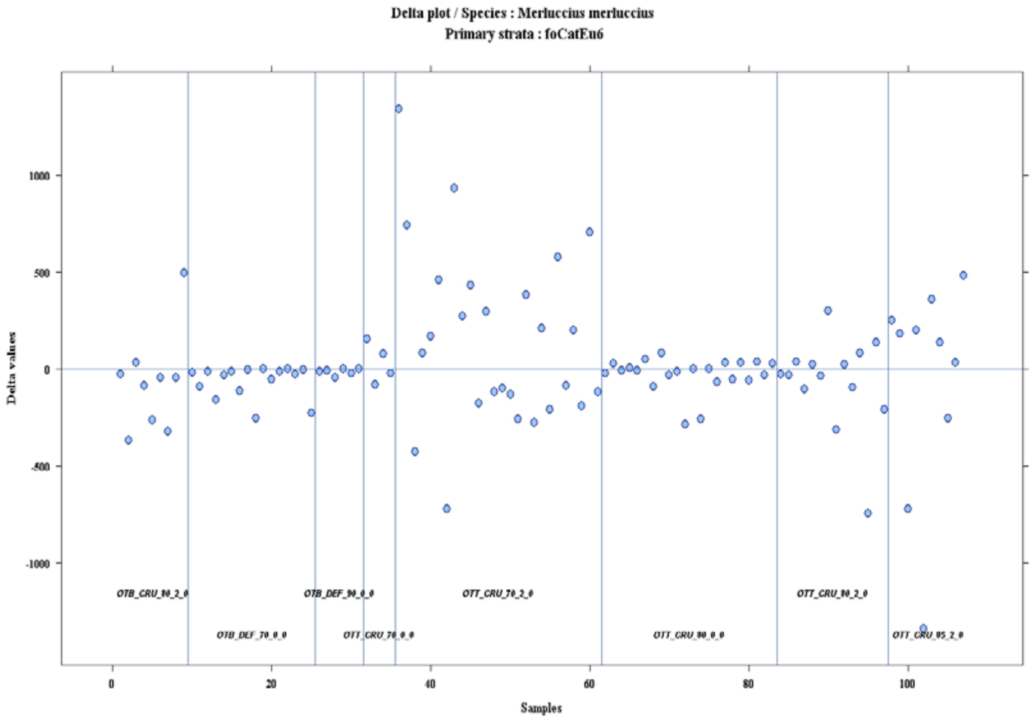

Figure 4: Delta plots for *Merluccius merluccius*

In the delta analysis, the larger length structures receive the lowest delta values, and conversely, the smallest length structures receive the highest delta values. It is thus surprising to see that it is a metier with a selective grid that displays the smallest length structures (OTT_CRU_70_2_0), although it is the smallest mesh size and delta values are widely spread. In general, no clear picture of differences are displayed in this figure, since all metiers seem to have spread delta values equitably above and under the overall mean (0). This would tend to say that all hake catch length structures are variable within metiers and not showing between metiers differences.

In order to confirm this statement, and visualise more common figures, a cumulative length structure (selectivity ogive) was drawn Figure 5 for hake. It quickly springs that unexpected outcomes are displayed, e.g. some metier with a selective device showing a smaller length structure than their counterpart without selective device, some larger mesh size showing smaller length structure than smaller mesh size, etc. Hopefully, some expected outcomes are shown also, but the general picture does not allow a clear discrimination on the length structure of hake based solely on the technical feature of the gear.

Taking into account more species was the idea for the last analysis. If the technical feature of a gear has some effects on the length structure of the catches, this should be reflected on all species length structures. After applying filters on number of length classes measured per species and trip and the number of metiers having caught the given species, it remained 9 species. The magnitude of the normalised values of L50 by species is given Figure 6. Some species display expected outcomes (*Solea solea, Trachurus trachurus*), others are more difficult to interpret.

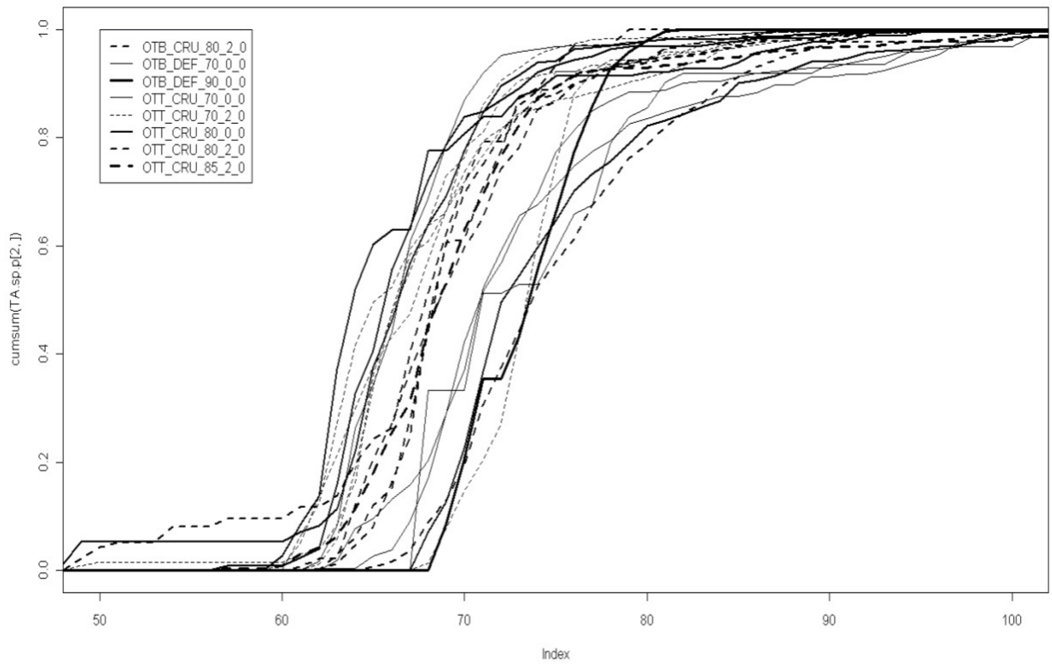

Figure 5: selectivity ogive for catches of *Merluccius merluccius*. The thickness of the lines refer to the mesh size and the presence of a selective device was dashed.

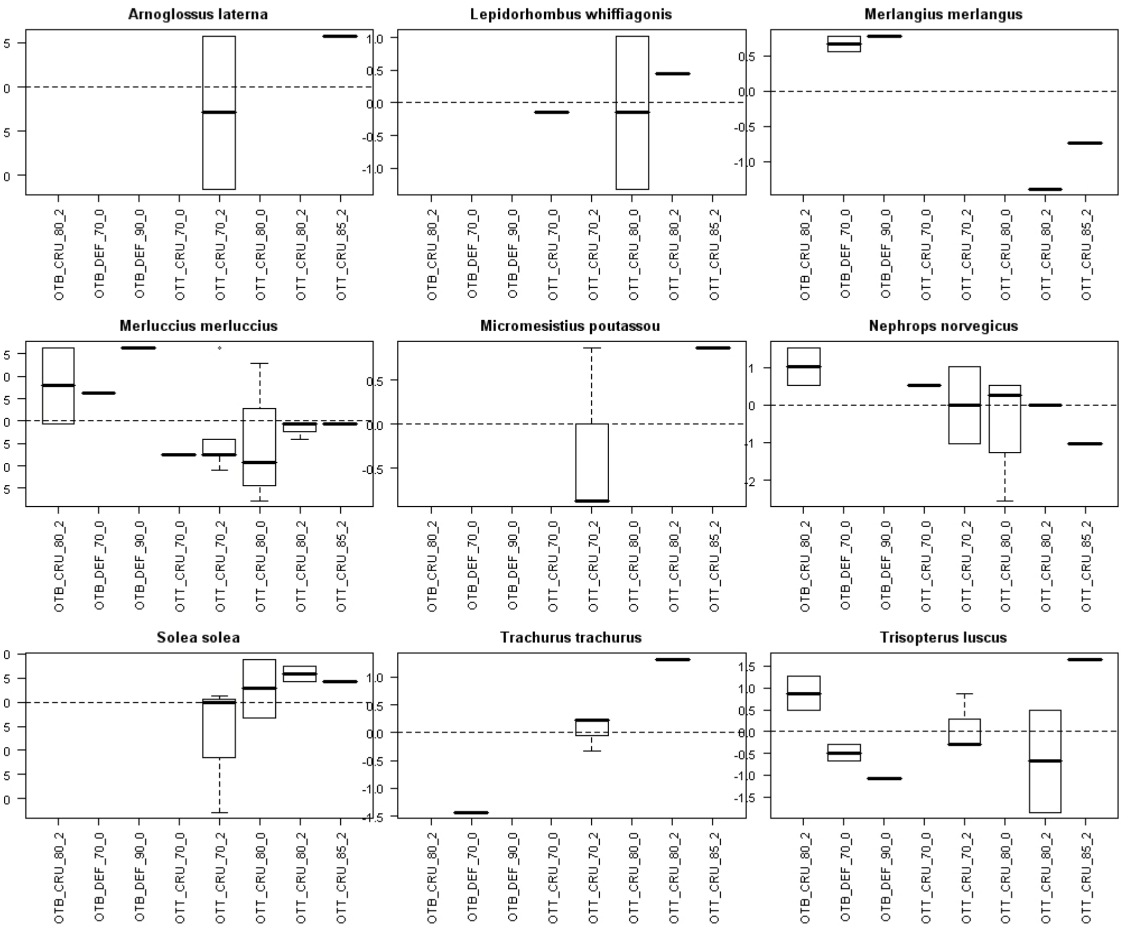

Figure 6: boxplot of normalised L50 per species

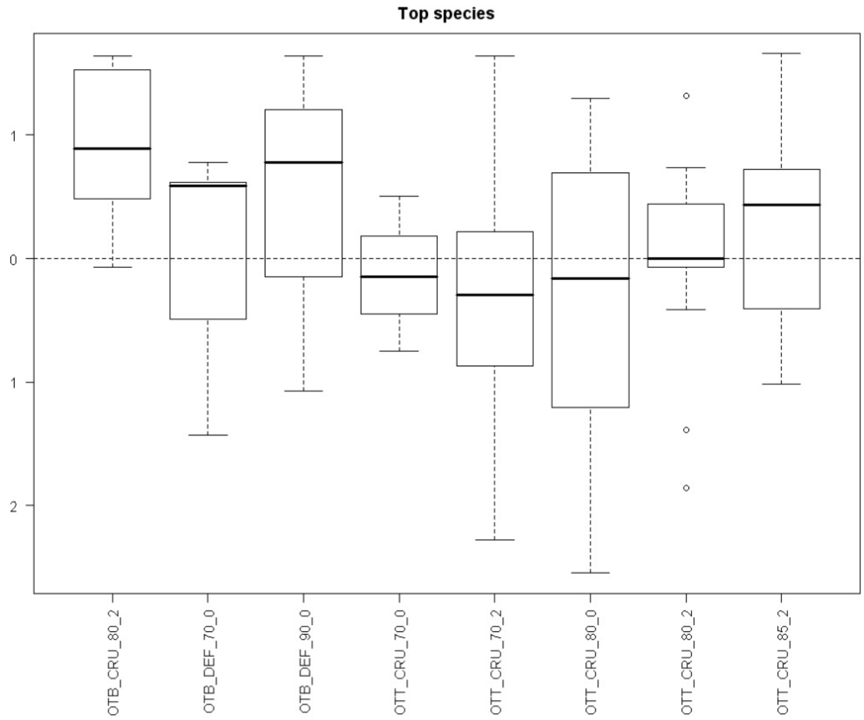

Figure 7: boxplot of normalised L50 for all species

Figure 7 displays the combination of L50 values for all species across metiers. This figure displays more logics, although unexpectedly OTB seems to show higher L50 values than OTT gears:

1) Within OTB, and independently of the targeted species, mesh size 70 shows smaller values of L50 than both mesh size 80 and 90.
2) Within OTT, mesh size 70 displays lower L50 values than mesh size 80 itself displaying lower L50 values than mesh size 85.
3) For the same mesh sizes, the presence of a selective grid displays a higher value than their counterpart without selective device, except for mesh size 70 where both are showing approximately the same magnitude.

Discussion

Discriminating one metier to another is not a simple task and it is not a manichean issue. The wild populations composing the catches are constantly evolving in time and space. A given exploitation pattern cannot be the signature of one metier at a given time in a given fishing area, but the resultant of the annual catches of one group of fishing trips. The catch profile and length structure of these fishing trips is obviously linked to the gear used and the areas fished, but the within metier heterogeneity often hides the differences between metiers.

Catch profiles has enabled to confirm the labelling of metiers done on-board and **discriminated accurately the metier targeting demersal from the metiers targeting crustaceans**. This only point validates, if needed, the method used. The split was much more difficult regarding the discards, where the first distinction was not possible to interpret.

The differentiation of length structures by metiers proved to be tricky. Indeed the mesh size were ranging from 70 to 90 mm, which is rather a close range for such analysis. There was also the presence of a selective device in some metiers to be quantified. Unexpectedly, the gear OTB showed a difference with OTT, whereas the starting postulate would have combined those 2 gears for sampling purposes. This result **call for further analysis, otherwise, it will be difficult to state that the combination of these two gears is based on scientific evidence.**

In some point, this study shows what we should never do, namely carry out a cluster analysis on a very small fraction of the population of fishing trips. Here the universe is composed of 20 trips, relatively close to each other, and the cluster analysis has provided similarities and differences, as it would show differences between two trips whatever similar they are. What is **important is to seek similarities and differences in all the fishing trips having operated on a given fishing ground during a given period**, not on a small fraction of them.

Even though WKPRECISE (ICES, 2008) recommended to set up sampling frames allowing more randomness in the sampling programmes, and considered the metier as a domain rather than a stratum, the scientific evidence to combine domains is as relevant as bringing scientific evidence to combine strata. Indeed, the number of samples falling in combined domains will be more numerous than in distinct domains. Moreover, the consideration of metiers as domains will authorise carrying out a posteriori analysis on metiers differences within a domain. **The methods used in this WD can serve as guidelines for doing such analysis** and the outcome here is appealing on the need to carry out such analysis, almost with a mandatory status.

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Annex 8: Working Document 4: Statistical comparisons of exploitation patterns (fish length distributions) between two gear types (OTM and PTB): Finland

ANNEX II of the Finnish NP 2009-2010 (Finland_NP-proposal_2009-2010_Text_15-May-09)

ANNEX II. Statistical comparisons of exploitation patterns (fish length distributions) between two gear types (OTM and PTM)

Background

According to DCF, metiers can be merged when they have similar and statistically proven exploitation patterns and the merging is supported by documentation. We have carried out statistical comparisons of exploitation patterns (fish length distributions) between two gear types ('Midwater otter trawl' - OTM and 'Midwater pair trawl' - PTM) used in fishery of small pelagic fish (i.e. herring and sprat).

Methods

Three statistical tools were used:

(1): Meaningful differences between the gear types were assessed using equivalence trials (Columb and Lutz 2009).

(2) The input for the equivalence trials (fish length probability distributions) was assessed using a Naïve Bayes Meta Classifier (Mierswa et al. 2006) by stacking (Hatami and Ebrahimpour 2007; Wolpert 1992) two base-level models that were a decision tree classifier and a k-nearest neighbor classifier.

(3): Comparison between length distributions between the gear types without assumptions on parameter distributions and, without a-priori assumptions on relationships among variables was done using a Generalized Regression Neural Network (Specht 1991).

Results

Equivalence trials

The equivalence trials suggested that the fish length confidence intervals of the two gears are more likely equivalent, than not (Figure 1). The difference in mean coverage between the two gears was both positive and negative in all areas that suggest random selection between the years (Table 1). Table 1 summarizes the statistics of the equivalence trials.

Generalized Regression Neural Network

The Generalized Regression Neural Network suggested that the difference in fish length between the two gear types is ± 7.0 mm on average (Figure 2). The fish length estimates (OTM minus PTM) were both positive and negative in all areas i.e. the estimated fish length differences did not show temporal selection pattern in any area (Figure 2). Table 2 summarises the statistics of the Generalized Regression Neural Network.

Bayes Meta classifier

Appendix 1 shows the fish length probability distributions of the Bayes Meta classifier that were used as an input in equivalence trials (Figures 3 – 27 in Appendix 1). The probability distributions show that the difference in fish lengths between the two gear types is ± 7.7 mm on average (OTM minus PTM; most likely values). The results of the Bayes Meta classifier and the Generalized Regression Neural Network were nearly identical (corr. 0.99, $R^2 = 0.98$, OTM minus PTM, most likely values).

Conclusions

The equivalence trials suggested that the differences in fish length distributions between the two gear types are more likely meaningless, than meaningful. The two other models (models 2 and 3) suggested that the differences in fish length distributions between the two trawl gear types are small (± 7.7 and ± 7.0 mm on average). In addition, all three models suggested that the differences in fish lengths were both positive and negative in all areas. This suggests random selection between the years i.e. that the fish length differences occur by chance. This suggests that the exploitation patterns of the two gears are similar and, therefore they can be merged and sampled side by side in the Baltic Sea for collecting data on Baltic herring and sprat stocks.

Full report available as pdf on WKMERGE sharepoint site.

Annex 9: Some common formulae applied in design-based fishery surveys.

The following is adapted from WKSMRF (ICES, 2009c) with some additional formulae from Allen (2009).

Probability Sampling Methods

There are a number of basic probability sampling designs that can be used to draw a survey sample from a sampling frame, and each design dictates a different specific set of estimation formulas for point estimators and point estimator variances (Sarndal *et al.*, 1992). The different possible designs offer advantages and disadvantages that should be considered in the selection of the design to be used for a particular survey.

Simple random sampling is the easiest design to implement and it allows use of the simplest estimators. In this sampling design, every element of the frame has a probability of being selected and their individual selection probabilities are equal. The point estimator of a population total ($\hat{t}_\pi$) is a simple formula based on the sum of the sample observations ($\sum_s y_k$), the sample size (n), and the frame size (N) as follows:

$$\hat{t}_\pi = \frac{N}{n}\sum_s y_k \, .$$

The estimator of point estimator variance ($\hat{V}(\hat{t}_\pi)$) is also a straightforward formula based on the sample variance (S^2_{ys}), the sample size (n), and the frame size (N) as follows:

$$\hat{V}(\hat{t}_\pi) = N^2 \frac{\left(1 - \frac{n}{N}\right)}{n} S^2_{ys} \, .$$

Stratified random sampling is another probability sampling design that can be used to reduce the variance of point estimators. In this design, the frame population is divided into subpopulations called strata, and each stratum is sampled independently. If strata are defined such that the elements of each stratum are relatively homogeneous with respect to the parameter of study and most of the frame population variability is due to differences among strata, then stratified sampling can lead to substantial gains in the precision of point estimators of the study parameter. In the stratified design, point estimates and estimates of point estimator variance are calculated separately for each sampled stratum. Because each stratum is sampled independently, both the point estimates and variance estimates can be summed to get total estimates for the frame population. If variability in the unknown study parameter is low within strata, then the stratum estimates of point estimator variance will be relatively low. The sum of the stratum variances would likely be much lower than the point estimator variance that would be obtained without stratification of the frame population. The key inputs for the estimates are the total size of each stratum (N_h), the sample size in each stratum (n_h), the sample mean in each stratum ($\bar{y}_{s_h}$), and the sample variance within each stratum ($S^2_{ys_h}$).

The point estimator is as follows:

$$\hat{t}_{\pi} = \sum_{k=1}^{H} N_h \bar{y}_{s_h} \ .$$

The estimator of point estimator variance ($\hat{V}(\hat{t}_{\pi})$ is as follows:

$$\hat{V}(\hat{t}_{\pi}) = \sum_{k=1}^{H} N_h^2 \frac{\left(1 - {n_h}/{N_h}\right)}{n_h} S_{ys_h}^2 \ .$$

Stratified sampling also offers the flexibility of differentially allocating sample among strata in ways that could further improve the overall precision of parameter estimates. Because the sampling of each stratum essentially comprises a separate survey, it is possible to allocate proportionally more of your total sample size for your study to the strata that have greater variability in the study parameter. In general, a stratified sampling design can lead to precision gains that are comparable to those obtained from a PPS sampling design, but the stratified design is often easier to implement than PPS and its variance estimators are simpler.

Cluster sampling is the type of sampling that must be used with indirect frames that identify subsets of target population elements rather than individual elements. In a simple random cluster sampling design, each frame unit represents a cluster of population elements and all clusters have a defined probability of being selected within a stratum. Once a sample of clusters is selected, then all or a random selection of elements within each of those clusters are observed. The samples provide a means of estimating the total catch or length composition of the vessels/trips comprising the cluster. A typical example of cluster sampling is when using a list of fishing access points as an indirect frame to gain access to vessels landing their catches.

The point estimators and estimators of precision are relatively straightforward for simple random cluster sampling where all elements of the cluster are sampled (one-stage sampling), and the estimators are based on the known total number of clusters in the frame (N_I), the number of sampled clusters (n_I), the mean of the totals observed for all elements within the sampled clusters ($\bar{t}_s$), and the variance of those observed totals among the sampled clusters (S_{ts}^2) as follows:

$$\hat{t}_{\pi} = N_I \bar{t}_{S_I} \text{, and}$$

$$\hat{V}(\hat{t}_{\pi}) = N_I^2 \frac{\left(1 - {n_I}/{N_I}\right)}{n_I} S_{ts_I}^2 \ .$$

Much like for direct element sampling, unequal probability cluster sampling or simple stratified cluster sampling designs can be used to obtain gains in the statistical precision of point estimators with more complicated estimation formulas. For example, the probability of selecting a port-day sampling unit can be related to the relative "size" of the port in terms of total landings, effort etc.

Two-stage sampling is similar to cluster sampling, except selected clusters are subsampled in this probability sampling design. This design is commonly used in fishery surveys where it is usually not easy to obtain observations from all of the population elements contained within a given unit cluster of an indirect sampling frame due to time constraints.

In such a case, the first stage of sampling would select a sample of sites and each site would represent a cluster of fishing trips. The second stage of sampling would consist of a simple random sampling of landings within each selected fishing access site. The primary sampling unit would be a landing site, and the secondary sampling unit would be an individual vessel landing. The point estimators and estimators of point estimator variance are considerably more complex for the two-stage simple random sampling design than for the simple random cluster sampling design. Nevertheless, estimation methods can be relatively straightforward if accurate cluster sizes are obtained in the first stage of sampling and combined with observations obtained from the individual elements sampled in the second stage. The point estimator of a population total is based on the number of clusters (N_I), the number of sampled clusters (n_I), the sizes of the sampled clusters (N_i), the means of observations obtained within the sampled clusters ($\bar{y}_{s_i}$) as follows:

$$\hat{t}_\pi = \frac{N_I}{n_I} \sum_{s_I} N_i \bar{y}_{s_i} = \frac{N_I}{n_I} \sum_{s_I} \hat{t}_{i\pi} \ .$$

The estimator of the point estimator variance also utilizes the sample variances within ($S^2_{ys_i}$) and among ($S^2_{\hat{t}s}$) the sample clusters as follows:

$$\hat{V}(\hat{t}_\pi) = N_I^2 \frac{\left(1 - {n_I}/{N_I}\right)}{n_I} S^2_{\hat{t}s_i} + \frac{N_I}{n_I} \sum_{s_I} N_i^2 \frac{\left(1 - {n_i}/{N_i}\right)}{n_i} S^2_{ys_i} \ .$$

More complicated **multi-stage sampling** designs can be used with indirect sampling frame, but the sampling protocols and estimation methods become increasingly more complex as more stages are added to the design (see Allen *et al*. 2002).

Unequal probability sampling is more complicated to implement and requires more complicated estimators, but it can be advantageous for increasing the precision of point estimators as measured by reduced point estimator variances. In this type of sampling design, the selection probabilities of individual frame elements are not equal. A special case of unequal probability sampling is called **probability-proportional-to-size (PPS) sampling**. In PPS sampling the selection probability of each frame unit is directly proportional to its known size with respect to a known auxiliary variable. If a known auxiliary variable is likely to be highly correlated with the unknown parameter to be estimated, then PPS sampling based on the known values of that auxiliary variable can lead to significant reductions in point estimator variance, hence more precise point estimators. For example, if large fishing vessels contribute disproportionately to the overall variance of discards or length/age estimates, it would be beneficial to use a PPS approach that would base individual vessel selection probabilities on vessel size or some other measure of "size". PPS approaches could also be applied when the primary sampling units are ports – days, if it is desired to increase the probability of sampling the larger ports where a large fraction of the fleet or total catches are derived from.

Although the estimator of total fishing effort or discards would be more complex using this approach, the estimation formula (Hansen-Horwitz estimator) for a point estimator ($\hat{t}_{pwr}$) would be a straightforward calculation based on the observations for each sample element (y_k), the predetermined selection probabilities of those elements (p_k), and the sample size (n) as follows:

$$\hat{t}_{pwr} = \frac{1}{n}\sum_{i=1}^{n}\frac{y_k}{p_k}.$$

The estimated variance of the point estimator ($\hat{V}\left(\hat{t}_{pwr}\right)$) would be calculated as follows:

$$\hat{V}\left(\hat{t}_{pwr}\right) = \frac{1}{n(n-1)}\left[\sum_{i=1}^{n}\left(\frac{y_k}{p_k}\right)^2 - \frac{1}{n}\left(\sum_{i=1}^{n}\frac{y_k}{p_k}\right)^2\right].$$

(see Cochrane, 1977 for equivalent formulae for the sample mean rather than frame total). An alternative formula (Horwitz-Thomson) is often used when it is probable that a unit will be sampled more than once (McCracken *et al.*, 1999). See standard texts for more details (e.g. Levy and Lemeshow, 1999). (Also see Table 2).

Ratio estimators (from Allen, 2009)

The ratio sample mean estimator, $\overline{y_R}$ utilises the correlation between the auxiliary variable, x, and the variable of interest, y, to improve the precision of the mean estimate. The ratio sample mean estimator is given as:

$$\overline{y}_R = \frac{\overline{y}}{\overline{x}}\overline{X}$$

where $\overline{x}$ and $\overline{y}$ are the sample means of x and y respectively, and $\overline{X}$ is the population mean of x. The estimated sample variance of the mean is given as:

$$v(\overline{y}_R) = \frac{1}{n(n-1)}\sum_{i=1}^{n}\left(y_i - \frac{\overline{y}}{\overline{x}}x_i\right)^2$$

The ratio estimator is biased in the order of 1/n and its standard error has a bias in the order of 1/√n for smaller sample sizes and when there is a weak correlation between the auxiliary variable x and the variable of interest, y. However for large sample sizes (≥30) the bias is negligible.

Regression estimators (from Allen, 2009)

The linear regression sample mean estimator, $\overline{y}_{LR}$, like the ratio mean estimator, makes use of the correlation between *x* and *y* to increase the precision of the mean estimate:

$$\overline{y}_{LR} = \overline{y} + b\left(\overline{X} - \overline{x}\right)$$

where *b* is the least squares estimate of the coefficient of the regression of *y* on *x*. The estimated sample variance of the mean is:

$$v(\bar{y}_{LR}) = \frac{1}{n(n-2)} \sum_{i=1}^{n} \left[(y_i - \bar{y}) - b(x_i - \bar{x}) \right]^2$$

If the relationship between *y* and *x* is non linear, then the regression estimator mean has a bias of the order of 1/n while its standard error has a bias in the order of $1/\sqrt{n}$. the bias becomes negligible in large samples. The ratio estimator is a particular case of the regression estimator when the fitted relationship between *y* and *x* is a straight line and the variance in the *y* residuals is proportional to *x*.

For ratio, regression or pps estimators to be an improvement over simple random sampling, there needs to be a significant correlation *r* between *x* and *y*, in which case the precision of the regression estimate relative to the simple random sampling estimate can be approximated by $(1-r^2)$ (Cochran, 1977). Allen (2009) also shows that the relative precision of the different forms of estimator depend on whether the variance of *y* is constant, is directly proportional to *x*, or increases with *x* at a rate greater than direct proportionality. Relative performance also depends on whether the intercept of the regression of *y* on *x* has a non-zero intercept.

Annex 10: Proposed guidelines for description of national schemes for metier based biological sampling, for inclusion in National programmes

The following headings and guidelines are proposed as a framework for member States to describe their fishery sampling schemes in their DCF National Programmes for 2011–2013.

Member State:

RCM regions covered:

The objectives of the sampling schemes for collecting metier-based biological data and the types of estimates provided by the sampling schemes
e.g. (a) DCF requirements for concurrent length sampling, discards data etc by defined metiers; (b) other national requirements (specify).

Sampling frames adopted to provide metier-based biological sampling data for retained and discarded catch, and the primary sampling units comprising the frames
e.g. list of vessels, area list of sampling sites for on-shore sampling etc. The frame should comprise non-overlapping primary sampling units that form the first stage in selecting units for sampling, for example vessels, port x time period. Does the frame cover the population to be sampled or are there parts of the population excluded for sampling – e.g. vessels too small to take observers or refusing access; significant ports or groups of sampling sites too remotely located to permit sampling or excluded for other reasons.

Stratification employed in data collections for retained and discarded catch, including the basis for the stratification
e.g. geographic, temporal, vessel LOA classes, gear type etc. Is stratification designed for improving precision, improving spatiotemporal coverage, providing increased data for specific areas/vessels/times etc., ensuring adequate coverage of Level 5-6 metiers (domains) or for logistical reasons (e.g. distribution of sampling teams)? Are there Level 5 – 6 metiers that can be treated as sampling strata rather than as domains? Has any statistical justification been provided for merging any LOA classes in Commission Decision 2008/949/EC Appendix IV, as stated in 2008/949/EC paragraph B1.2.1)?

Procedures for selecting vessels / trips for sampling retained and discarded catch for metier-related biological variables.
e.g. Census; probability methods (stratified random sampling; probability proportional to size etc.); non-probability (ad hoc) methods. Provide justification for the methods chosen for selecting units for sampling at-sea and on-shore. Describe the selection of primary sampling units (e.g. vessels; port x time blocks) and secondary sampling units (trips within vessels for vessel list frames; landings within clusters ashore).

Basis for determining the sampling intensity per sampling frame and stratum
e.g. precision targets; meeting DCF minimum requirements for trips per metier; other information on variability amongst PSUs in the strata. Is there a fixed sampling effort defined by available resources and how is this apportioned amongst frames and strata? Has an optimisation routine been applied? Are cluster sampling and effective sample size considered in the design of the sampling scheme?

Treatment of non-accessible vessels or groups of vessels e.g. is information recorded to allow evaluation of potential biases, or auxiliary variables collected to allow imputation using modeling approaches?

Rules used for post-hoc allocation of individual trips to metiers

e.g. How is Commission Decision 2008/949/EC Appendix IV footnote (b) interpreted? (*The retained part of the catch should be classified by target assemblage (crustaceans, cephalopods, demersal fish, etc.) at a trip level or at a fishing operation level when possible, and sorted by weight or by total value in the case of valuable species (e.g. Nephrops, Tunas). The target assemblage that comes up at the first position should be considered as the target assemblage to be reported in the matrix*.)

Basis of any merging (pooling) of metiers given in the National programme of the member State

e.g. target assemblage and/or mesh poorly definable in advance; reduce the number of domains (metiers) for which data could be provided given available sampling resources; avoid over-stratification etc. Have any statistical methods been used to identify or defend merging of metiers, such as multivariate analysis?

Annex 11: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. MS to ensure sampling designs takes account of guidelines provided by WKMERGE. Use WKMERGE guidelines for NP proposals	MS
2. Clients for data must recognise the cost of providing estimates for domains specified at too highly resolved metier level that contribute less than the main metiers (see also WKPRECISE)	EC; RFMOs
3. Primary data held in databases should be real observations and not imputations done manually or with automated routines. Imputation must be carried out external to the data base using known robust methods. If modeling is to be used for imputation (e.g. for non-accessible vessels), the data collection scheme should ensure that the necessary auxiliary data are collected for those vessels. (End users to be made aware)	MS; end users (ICES; STECF; JRC)
4. Strata should be defined so that there is controlled sample selection probability. Take necessary steps to achieve representative sampling of fishing trips or vessels within strata using random or systematic (with random element) schemes. Avoid targeted non-random sampling (quota sampling) to reach sample sizes for highly resolved domains (e.g. Level 6 metiers) present within the primary sampling strata. Sampling schemes should provide the ability to provide data allowing robust estimates for domains within strata, when estimates by domain are required..	MS
5. Where key variables that are required for establishing sampling and estimation schemes and determining sampling probability or weighting (e.g. mesh size; area fished) are missing or inaccurately recorded in vessel log-books or not available (e.g. small vessels without logbooks) – the impact on estimation should be evaluated and steps taken, if necessary, to improve recording accuracy or collection of variables.	MS; EC
6. Further development of data bases and COST tools should aim to cater for the different possible sampling designs and associated raising procedures described in WKMERGE. Otherwise consider use of commercially available gold-standard software such as SUDAAN© (http://www.rti.org/sudaan/index.cfm) and Survey analysis package in R (package "survey", http://faculty.washington.edu/tlumley/survey/	EC; STECF SGRN, MS
7. Formation of a Study Group or EU contract would be appropriate to consider methods and tools for optimisation of sampling schemes between MS to achieve international precision targets and consistent collection of data to allow analysis by domains covering international strata within regions (e.g. metiers) – (conditional on having the data collected on an appropriate basis for input to optimisation schemes.)	PGCCDBS/PGMED / RCM
8. Merging of metiers should be treated as a concept more applicable to a-priori defining domains of interest e.g. metiers that are stable in time. This is distinct from establishing optimal stratification for sampling in order to provide the domain data. Any scientific evidence brought for grouping metiers should be discussed at RCMs for international agreement. Further development and agreement of statistical methods e.g. multi-variate methods is recommended for identifying homogeneous metiers that are stable over time and relevant to fishery management.	MS, RCM