FAO EAF–Nansen Project Report No. 14 EAF-N/PR/14 (En)

Report of the

EXPERT WORKSHOP ON INDICATORS FOR ECOSYSTEM SURVEYS

Rome, Italy, 29-31 August 2011

THE EAF-NANSEN PROJECT

FAO started the implementation of the project "Strengthening the Knowledge Base for and Implementing an Ecosystem Approach to Marine Fisheries in Developing Countries (EAF-Nansen GCP/INT/003/NOR)" in December 2006 with funding from the Norwegian Agency for Development Cooperation (Norad). The EAF-Nansen project is a follow-up to earlier projects/programmes in a partnership involving FAO, Norad and the Institute of Marine Research (IMR), Bergen, Norway on assessment and management of marine fishery resources in developing countries. The project works in partnership with governments and also Global Environment Facility (GEF)-supported Large Marine Ecosystem (LME) projects and other projects that have the potential to contribute to some components of the EAF-Nansen project.

The EAF-Nansen project offers an opportunity to coastal countries in sub-Saharan Africa, working in partnership with the project, to receive technical support from FAO for the development of national and regional frameworks for the implementation of Ecosystem Approach to Fisheries management and to acquire additional knowledge on their marine ecosystems for their use in planning and monitoring. The project contributes to building the capacity of national fisheries management administrations in ecological risk assessment methods to identify critical management issues and in the preparation, operationalization and tracking the progress of implementation of fisheries management plans consistent with the ecosystem approach to fisheries.

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STRENGTHENING THE KNOWLEDGE BASE FOR AND
IMPLEMENTING AN ECOSYSTEM APPROACH TO
MARINE FISHERIES IN DEVELOPING COUNTRIES
(EAF-NANSEN GCP/INT/003/NOR)

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2013

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PREPARATION OF THIS DOCUMENT

The Expert Workshop on indicators for ecosystem surveys was held in Rome from 29 to 31 August 2011 within the framework of the EAF-Nansen project (Strengthening the Knowledge Base for and Implementing an Ecosystem Approach to Marine Fisheries in Developing Countries). The workshop was attended by 16 experts from Africa, Asia and Europe. This report captures the presentations made at the workshop and provides highlights of the discussions that followed. Many of the participants contributed to the preparation of this report both during and after the expert workshop.

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ABSTRACT

The Expert Workshop on indicators for ecosystem surveys was held in Rome from 29 to 31 August 2011 under the EAF-Nansen project (Strengthening the Knowledge Base for and Implementing an Ecosystem Approach to Marine Fisheries in Developing Countries). It was attended by 16 participants from Africa, Asia and Europe.

The principal objective of the workshop was to identify indicators for ecosystem surveys which could lead to the establishment of a list of ecosystem features and associated survey data for an ecosystem approach to fisheries. The participants were expected to identify key management objectives and priorities, and produce a list of ecosystem indicators to address them. Discussions centered on the following main questions: How should research vessels (RVs) be used to assess the ecosystem status (survey design, etc.)? What should be the survey priority of the RV Dr. Fridtjof Nansen? What RV data are needed to feed into an EAF? How can we gather and analyze existing survey data to produce an appropriate and workable baseline for monitoring the oceans?

A paper (Using research vessels to build a knowledge base for the ecosystem approach to fisheries) prepared as background was discussed. The paper focussed on the practical aspects of running an ecosystem survey using a RV, and taking into account the constraints arising when small vessels, possibly being temporarily adapted for survey work, were used. Some findings of the Institute of Marine Research of Bergen’s Barents Sea survey programme, which focused effectively on the ecosystem from 2004 to 2008, were presented and discussed.

Two tables were developed; one relevant to monitoring impacts of fishing on a marine ecosystem, and the other relevant to ecosystem monitoring more generally.

Further discussion concerned how best to use the RV Dr. Fridtjof Nansen to contribute to an EAF in developing countries. Participants made suggestions for the design of the new vessel to replace the existing RV Dr Fridtjof Nansen. It was concluded that the new vessel should also be equipped for oceanographic studies since water masses, fronts and currents play major roles in the biology and migrations of species. The need to minimize time on-station was emphasized and a recommendation was made for multi-function dip devices, and autonomous equipment left at the station to be picked up later.

1. INTRODUCTION

The Expert Workshop on Ecosystem indicators for an ecosystem approach to fisheries (EAF) was held in Rome from 29 to 31 August 2011 under the EAF-Nansen project (Strengthening the Knowledge Base for and Implementing an Ecosystem Approach to Marine Fisheries in Developing Countries). The workshop was attended by 16 experts from Africa, Asia and Europe (Appendix I).

Kevern Cochrane, Director of the Resource Use and Conservation Division of the Department of Fisheries and Aquaculture of the Food and Agriculture Organization (FAO) welcomed the experts and thanked them for accepting to be part of this important exercise. He told the experts that the surveys conducted by the RV Dr. Fridtjof Nansen constitute a major component of the EAF-Nansen project and are important sources of data and information for many coastal developing countries, especially those in Africa. He underscored the need to carry out the surveys efficiently to ensure effective contribution towards the implementation of the EAF by the recipient countries.

Giving the background to the workshop Gabriella Bianchi, Coordinator of the Marine and Inland Fisheries Service (FIRF), recalled the expert workshop on indicators for ecosystem approach which was held in Rome in April 2009. She said that the need to organise a separate consultation on indicators for ecosystems surveys was expressed at that workshop. The principal objective of the present workshop, she said, is to identify indicators for ecosystem surveys which could lead to establishing a list of ecosystem features and associated survey data for an EAF. It is expected that the workshop will identify key management objectives and priorities, and produce a list of ecosystem indicators to address them.

Referring to the Aide memoire prepared for the meeting, Ms Bianchi said that the discussions are to be centered on the following four main questions:

1. How should RVs be used to assess the ecosystem status (survey design, etc)?
2. What should be the priority of the RV Dr Fridtjof Nansen?
3. What RV data are needed to feed into an EAF?
4. How can we gather and analyze existing survey data (including Nansen data) to produce an appropriate and workable baseline for monitoring the oceans?

Ms Bianchi continued that FAO is also looking for some guidance on the following:

1. Defining ecosystem survey objectives and reference points vis-à-vis the survey objectives;
2. Determining the indicators to measure attainment of objectives (using FAO framework?) at the appropriate level; and
3. Identifying what issues might arise in the use and presentation of these indicators for management.

The participants then introduced themselves and presented their backgrounds and interests in the subject matter. Dave Reid (Marine Institute, Galway, U.K.) and Kathrine Michalsen (Institute of Marine Research (IMR), Norway) were elected chair and vice chair respectively. Tore Stromme agreed to minute items with particular relevance to the Nansen survey programme and John Cotter agreed to serve as the general rapporteur.

2. DISCUSSION ON THE AGENDA AND SCOPE OF THE WORK

Following some discussions on the Provisional Agenda (Appendix II) there was consensus among the experts that their task at the workshop was mainly concerned with fishery-independent surveys and the data that emanate from them. It was agreed that normally such data would be collected by fisheries RVs classified as such by the International Maritime Organization (IMO). Other platforms such as fishing vessels chartered for specific investigations, autonomous underwater vehicles (AUVs), and satellites were also considered.

The experts agreed that there were two parts to the task: (i) to advise the EAF-Nansen project (hence Norad, FAO and IMR) on the best use of RV *Dr Fridjof Nansen* for surveys in support of the ecosystem approach to fisheries, and (ii) to advise others which measurements to make with a locally available RV and how best to make them so as to contribute to the development and implementation of an EAF.

There was a general consensus that fishery-independent surveys of ecosystems should, whenever possible, be preceded by collation of all available information in order to scientifically describe the ecosystem and its key features and processes. This was expected to help determine priorities for monitoring, to minimise the inadvertent collection of useless data, and to help decide which measures had to be implemented from a RV, and which collected by other means. Questions were raised over whether moored facilities, underwater monitoring systems, tagging studies, stomach contents analyses, and remote sensing should be included within the scope of the group’s report.

3. PRESENTATIONS

3.1 The background review paper

John Cotter presented the paper (***Using research vessels to build a knowledge base for the ecosystem approach to fisheries***) that he had prepared as background for discussions at the meeting (Appendix III).

He noted that considering the extensive previously published research on EAF, the paper focussed on the practical aspects of running an ecosystem survey using a RV, and taking into account the constraints arising when small vessels, possibly being temporarily adapted for survey work, were used. A monitoring approach, designed to build up time series, was advocated. The paper noted that the simplest RV surveys might only produce species lists by station. On the other hand, modern, specially designed RVs could produce a full list of catch per unit effort (CPUEs), length frequencies, biological measures, and mappings of benthic resources among others. Recommendations on indicators should allow for operational constraints, e.g. maximum time on-station. This is a particularly important issue when ecosystem monitoring is part of a groundfish survey (GFS) primarily focussed on commercial species.

In the discussions that followed the presentation, the experts noted that the paper gave little or no attention to plankton and hydrography, both of which could be important to an ecosystem approach. Plankton sampling can be carried out easily on research surveys but analysis of samples is costly, depending on the information required. In some regions, hydrography can vary extensively from year to year. The general problem of defining the ecosystem to be monitored especially when there are no natural boundaries, such as on land, was also considered. One approach proposed was to use biogeographic regions. Another was to monitor primarily the fished regions or to delimit the ecosystem with the aid of hydrodynamic models and foodweb studies. Protecting fish refugia, e.g. reefs or other essential habitat was raised as a priority. So too was public perception of ecosystems which tends to centre on charismatic species such as turtles. A question arose over whether an ecosystem survey should (i) only consider the effects of fishing on the ecosystem or (ii) consider both the effects of fishing on the ecosystem and the effects of the ecosystem on fishing. Changing climate, physical disturbances, and alien species were mentioned in the latter context. Characterization of habitats so as to allow specific monitoring of them was suggested as one way to reduce the number of indicators needing attention under an EAF.

The nature of RVs was discussed. There was support for a RV potentially being a small vessel or a chartered fishing vessel without special facilities. In some countries, this is all that would be available and FAO was expected to supply specific recommendations for ecosystem monitoring in these circumstances. It was reported that guidance on the level of investment in RV facilities in relation to the value of the fisheries was being prepared. It was noted that unfortunately some developing countries that have valuable industrial-scale fisheries do not have RVs to monitor the supporting ecosystem.

The value of one-off ecosystem surveys was questioned e.g. for describing ‘baseline’ conditions or for assisting design of a subsequent ongoing monitoring survey. There was general agreement that they should be used judiciously for these purposes. The ever-changing nature of ecosystems should be acknowledged, however, and this necessitates ongoing monitoring. This notwithstanding, surveys with the RV Dr Fridtjof Nansen in some cases could only be repeated in the same geographic region with 10- or 20-year gaps because of limited opportunities. There was currently an opportunity to add extra ecosystem measures to these return surveys.

3.2 The RV Dr Fridtjof Nansen survey programme

Tore Stromme made a presentation on the RV Dr Fridtjof Nansen survey programme. He said that the Nansen is a state-of-the-art ocean-going RV with wide capabilities and operated within the partnership between the Norwegian Agency for Development Cooperation (Norad), IMR Bergen, and FAO.

Mr Stromme pointed out that in the 1960s the Nansen survey programme was focussed on assessing the fishery resources of developing countries. Nowadays, the project is directed towards implementing an ecosystem approach to fishery management (EAF) including hydrographic monitoring. Many examples of data gathered on fisheries in the waters of developing countries were given. Pelagic fish stocks were surveyed acoustically with trawl verification of species. Demersal fish stocks were surveyed through bottom trawling. Epibenthic sampling had been carried out but there was, as yet, little evident ecological connection with the fishing data.

In his conclusion, Mr Stromme expressed the hope that that the meeting would provide guidance on creating a framework for research priorities on how to use RVs like the Dr Fridtjof Nansen for EAF, and on how to choose and use indicators for that purpose.

Afterwards, discussion considered the range of scientific approaches to EAF, whether, at one extreme, to try to understand the ecosystem and all of its component parts and external drivers so that responses to fishing could be predicted or, at the other extreme, to reduce management to a set of automatic responses to the measured values of selected indicators.

3.3 The Barents Sea ecosystem survey programme

Kathrine Michalsen of the IMR, Bergen, Norway presented findings of the Barents Sea survey programme which focussed effectively on the ecosystem from 2004 to 2008. Cutbacks were subsequently implemented. Harmonization of gears used had been obtained by collaboration between Russia and Norway.

At each station, conductivity, temperature, depth (CTD), bottom and pelagic trawls, plankton nets and epibenthic trawls were deployed. Specifically, results were obtained for gadoids, 0-group fish, and zoo- and phytoplankton biomasses by size groups. Between stations, acoustic surveying along transects, and observations of marine mammals and seabirds were carried out. Special studies were made of infauna, parasites, and pollution.

Ms Michalsen noted that the importance of careful standardization was one lesson learnt from the work. Another was that stomach contents revealed many more fish species than were found in the trawls. Biomass calculations found that marine mammals and seabirds consume 1.5 and 1.0 times, respectively, the quantities of fish removed by the fisheries in the Barents Sea. The survey was considered valuable scientifically and had been used as input to management plans. However, it had not so far been directly used for decision making by fishery managers.

Discussions considered the problem of plugging ecosystem data into management systems based on analytical assessments. Some official advisory groups considered ecosystem data to be insufficiently accurate and preferred the use of landings data. One view was that this attitude followed from a 'command-and-control', centralized approach to fisheries; localized management committees using risk assessment techniques to decide where and when to take action might be more flexible about the incorporation of ecosystem data into their decision making.

The following were agreed upon:

i. Fisheries should be managed adaptively within a risk-based advisory system;
ii. Setting the goals of management should be devolved to multi-skilled management groups with direct interest in the continuing productivity of the fishery; and
iii. The same group should identify the differences between fishery-caused and naturally-caused changes in important indicators.

3.4 EAF and the conventional fisheries management approach

Gabriella Bianchi presented a comparison of the EAF with traditional fisheries management (FM). She noted that there are many contrasts, e.g. EAF is more participatory, has wider objectives, is adaptive rather than predictive, and uses all available knowledge rather than being focussed on commercial stocks. She said that one goal of the EAF-Nansen project is to assist countries to develop their fisheries management procedures into an ecosystem approach in which issues must be identified and prioritized, e.g. using Scale Intensity Consequence Analysis (SICA) and Productivity-Susceptibility Analysis (PSA) risk assessment methods developed in Australia (Hobday *et al.*, 2007). Operational objectives must be set for each ecosystem component, indicators of progress towards those objectives must be designed, and management options considered. It is then necessary to monitor the indicators with respect to reference points or directions. Usually, this will involve collection of fisheries-independent information, e.g. using a RV.

Many points were raised in the discussions that followed the presentation. These related, among others, to the concept of 'ecological well-being' and the need for collective decision-making after examining the scientific issues as part of EAF. Doubts were expressed whether RV surveys could provide indicators of sufficient precision and clarity for fishery managers to use as a basis for controversial decisions.

4. DISCUSSION

Working in two groups, two advisory tables were developed; one relevant to monitoring impacts of fishing on a marine ecosystem, and the other relevant to ecosystem monitoring more generally. The tables were discussed and finalized in a plenary session. Ideas from the Oslo-Paris Convention quality status reports and the Marine strategy framework directive of the European Union were taken into account during discussions, notably recommendations to monitor the foodweb, biodiversity, commercial fish, and seafloor integrity. Other matters arising were genetics and stock integrity, plankton, oceanography, threatened, endangered, and protected (TEP) species under the International Union for Conservation of Nature (IUCN) classification, marine mammals, reptiles, cephalopods and seabirds. Bacteria and viruses, though acknowledged as important components of an ecosystem were omitted because of a perceived lack of supporting science for EAF purposes.

The tables, as completed at the meeting but with some re-formatting subsequently, are attached to this report. Explanatory text was thought necessary to supplement the tables but there was not enough time to prepare it at the meeting. Instead, notes have been added to the tables based on discussions. They are linked to items in the tables by superscript numbers. The tables describe high levels of monitoring that often would not be possible with limited resources. However, it was noted that some developing countries could afford to invest heavily in marine ecosystem research and monitoring because of richly productive fisheries in their waters. Additionally, the EAF-Nansen project provides help to developing countries to improve their ecosystem monitoring. The meeting agreed that the tables should be considered as lists of options for monitoring depending on the type and location of the ecosystem, existing knowledge, and facilities on board the RV. Survey sampling and design considerations were also relevant as discussed in the background document prepared for the meeting.

Setting priorities for the different RV monitoring options would depend on local management objectives. In the Namibian hake fishery, for example, priorities were to implement an EAF and obtain certification of the fishery. Other possible objectives could be to address conflicts between a fishery and protected species, or to fill gaps in baseline information. Another agreed way of assessing priorities for ecosystem monitoring was to use ecological risk assessment procedures developed in Australia (Hobday *et al.*, 2007) and now being applied widely elsewhere.

5. OPTIMISING THE USE OF THE RV DR FRIDTJOF NANSEN

The two tables developed at the workshop (Tables 1 and 2) also include alternatives to monitoring ecosystems with a RV but the meeting did not have the time to attempt a ranking of the scientific merits or costs of the different methods.

The participants found Table 1 to be most helpful as Table 2 appeared ambitious for some national marine scientific facilities. Another comment referred to tropical fisheries where there can be a problem identifying key species in food webs or in essential ecological processes because of the very large numbers of species typically present. In such circumstances, it was agreed that a RV survey should be equipped with a robust list of the species being targeted, i.e. those of most scientific interest.

Further discussion concerned how best to use the RV Dr. Fridtjof Nansen and, in due course, a replacement RV to contribute to an EAF in developing countries. One view was that there should be general objectives for Nansen surveys including fish, plankton, stomach sampling and benthos. Taxonomic aspects should be emphasized with, possibly, lists of priority species to be monitored for each marine ecosystem. Attention should also be given to ecosystem boundaries, for example on the edge of continental slopes, and to vertically migrating layers of organisms. Another view was that increasing the between-transect distance of acoustic surveys from 20 to 30 nm could free some ship time for additional ecosystem studies without significantly affecting the results of the surveys.

Tore Stromme told the meeting that many of these aspects already formed parts of Nansen surveys except that there were few resources for taxonomy and stomach contents analyses. Shelf studies are likely to be a focus next year in a further acoustic survey for pelagic resources off the northwestern African coast. A 10 nm transect distance had always been used for pelagic surveys because it provided continuity of signal from the resource. A 20 nm interval was generally used for demersal fish resources surveys. The transects were orientated perpendicular to the shoreline and were long enough to find the offshore limits of shoals; from experience, extending them further would not be productive.

As Norad was currently considering replacement of the RV Dr Fridtjof Nansen because of its age, the meeting was invited to put forward suggestions for the design of the replacement vessel. The latest acoustic and video facilities for mapping benthic habitats were thought to be very important. For example, in North Atlantic waters, despite the large amounts of research done there already, it had been found that searches for vulnerable benthic habitats were still revealing locations worthy of protection from trawling. The replacement vessel should also be equipped for oceanographic studies since water masses, fronts and currents play major roles in the biology and migrations of species. The need to minimize time on-station was emphasized so that the RV is free to visit more localities. On-station times can be reduced using multi-function dip devices (measuring CTD and other variables), and by autonomous equipment left at the station being picked up later, e.g. benthic landers and incubation devices for respirometry and productivity studies.

Following from comments that high-specification RVs may use only a fraction of their capabilities on a single cruise, it was suggested that Norad invest in two basic and adaptable vessels, rather than a single ‘state-of-the-art’ multi-function vessel. The pair might consist of two commercial fishing vessels (FVs) designed for low running costs, or of one moderately specified vessel for special studies plus a basic vessel for straightforward fishing and acoustic activities that it could accomplish more cheaply than the RV. The FV could be designed to sample shallow waters which are inaccessible by a large RV because of its draught, and two vessels can be better than one when large areas are to be sampled. FVs were reported to be well suited for routine deployment of autonomous underwater vehicles (AUVs) for mapping benthic habitats in Northwest Atlantic Fisheries Organization (NAFO) waters. In that case the fishing industry is contributing to basic EAF monitoring. The meeting agreed that collaboration with the industry on EAF is important whenever possible.

Another suggestion was for a helicopter landing pad on the replacement RV. This would enhance synoptic sampling capabilities and permit aerial surveys. Helicopters have high operating costs but can sample large areas very quickly if only a single dip at each station is needed. This had been found to tip the economics in favour of helicopters rather than RVs for some studies, e.g. for ichthyoplankton surveys.

6. NEXT STEPS

John Cotter agreed to tidy the tables (Tables 1 and 2), add notes, and also to finalise the report of the meeting. It was agreed that he should subsequently attempt to unite Tables 1 and 2 and their accompanying notes with the background document into a single report from the meeting. However, there was a need to carefully consider such a document and, preferably, find opportunities to test some of its recommendations. This could result in delays before publishing it.

Table 1 (2 panels): Options for monitoring the impacts of fishing on aquatic ecosystems
Items marked with * require that monitoring be carried out in the correct season.

Abbreviations: A = age; ADCP = Acoustic Doppler current profiler; AFD = age frequency distribution; AUV = autonomous underwater vehicle; B = biomass (total, or spawners only); CPUE = catch per unit effort; CTD = conductivity, temperature, depth; EIA = environmental impact assessment; Est. = estimated; L50 = median length; LFD = length frequency distribution; MBES = multi-beam echosounder; MTL = mean trophic level; N = abundance; nm = nautical mile; RV = research vessel; spp. = species (plural); SSB = spawning stock biomass; T = temperature; VMS = vessel monitoring system (for locating commercial fishing vessels).

Superscript-numbered notes:

1. 'Ecosystem components' are intended as widely understood groupings of the essential parts of an ecosystem. The term was previously used by Hobday *et al.* (2007).
2. 'Parameter' refers to the true – usually unknown – variable or value in the ecosystem.
3. 'Estimator or indicator' refers to a variable thought to show a monotonic functional relationship to the parameter. Proportionality is ideal but not always achievable.
4. It is assumed that appropriate davits/gantries, winches, and sorting facilities are available as a minimum on the RV.
5. 'Alternative data sources' refers to sources other than RVs. Fishery-independent alternatives include platforms, satellites, AUVs. Fishery-dependent alternatives are those associated with commercial fishing. No assessment of the relative merits of RV data and alternative sources can be made in this table.
6. Sustainable populations must include a sufficient proportion of individuals large enough to be capable of breeding.
7. Spatial indicators not sensitive to zero values are defined by Woillez *et al.* (2009).
8. 'Observer' here means a person observing fishing on a commercial fishing vessel at sea.
9. The 'management objectives' column found in table 1 has been omitted from table 2.
10. An 'occupancy' is the proportion of fished stations occupied by at least one individual of a species.
11. Size structures, weighings, abundances, and occupancies[10] of living organisms all require accurate effort measures and size selectivities.
12. Total particulate matter (TPM) = inorganic matter, particulate inorganic matter (PIM) + particulate organic matter (POM). They can be measured fairly easily but separating the living component is difficult.
13. Seabird surveys from RVs: recent references are by Clarke *et al.* (2003), and Hyrenbach *et al.* (2007). See also Tasker *et al*. (1984).
14. Distance sampling surveys for marine mammals and seabirds: recent references are by Thomas *et al*. (2004), and Buckland *et al.* (2004).
15. Habitat sampling: a recent reference is by Kenny *et al.* (2003).
16. Genetics: a recent European research project is presented at http://fishpoptrace.jrc.ec.europa.eu/

Table 1, panel 1 (see abbreviations and notes above)
Monitoring impacts of fishing

Ecosystem component[1]	*Management objective*	*Parameter*[2]	*Estimator or indicator*[3]	*Research survey data or method*	*Alternative data sources*[5]	*At-sea equipment & procedures*[4]
Main target species or stocks	Maintain stock biomass at sustainable levels, e.g. B_{MSY} or SSB > preset levels	Total biomass of population	Est. biomass	Density (N or B/unit area) collected through: - CPUE[11] - Echo-integration - Egg production, mainly pelagic spp.	Catch and effort data from commercial fisheries Aerial surveys Visual surveys	CPUE: Standardized sampling (e.g. fishing) gear and gear monitoring, measuring boards, motion-compensated scales Echo-integration: Acoustic equipment Midwater trawl Egg production: Standardized plankton sampler and midwater trawl, Maturity-staging scales
		Length/weight/ age structure of population[6]	Est. size/age structure (frequency distributions, quantiles, e.g. L50)	Length/weight/age frequencies of RV catches[11]	Length/weight/age frequencies of commercial fish catches	Measuring boards, Motion-compensated scales, Otolith collecting
		Reproductive ability	Est. SSB/ Maturity ogive*	Maturity* at length or at age in RV catches	Port and observer[8] sampling of commercial catches	Measuring boards, Maturity-staging scales, Otolith collecting
		Spatial-temporal distribution	Spatial densities for N or B, Spatial variation of LFDs, AFDs Centre of gravity, inertia, etc.[7] Average CPUE	Point CPUE estimates of density (N, N-at-A, N-at-L)[11]	In some cases, from combining observer + VMS data	As for CPUE or Echo-integration, above

Table 1, panel 2 (see abbreviations and notes above Table 1)

Monitoring impacts of fishing						
Ecosystem component[1]	***Management objective***	***Parameter[2]***	***Estimator or indicator[3]***	***Research survey data or method***	***Alternative data sources[5]***	***At-sea equipment & procedures[4]***
Main target spp. or stocks (continued)	Maintain genetic integrity and diversity	Stock structure	Degree of genetic isolation[16]	Samples collected following standard genetic protocols	Samples collected following standard genetic protocols	See references for protocols
Other species	As for target spp.					
Threatened spp. (sea birds, mammals, etc.)	Minimize fisheries impacts on these species	Distribution (by species) Abundance(by species)	Distribution, Est. abundance	Number of sightings per nm[13,14] Occupancies[10,11] Photo identification	Aerial surveys, Shore-based surveys of colonies	Observation post Binoculars Camera
Habitat (sea floor integrity)	Minimize adverse impacts on benthic habitats	Habitat/Biotopes sediment particle size Geomorphology Topography Hydrographic features (T,S,O, currents) Depth Habitat stability Benthos structure and function	Classification and mapping (biotic and abiotic) Mapping of reference sights	Acoustic bottom backscatter Sediment and biota sampling (macro, mega, info-, epi-infauna, motile, sessile), rapid assessments	Geological surveys Hydrographic surveys Free international hydrographic databases World Ocean Atlas EIA by industries Biological traits	Habitat classification and mapping[15]: Acoustic mapping: - Echosounders (preferably multi-beam, MBES) - Underwater video - Side-scan sonar Groundtruthing: - Grabs (mainly for infauna); Corer - Epibenthic trawl - Dredges
Ecosystem structure & function (food web)	Maintain ecosystem structure and functioning	Abundance/biomass of key species, e.g. for predator-prey relationships	Ecosystem modeling Diversity measures ABC curves Size spectrum MTL	Est. of primary production* Stomach content analyses Stable isotopes	Large fish abundance indicator from commercial landings Remote sensing of chlorophyll by satellite*	As for target spp. for fish, See also plankton sampling in table 2 below

Table 2 (6 panels): Options for monitoring aquatic ecosystems, given an initial characterization of the system based on available knowledge. Those marked * require that monitoring be carried out in the correct season. See abbreviations and notes above Table 1.

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Water	Physico-chemical properties (T, conductivity, O_2, transmission, pH)	Measures of CTD, O_2, light transmission, pH	Piped, under-way systems Dip stations Water-bottle stations Towed undulators	Hydrographic surveys Free international hydrographic databases World Ocean Atlas EIA by industries Satellites Deployed moorings AUVs	Thermosalinographs Multi-function dip devices (e.g. CTD carousels) Sampling bottle systems Secchi discs
	Nutrients (N,P, Si, micro-nutrients)	Nutrients (N, P, Si, micro-nutrients)*	Water bottles Piped under-way systems	Some hydrographic surveys	Water bottles
	Water mass distribution	Temp-salinity profiles	CTD stations Underwater undulating samplers	Hydrographic surveys Free international hydrographic databases World Ocean Atlas	Hydrographic CTD (accurate to 3 decimal places)
	Currents and circulation	Eulerian & Lagrangian measures of velocity	ADCP Seabed drifters	Hydrographic surveys Current-metre moorings, Free international hydrographic databases World Ocean Atlas Models	ADCP Seabed drifters Current-metre moorings

Table 2, panel 2 (see abbreviations and notes above Table 1)

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Sea bed	Habitat/biotopes: Sediment characteristics, e.g. particle size, organic matter, carbonate Geomorphology Topography Hydrographic features e.g. T, S, O currents, Depth Habitat stability Benthos structure and function	Classification and mapping (biotic and abiotic), Mapping of reference sites	Acoustic bottom backscatter Sediment and biota sampling (macro, mega, info-, epi- in-fauna, motile, sessile)[11], rapid assessments	Geological surveys Hydrographic surveys Free international hydrographic databases World Ocean Atlas EIA by industries Biological traits	Habitat classification and mapping: Acoustic mapping: - Echosounders (preferably MBES) - Underwater video - Side-scan sonar Groundtruthing: - Grabs (mainly for infauna); Corer - Epibenthic trawl - Dredges
Benthic fauna	Biomass by taxonomic categories	Infauna, epifauna weighings (dry, wet, organic)	Grabbing Coring Benthic trawling and dredging[11]	None	Grabs, corers, trawls, dredges, sledges Sorting facilities on deck Standardized sieves Motion-compensated balances
	Community structure	Abundances Diversity Size structures	Results from grabbing, coring, benthic trawling/dredging[11]; Visual/video	None	Grabs, corers, trawls, dredges, photographic sledges, TV sledges Sorting facilities on deck Standardized sieves
	Production	O_2 consumption of cores	Experiments on deck Biomass results Benthic lander systems	From biomass/production ratios	Corers, respirometric system Benthic lander systems
	Population dynamics for key species	Age, size compositions Abundances recruitments	Age and size compositions[11] Abundances[11]	Landings data for commercial spp.	Various ageing and measuring equipment depending on species

Table 2, panel 3 (see abbreviations and notes above Table 1)

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Plankton	Biomass of phytoplankton Phytoplankton production Species composition Vertical and spatial distribution	Biomass: - Chlorophyll a /unit volume - Derived from biomass & POC Production: - In situ or simulated in situ incubations Species composition: - Microscopic counts/unit vol. - Spectral composition/colour	Measures from water bottles Fluorescence measures In situ light levels	Remote sensing satellites Meteorological information Continuous Plankton Recorder (CPR)	Water bottles Fluorescence metre Incubation facilities Microscopes Optical plankton counters Towed optical systems Analytical flow cytometer (AFC)
	Biomasses of zooplankton (categorized as micro, meso, macro, gelatinous)	Biomass: - Wet & dry weights by category/sizes Production and population dynamics for key spp: - Rate measures (e.g. egg production, moulting, metabolism) Species composition: - Size spectrum - Taxonomy - Functional groupings	Measures from water bottles Plankton nets Optical systems Acoustic systems Stomach analyses of zooplankton grazers, e.g. small pelagics	Coastal and moored plankton stations CPR	Water bottles Plankton nets Optical systems Acoustic systems Microscopes Towed optical systems Continuous under-way fish egg sampler

Table 2, panel 4 (see abbreviations and notes above Table 1)

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Plankton continued	Biomass of organic particulates excluding living zoo and phytoplankton (so far as can be separated)[12]	Particulate organic carbon (POC) Particulate organic matter (POM) Particle size spectrum of organic fraction Dried and ash-free weight	Mainly collected from water bottles	Coastal and moored plankton stations	Filtration and weighing in a laboratory
	Mass of inorganic particulates[12]	Ash weight Size spectrum	Mainly collected from water bottles	Coastal and moored plankton stations	Filtration and weighing in a laboratory
Demersal and pelagic fish, crustaceans (non-burying), and cephalopods	Total biomass	Est. biomass	Density (N or B/unit area) collected through: - CPUE[11] - Echo-integration - Egg production, mainly pelagic spp.	Catch and effort data from commercial fisheries Aerial surveys Visual surveys	CPUE: - Standardized sampling (e.g. fishing) gear and gear monitoring, measuring boards, motion-compensated scales Echo-integration: - Acoustic equipment - Midwater trawl Egg production: - Standardized plankton sampler and midwater trawl - Maturity-staging scales
	Length/weight/age structure	L/W/A frequencies, quantiles	Est. L/W/A frequencies, quantiles from catches[11]	Size compositions of landings Port and observer sampling	Measuring boards Otolith taking equipment Calipers Motion-compensated scales

Table 2, panel 5 (see abbreviations and notes above Table 1)

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Demersal and pelagic fish, crustaceans (non-burying), and cephalopods continued	Feeding	Diet (composition, total weight of stomach content)	Stomach sampling	None	Dissection equipment Microscope Motion-compensated fine scales
	Reproductive ability	Est. SSB/ Maturity ogive* Length quantiles	Maturity* at length or at age in RV catches Histology Gonad and liver weights	Port and observer[8] sampling of commercial catches	Measuring boards Maturity-staging scales Otolith collecting fixatives Motion-compensated fine scales
	Spatial and temporal distribution	Spatial densities for N or B Spatial variation of LFDs, AFDs Centre of gravity inertia, etc.[7] Average CPUE	Point CPUE estimates of density (N, N-at-A, N-at-L)[11]	In some cases, from combining observer+VMS data Tagging	As for CPUE or Echo-integration, above
	Ecotoxicology	Concentrations in tissues	Tissue samples	Port and observer[8] sampling of commercial catches	Dissection equipment Freezer storage
	Health/condition	Parasites Diseases Weight/length	Histopathology Visual inspections Condition factors*	None	Motion-compensated fine scales Microscope Measuring board
	Stock structure	Degree of genetic isolation[16]	Standardized genetic sampling	Port and observer[8] sampling of commercial catches using standardized genetic protocols	Freezer storage

Table 2, panel 6 (see abbreviations and notes above Table 1)

Ecosystem monitoring[9]					
Ecosystem component[1]	***Parameter***[2]	***Estimator or indicator***[3]	***Research survey data or method***	***Alternative data sources***[5]	***At-sea equipment & procedures***[4]
Marine mammals, Reptiles, Sharks, large rays, Rare species IUCN Threatened, endangered or protected species (to be released as soon as possible)	Abundance	Sightings	N per time, or distance, or area[14] Occupancies[10,11] Photo identification Passive acoustics (mostly mammals)	Arial surveys Shore-based surveys Passive acoustic buoys Scientific catch surveys Tagging Seal scat collection and analysis	Observation post Binoculars Camera Taxonomic guide Hydrophones
Seabirds	Abundance	N per unit area	Distance sampling[14] Strip sampling[13]	Shore-based surveys of colonies	Observation post Binoculars Camera Taxonomic guide

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Appendix II: Provisional Agenda

DAY 1 (Monday, 29 August 2011):	
09.00	Opening
	○ Opening remarks by Dr Kevern Cochrane, Director FIRX ○ Introduction ○ Election of Chairs/Moderators and Rapporteurs ○ Adoption of the Agenda ○ Objectives of the expert workshop (Gabriella Bianchi) ○ Brief introductory remarks by experts
10.30	*Morning Tea / Coffee*
10.50	Presentation of the background review paper ○ Discussions
12.30	*Lunch*
13.30	○ Discussions
15.00	*Afternoon Tea / Coffee*
15.20	○ General discussions and additional information by participants on their experiences in developing and using ecosystem indicators, especially in fisheries science and management
17.00	Close of Day 1 sessions
DAY 2 (Tuesday, 30 August 2011)	
09.00	○ Defining ecosystem survey objectives
10.30	*Morning Tea / Coffee*
10.50	○ Examination of list of issues and indicators
13.00	*Lunch*
14.00	○ Determining the indicators and defining reference points vis-à-vis the objectives
15.30	*Afternoon Tea / Coffee*
15.50	○ Identifying what issues might arise in the use and presentation of these indicators for management
17.00	Close of Day 2

DAY 3 (Wednesday 31 August 2011)	
09.00	○ Vessel and human capability required to undertake ecosystem surveys
10.30	*Morning Tea / Coffee*
11.00	○ Discussions
12.30	*Lunch*
13.30	○ Providing advice • a framework for research priorities that can be addressed by ecosystem surveys • Revision of the background paper and the best format in which to publish it • What types of outputs are needed for whom and what form and structure should they take?
15.30	*Afternoon Tea / Coffee*
16.00	○ Outstanding issues
16.30	**Closing of workshop**

USING RESEARCH VESSELS FOR AN ECOSYSTEM APPROACH TO FISHERIES

Draft paper produced following an expert workshop, 29-31 August 2011
Food and Agriculture Organization of the United Nations,
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GLOSSARY

Meanings mostly follow conventional useage but some adjustments were found helpful in preparing the text of this report. Italicized words refer to other entries.

Term or abbreviation	**Meaning intended in this report**
AUV	Autonomous underwater vehicle
Catch per unit of effort (CPUE)	Number or weight of fish caught per unit of applied fishing effort, eg. per hour, per *nm* towed.
Catch sampling	*Sampling* from a catch on the deck of an RV
Catching device or gear	A fishing net, benthic grab, dredge, plankton net, corer or other device intended to catch marine animals or plants. This is a type of *sampling device.*
Categorical variable	Includes *ordered categorical variables* and qualitative categorical variables, eg. ‘red, green, blue’.
Component	A colloquial grouping of parts of an ecosystem, both living and physical. eg. ‘fish’, ‘seafloor habitat’, ‘seawater’.
Cruise	One trip to sea by an *RV* as part of an *EMS*.
Demersal	Pertaining to the seafloor.
Domain	A marine *region* together with a period of time. eg. *species domain*, *survey domain*
EAF	Ecosystem approach to fisheries. See Introduction, section 1
Ecosystem	“The biological community together with its physical environment” (Begon *et al.*, 1996, citing Tansley, 1935). Defining an ecosystem for an *EAF* usually requires subjectively chosen limits.
Ecosystem monitoring program (EMP)	A scientifically designed monitoring program intended to increase knowledge about an ecosystem and to signal when action is needed to safeguard the options for future generations to benefit from the full range of goods and services provided by the ecosystem (FAO, 2003). An EMP may involve an RV *EMS* and/or other means of collecting ecosystem data.
Effort	Measure approximately proportional to the risk of a species being caught with a certain catching device. eg. towing time or distance for a trawl, volume of sediment taken by a grab.

EMS	Ecosystem monitoring *survey* conducted by an *RV* as part or all of an *EMP*.
Enclosure	One *domain* encloses another if the whole of the second is inside the boundary of the first. See also *overlapping.*
Fishery domain	The region and period of operation of a fishery. It may be seasonal or year-round.
General objectives (GO)	Objectives of EAF for specified ecosystem components. eg. 'No further erosion of biodiversity in reef communities.' GOs should be consistent with *goals*, and should permit formulation by scientists of *operational objectives*.
Goals	Generally worded, top-level, objectives for a marine ecosystem which an EAF committee intends to achieve through management. eg. 'No further loss of biodiversity.' *Goals* should permit formulation of *general objectives* and, beneath them, *operational objectives.*
Groundfish survey (GFS)	A *demersal* trawl survey primarily designed to estimate *CPUE indices* for commercial species of fish.
Haul	A retrieval of a fishing gear; also the catch contained. Hauls are also called 'sets'.
Index	An index is here intended to mean an *indicator* assumed to be approximately proportional to an ecosystem *parameter*. eg. *CPUE* for population abundance.
Indicator	A statistical estimate, based on a *sample set* of *measures*, thought to inform about the unknown state of an ecosystem. eg. a *mean* length calculated from *N* catches as an indicator of the mean length of the whole population.
Lattice-stratified survey	A survey design having a grid of square, possibly rectangular, sampling strata from each of which one or more *sampling units* are taken.
Managers	People responsible for managing the fisheries and, possibly, other ecosystem services. Under *EAF*, managers would be a committee of people interested for business, social, economic, conservationist, scientific or other reasons
Mean over fish	When one or more *measures* of a variable are made at a *station* (eg. for fish), the average of all measures without regard to station.
Mean over stations	When one or more *measures* of a variable are made at a *station* (eg. for fish), the average of the station averages.
Measure	A direct measurement at sea, eg. the length of a fish, the weight of a catch, the strength of the wind or current, the conductivity of water collected in a

	bottle.
nm	Nautical mile
Occupancy	The proportion of *stations* fished at which at least one individual of a species is present.
Operational objective (OO)	Detailed objectives of EAF for individual units of specified ecosystem components. eg. 'CPUE of mature individuals of Species X to be > Y kg.hr^{-1}.' OOs should be consistent with *general objectives* and, above them, *goals*.
Ordered categorical variable	A set of intervals that can be ordered by magnitude, eg. 'Lo, Med, Hi', '0 – 5, 6 -10, 11 – 20'
Overlapping	One *domain* is said to overlap another if they share some time and space but neither totally *encloses* the other. [Elsewhere, overlap includes enclosure, but not in this report.]
Pelagic	Pertaining to mid and surface waters
Percentile	A *quantile* written in percentage terms, with $0 \le p \le 100$
Presence-absence variable	Binary number: 0 = absent, 1 = present, ie. one or more.
Quantile	The value, $\tilde{y}_p$, of a variable, *y*, is said to be the *p*'th quantile of a population when a proportion, *p*, exhibits values of *y* less than or equal to $\tilde{y}_p$; eg. the median, $\tilde{y}_{0.5}$. Quantiles estimated from samples must allow for *n* odd or even. See also *percentile*.
Randomly located station	One whose longitude and latitude co-ordinates are each drawn from a uniform statistical density function enclosing the *stratum* or *survey domain*. Co-ordinates falling outside the domain are not used.
Region	A bounded area of sea
Research vessel (RV)	A vessel allocated for taking samples and making measurements at sea independently of any fishery or of other commercial pressures so that all work can be conducted to objective, scientific standards. At least one of the crew should be scientifically trained.
Sample	A *sample set* or a *sampling unit*. The term has been avoided when there can be ambiguity.
Sample set	A set of *N sampling units*.
Sampling	Process of removing *sampling units* from a population or substance for scientific purposes. The 'population' might be in the sea, or a catch on

	deck.
Sampling device	A device designed to collect or observe any part of an ecosystem. Includes a *catching device*.
Sampling domain	That part of the *survey domain* that is accessible to a specified *sampling device*.
Sampling unit	The smallest unit of a *sampling* task, eg. one *haul* of a net, one retrieval of a grab, one value read from a dipped electrode, one bottle of seawater, one basket of fish from a catch.
Selectivity	<u>Size selectivity</u>: mathematical function of size (usually length) for a specified species that measures the proportion of individuals that are exposed to a catching device and caught. <u>Species selectivity</u>: How many species are caught by a catching device.
Set	See *haul*
Species domain	The *region* occupied by a species and the period when it is present. It may vary seasonally because of migrations or life history.
Station	Any marine sampling location, defined by longitude, latitude, time and depth marking the start and end, or just the mid-point, of the tow or dip.
Stratum (plural=strata)	A defined part of a *survey domain*.
Survey	One repetition of all monitoring tasks at all stations for an *EMS*. Often a *survey* is completed with one *cruise* by one *RV*.
Survey domain	The *region* surveyed by an *RV* together with the seasonal period of each *survey* .
TEP species	Threatened, endangered or protected species. Also known as ‘PETs’.
Unit	The smallest relevant part of an ecosystem *component*. See Introduction, section 1.

SUMMARY

An ecosystem monitoring survey (EMS) conducted by a research vessel (RV) for the purpose of an ecosystem approach to fisheries management is more complicated than a groundfish survey (GFS) focused primarily on commercial fish species. An EMS survey must deal with many more species, perhaps hundreds, most of which are not demersal fish. More than one type of gear with different catching powers is likely to be fished and many species will not be caught well by any of them. Some species will be enclosed by the survey, others only partially. Supplementary sampling techniques may include seabird sight surveys and acoustic monitoring of habitat structure. Conducting all of these activities on a single RV makes special demands for deckspace, laboratory cabins, scheduling, cruise planning and so on. An EMS can feasibly monitor many ecosystem components including: water, plankton, jellyplankton, pelagic fish, demersal fish and skates and rays depending on the type of trawl used, attached and mobile epibenthos, infauna, seafloor habitats, and seabirds. Components less suited for RV monitoring are ctenophores, cephalopods, pelagic sharks, marine mammals, sea turtles, and sea snakes.

Several types of vessel can be used for ecosystem work. A low-cost, somewhat constrained option is to combine the EMS with a GFS already undertaken for assessing commercial stocks. A purpose-built RVs is expensive and offers the most on-board facilities for an EMS but it may not, in fact, be needed for all EMS work, or it may be too big to visit shallow waters. Chartered fishing vessels are cheaper RVs but suffer from limited deck space, lively sea motion, lack of height for sight surveys, and uncontrolled modifications by the owner that can create intercalibration problems from year to year. Random selection of vessels from a fishing fleet is suggested to get around intercalibration problems. Multiple RVs can be co-ordinated for an ecosystem survey allowing sampling over wider areas and at different places.

Sampling techniques for an EMS may include demersal trawling, oceanographic and plankton sampling, acoustic techniques such as echosounders and sidescan sonar for monitoring benthic habitats, grabbing, beam trawling, dredging, sight surveys for seabirds, mammals and, possibly, jellyplankton. Passive acoustic listening to vocal marine animals awaits development of routine techniques. All sampling methods required detailed protocols so that different scientific crews can standardize their work on every RV monitoring cruise. Taxonomic skills and thorough training in all sampling techniques are critical for EMSs. The occurrence of confusable species should be expected and dealt with by naming them in standard ways.

Bounding the survey domain before designing the survey should take into account the distributions of priority species and could be assisted by a ‘Species database’ holding distributions, migrations, and habitat preferences for each species. Boundaries should also take into account feasibility of sampling on different types of seafloor by different gears. The season of an EMS must be carefully chosen because many indicators are sensitive to seasonal growth, temperature, migrations, and reproductive cycles. Different catching devices are unlikely to be intercalibrated for different catchabilities for each species, implying that caution is needed when interpreting multispecies data from an EMS.

Replicate sampling at individual stations is not recommended because of the environmental heterogeneity and the need to spread stations widely. Instead, regional estimation with design-based, randomized sampling schemes is proposed. Sampling may be stratified so that evenness of coverage is better than for simple random sampling, or so that major features of the ecosystem, eg. different habitats, are focussed on if this is thought to be more informative for EAF. The number of strata should be low with many stations in each for maximum precision and dependability of EMS results. Model-based estimation is proposed when EMS results will be analysed by fitting a model, eg. contours. A regular grid of stations then provides equal densities of information for fitting the model. Grids may estimate summarizing statistics, eg. the mean, with bias. Another design, lattice-stratified with one station per square stratum is put forward as a compromise reasonably good for both regional estimation and modelling.

The processing of catches, whether from the main trawl or some other catching device must be planned to suit the space, time, and scientific crew available. Protocols are essential for every gear. Depending on facilities on board, catch processing generally involves firstly, species identification, then quantification, then length measurements and, finally, additional sampling for biological measures. Catch-based indicators can be graded to correspond to these different levels of processing.

Indicators for species lists include occupancies, spatial positive area, and the Bayesian occupancy index (BOI). They appear to be particularly suitable for rare and poorly catchable species. CPUE-based indicators for many non-commercial species are likely to be poorly measured because of poor catchabilities and other reasons. *A priori* groupings of species by expected sensitivities to fishing or other factors is important for reducing the number of potentially confusing trends when examining CPUE time series. Intrinsic population growth rate, spatial indicators, and multivariate techniques can smooth them and reduce their dimensionality. The threat index assesses extinction risk from survey CPUEs. The L25, L50, and L75 (or other) length quantiles reduce the multi-dimensionality of length-frequency distributions while still distinguishing recruiting classes from newly mature animals and older broodstock. Sizes can be used to create composite community indicators that have been shown to vary over time, probably as a result of fishing. Weight-at-length or bodily condition can indicate growing conditions and perhaps density-dependent effects of strong year classes. Reproductive indicators should only be assessed by RV surveys occurring in the months just before spawning. Length- or age-at-maturity is useful for estimating breeding proportions in a population. A large table lists indicators alongside the several groupings of ecosystem components for monitoring and managing the effects of commercial fisheries. Another lists indicators and components for monitoring the ecosystem. The tables put forward options; monitoring of all of them would require considerable RV resources. drawn up by the FAO expert committee on using RVs for EAF

Several theoretical and practical constraints should be considered when analysing EMS data. Many statistical and modelling methods are available for ecosystem measures. They differ in the assumptions needed. Changes in habitat quality may be related to changes of fishing effort by quadrat using a nonparametric correlation method. Community indicators can mostly be calculated from abundance, size, and weight data collected by an ecosystem survey.

The report is finished with notes on applying EMS results for an EAF management. The reference point, and ecological risk assessment methods are briefly described. A short check-list of items to consider when planning an ecosystem survey is also given.

1 INTRODUCTION

An ‘Ecosystem Approach to Fisheries’ (EAF) according to the Food and Agriculture Organization of the United Nations (FAO, 2003):

> *‘strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries.’*

Its purpose

> *‘is to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems.’*

FAO has also advised on responsible fishing (FAO, 1995), further on the EAF itself (FAO, 2005), on indicators for sustainable development of marine fisheries (FAO, 1999), and on ecosystem modelling (FAO, 2008). Following from these ideas, an EAF requires, among many other things (FAO, 2003):

1. At least basic knowledge of the components of the ecosystem, and of the fisheries it hosts, and
2. An ecosystem monitoring program designed to increase knowledge and to signal when action is needed to safeguard ‘*the options for future generations to benefit . . .*’.

The present report discusses Ecosystem Monitoring Surveys (EMSs) intended to assist an EAF and conducted by research vessels (RVs). An RV is defined as a vessel allocated for sampling and making measurements at sea independently of any fishery or other commercial pressures so that all work can be conducted to objective, scientific standards. At least one of the crew should be scientifically trained. In principle, an RV may range from a 2-person canoe, through a specially chartered fishing vessel, to a state-of-the-art ocean-going ship equipped to fish and sample in several different ways, and crewed by a dozen or more scientists. Much valuable ecosystem survey work can be achieved with basic RVs, so this report is written to allow for a range of RV capabilities.

Figure 1.1 portrays schematically how an RV EMS might fit in with an EAF management. An EAF committee is responsible for the decisions on policies and fisheries management. The committee might consist of

- Leaders of fishing industries
- Fish retailers, transporters, processors and other people with businesses dependent on fishing

- Fisheries partnership organizations working to improve the sustainability of commercial fishing
- Legal or political representatives
- Advisors on marine science, economics and sociology
- Other interested non-government organizations, and
- Other users of the marine ecosystem.

The EAF committee considers environmental legislation, socio-economic information, and ecological advice from marine scientists before drawing up and agreeing top-level goals for the state of the ecosystem required. The goals may be quite vague if that assists finding agreement. They are later refined with further scientific advice into general objectives (GOs) for ecosystem components[1], eg. for 'fish', then into detailed 'operational objectives' (OOs) for important units[2] of a component, eg. for one species of fish. Attainment or otherwise of the OOs and GOs should be verifiable using measures[3] or indicators derived from monitoring the ecosystem, where indicator is defined (Anonymous, 2011) as

'*Something that is measured (not necessarily numerically) and used to track an operational objective.*'

Indicators should be matched with some kind of performance measure (Fletcher *et al.*, 2005) to gauge the success of management. Based on the findings of the RV survey, the ongoing task of the EAF committee is to decide whether or not commercial fishing in the ecosystem should be adjusted and, if so, by how much. Brief discussion of decision making will be found in section 7.

EMSs contrast with groundfish surveys (GFSs), as widely used by fishery-management agencies at the present time. See Table 1.1. Whereas a GFS is typically concerned with a handful of commercial fish species caught with a demersal trawl, an EMS must deal with many species, possibly hundreds, from different zoological groups, may use more than one catching device[4], and may additionally sample water and sediments. Expansion of the roles of an RV survey in this way puts new emphasis on old questions about GFS design, raises some new ones, and leads to additional constraints on what can and should be measured.

The operational aspects of an EMS have received relatively little attention in the extensive literature on EAF hitherto. The present report is intended as a convenient collection of issues

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[1] 'Ecosystem component' is a colloquial grouping of parts of an ecosystem, eg. 'fish'.
[2] Similar terms were used for ecological risk assessment of fisheries (Hobday et al., 2007).
[3] 'Measure' refers to any measurement made at sea, not necessarily an indicator.
[4] 'Catching device' refers to nets, grabs, dredges, plankton devices, or any device for catching marine animals or plants.

meriting thought and discussion preferably before, rather than after a survey has become fixed in approach for the sake of comparability over time. Questions addressed here include:

- Where are the boundaries of the ecosystem supporting the fisheries to be managed?
- Which of its ecological components can feasibly be monitored, and why?
- Which ecological indicators are commensurate with the available RV resources?
- What survey design will produce reliable results year by year, given the practical constraints?
- How should survey catches be processed, and measures on them analysed so as best to inform an EAF?

The last part of the report briefly discusses application of EMS results to fishery management. Many references are cited, often as signposts to additional information. Readers are warned that the author does not claim first-hand experience of all the scientific fields discussed, nor a balanced knowledge of EAF literature.

RVs are not the only sources of fishery-independent ecosystem data. Satellites, helicopters, continuous plankton recorders towed behind ships of passage, shore-based observations, divers, and autonomous underwater vehicles (AUVs) are examples of other sources that could supplement an EMS as part of an overall ecosystem monitoring program (EMP). Non-RV sources are mentioned peripherally in this report.

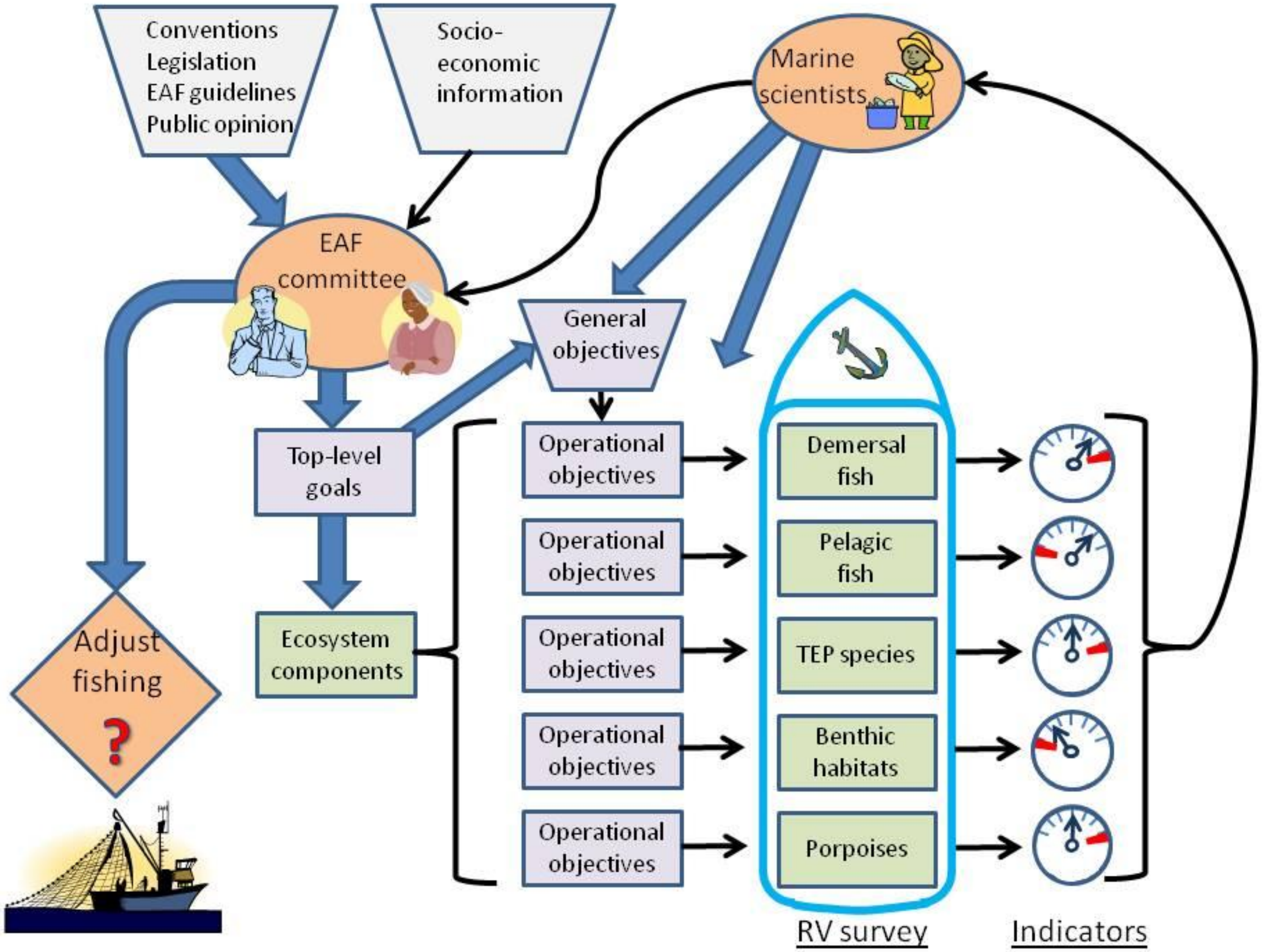

Figure 1.1 Schematic diagram of how an research vessel (RV) ecosystem survey might fit into an Ecosystem Approach to Fisheries (EAF) management . Block arrows represent flow of policies; line arrows represent flow of information and data.

Table 1.1. Some differences between groundfish surveys (GFSs) and ecosystem monitoring surveys (EMS), both using research vessels (RVs). CPUE = catch per unit of effort.

Topic	**Groundfish survey**	**Ecosystem survey**
Species of main interest	Several species of commercially valuable fish	Possibly 100s of species, commercial and uncommercial
Typical catching devices	Demersal trawl	Various trawls, grabs, dredges, sight surveys, possibly plankton sampling
Indicators of main interest	Abundance or biomass CPUEs by species	Quantitative, qualitative, and multispecies/community indicators
Catchabilities	Trawl designed for good catchabilities of target species	Many species of ecological interest are poorly catchable Catchabilities vary widely across species
Species distributions geographically	Survey designed to enclose all species domains of interest so far as possible	Many species domains are only partly overlapped by the survey domain (section 3)
Size selectivities	Commercial species fully selected by small mesh codend; some large fish may swim in front of trawl	Size selectivities variable by species and gear. Affected by habitat, swimming habits, migrations, cryptic behaviour.
Knowledge of migrations; choice of survey season	Generally good; survey season can be planned	Poor for many species Survey season may not suit all Some indicators very sensitive to season
Data processing	Abundances, lengths, ages, biomasses for several species	Potentially many more data for many species and indicators
Taxonomic skills required	For identification of main commercial species	Extensive taxonomic skills for different animal groups.

2 PLANNING AN RV ECOSYSTEM MONITORING SURVEY (EMS)

Several interlinked tasks must be attended to in advance of an ecosystem monitoring survey (EMS) to be carried out by an RV. Some of the more important are listed and discussed in this section. Figure 2.1 summarizes schematically how initial planning of an EMS might proceed. Different ecosystem measures call for different sampling devices, different RV facilities, and different sampling domains[5]. It is important, therefore, to plan the survey so that objectives chosen for it will be matched to the available resources.

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[5] 'Sampling domain' refers to the region and season of sampling.

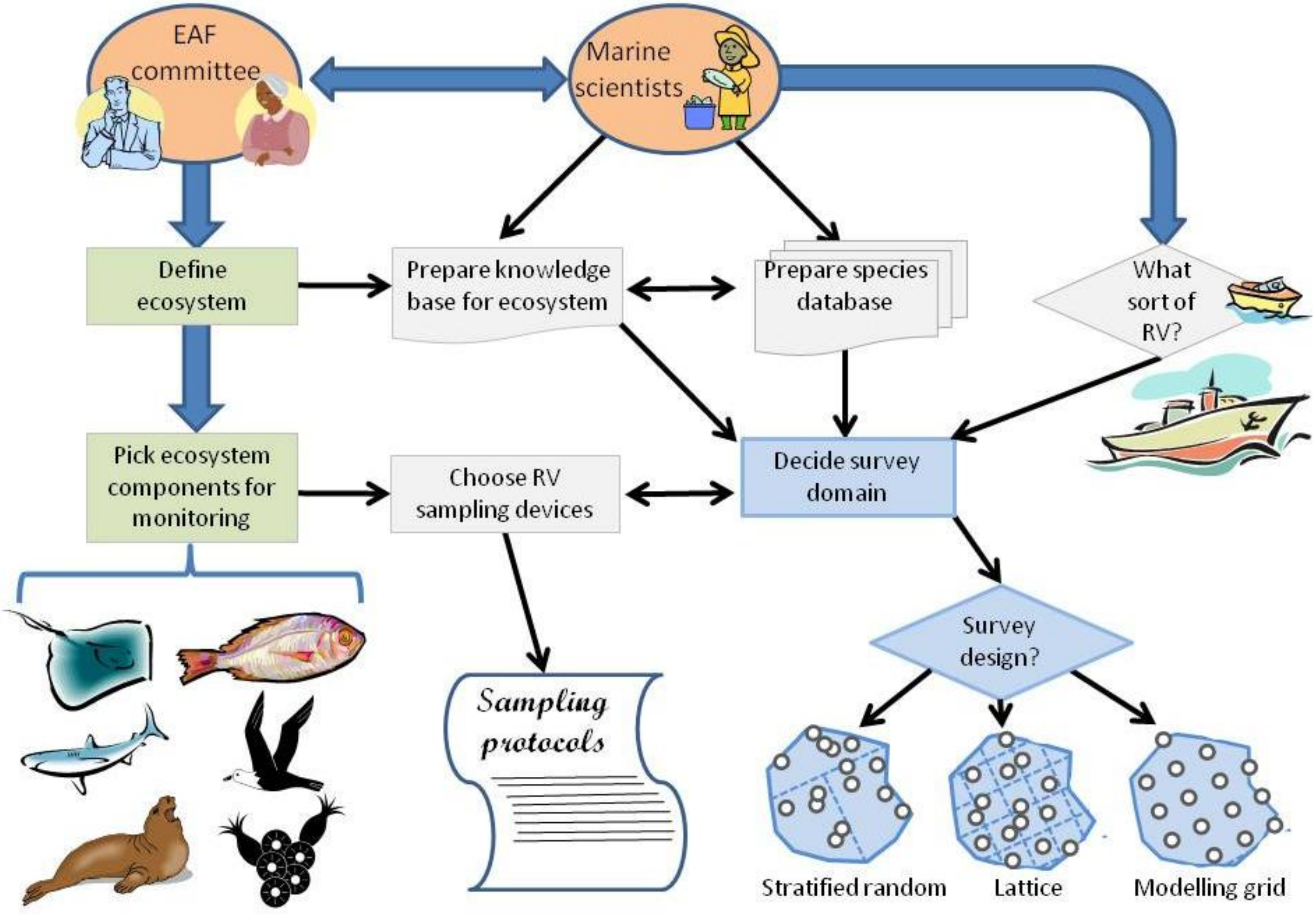

Figure 2.1 Schematic diagram depicting initial planning of an ecosystem monitoring survey (EMS). Block arrows represent flow of policies; line arrows represent flow of information and data.

2.1 Defining the ecosystem to be monitored

A scientific definition of 'ecosystem' is '*The biological community together with its physical environment*' (Begon *et al.*, 1996, citing Tansley, 1935). Such definitions are vague for fisheries management unless the ecosystem is conveniently surrounded by land on most or all sides,. FAO (2003) states that '*Ecosystems are usually spatially defined (i.e. they are sufficiently different from adjacent areas to be recognized as a functional unit) but most of them have no fixed boundaries, especially within the marine environment, and they exchange matter and information with neighbouring ecosystems.*' The implication is that an ecosystem for EAF purposes must often be defined in a practical way.

Obvious solutions are to use the geographic limits of fishing, or existing political or legal regions. FAO (2003) states: '*From a practical perspective, EAF will need to recognize existing fisheries, management entities and jurisdictions and build incrementally on these* . . .' Shortcomings of tying the survey closely to the fished region are that ecological effects of fishing may spread outside, and external factors may affect the ecology and fisheries inside. Unfortunately, the lack of sampling outside the surveyed region may prevent such effects being discovered. There may also be fish refugia or essential fish habitat (Benaka, 1999, Barnes and Thomas, 2005), eg. nursery areas, relevant for monitoring in some way but existing outside the fished domain.

A more scientific solution is to examine the bathymetry, hydrography, productivity, trophically related populations, and taxonomic structure of an ecosystem. Of course, starting with no information, this would be an enormous task. Fortunately, help is available. Recent, global biogeographic studies are rich sources of basic scientific information for most marine regions around the world. Fifty 'Large marine ecosystems' (LME, http://www.lme.noaa.gov/) have been defined and described, accounting for more than 95% of annual global fishery yields (Sherman and Duda, 1999, Hempel and Sherman, 2003). Modern developments in satellite monitoring have enabled a different biogeographic regionalization of global seas on the basis of phytoplankton productivity and biogeochemistry (Longhurst, 2007). Other systems include one favoured by Spaulding et al. (2007) that is based on taxonomy, evolutionary history, patterns of dispersal, and isolation. These various sources can provide useful scientific context even for small-scale fisheries.

The existence of different marine regionalization systems unfortunately implies that there is little concensus on how scientific information should be applied to delimit an 'ecosystem' for monitoring purposes. Local factors are likely to be important for placing boundaries, eg. upwelling currents, water clarity, temperature-salinity depth profiles, nutrient inputs, and seafloor types. Practical constraints and costs will also be important considerations, as will the balance between sampling a large area thinly or a small area intensely, given a fixed total survey cost. These are all matters for discussion within the EAF committee. Choosing the 'survey domain' in relation to ecosystem boundaries is a separate issue falling to the scientific advisors. See section 3.1.

2.2 Developing a knowledge base

Having chosen the boundaries of the ecosystem to be managed under an EAF, collation of all available scientific information about it into a readily accessible 'knowledge base' relevant to EAF management is, if not already done, the next sensible step before designing the RV monitoring survey. That way, the monitoring can be designed to be most informative. Important ecological topics include:

- Water mass structures, current patterns, temperature, salinity, and water clarity.
- Seasonal mixing and planktonic production.
- Seafloor geomorphology and sedimentary zones.
- Biogenic reefs.
- The foodweb and the biology of species with significant trophic roles.
- Species that are endemic (found nowhere else) or emblematic, eg. rare seabirds.
- Species that are categorized as 'Threatened, endangered, or protected' (TEP), eg. red-listed by the International Union for the Conservation of Nature (www.iucn.org).
- Species that are invasive (Rilov and Crooks, 2009).
- The fisheries, the biology of the principal target species, and discarding.

The knowledge base can be started with, for example, the biogeographic sources listed in the previous section. Several global sources of oceanographic and satellite monitoring data are available (Fromentin *et al.*, 2005, Longhurst, 2007) that may provide more detailed, localized information. Taxonomic reference works for much of the world are available from FAO (http://www.fao.org/fishery/fishfinder/en) and other organizations on the world-wide web, many of them specialized in some way, eg. relating to invasives, or extinction risk. Local fishers, scientists and naturalists are other important sources to consult.

Agreed gaps in the initial knowledge base may indicate that an exploratory ‘baseline’ RV survey is needed before designing and carrying out monitoring surveys. It might reveal previously undiscovered seafloor habitats, allow better delimitation of the distributions of key trophic or TEP species, or better define important hydrographic features. However, the danger with baseline surveys is that they provide only a single, season-linked snapshot. Furthermore, the ecological state they explore may already have been substantially changed by historical fishing or other anthropogenic factors, the so-called ‘shifting baseline syndrome’ (Pauly, 1995).

2.3 Which ecosystem components?

A convenient, informal way to classify the numerous features of a marine ecosystem is as ‘components’, both living and physical (Hobday *et al.*, 2007). The subsections below summarize reasons for monitoring most of the components likely to be considered under an EAF. Issues pertinent to planning an RV survey are also mentioned together with known alternatives to RV monitoring that, depending on circumstances, may be more cost-effective, though no comparative assessments of merits is attempted here. Some generally recognized components are not separately listed below, namely ‘target species’, ‘discarded species’, and ‘threatened endangered or protected’ (TEP) species, because of common features with other components. Other marine ecosystem components are not listed though they might be monitored on an EMS, for example meiofauna, bacteria, fungi, and viruses. Rees et al. (2008, citing Torsvik et al. 1996) state that ‘*microorganisms globally are the dominating organisms both concerning biomass and diversity*’. The general problem with them, aside from the low availability of appropriate specialists, is the difficulty of making connections between monitoring results and management of fisheries in the ecosystem.

Table 2.1 is a summarized checklist of components that can be sampled or are visible from an RV survey, stating basic reasons for monitoring them and the RV sampling methods that might be used, together with lead-in references, mostly from recent literature.

Table 2.1 (4 panels). Selected components of marine ecosystems, reasons for monitoring for an EAF, and typical sampling methods on research vessels (RVs) plus lead-in references. See http://www.iucnredlist.org/ for 'Red-listed' species.

Component	**Reasons for monitoring**	**RV sampling methods and references**
Water	Oceanographic properties may define ecosystem Nutrients and upwelling affect productivity Oxygen, temperature, transparency affect life	Water bottle strings Piped water auto-analyzers Current meters Dipped multi-sensor electrodes (Holden and Raitt, 1974)
Zooplankton	Food for pelagic fish Food for demersal fish larvae Transfer energy from phytoplankton Timing of productivity and species successions are important for fish recruitments Restrain phytoplankton populations and blooms	Towed plankton net (Beaugrand, 2005) (Reid *et al.*, 2000) (Suthers and Rissik, 2009) (Holden and Raitt, 1974)
Phytoplankton	Primary producers Timing of productivity and species successions important for zooplankton May cause blooms and low oxygen concentrations May create toxic blooms, poisoned shellfish	Towed plankton net (Suthers and Rissik, 2009) (Holden and Raitt, 1974)

Table 2.1. 2nd panel

Component	**Reasons for monitoring**	**RV sampling methods and references**
Jellyplankton	Voracious, generalist predators of zooplankton and pelagic fish May reduce recruitment of fish species May create unwelcome jellyblooms Interfere with fishing (burst nets)	Observers on deck Occurrence in trawl Plankton nets (Kirby and Beaugrand, 2009) (Stone, 2010)
Cephalopods	Predators that may compete with fish Commercial value of some species Biodiversity legislation	Occurrence in catches (Zuur and Pierce, 2004) Jigging (Bjarnason and Carlesi, 1992)
Pelagic fish	Food for many predatory species Some species are over-fished Pelagics transmit carbon energy up the food chain Restrain zooplankton populations Eat planktonic eggs of other fish, jelly plankton Commercially important	Echosounder + midwater trawl (Simmonds and MacLennan, 2005) Occurrence in demersal high-headline trawl catches
Demersal fish	Food for top predators Several species are over-fished Help to control pelagic populations Transfer energy from seafloor to nekton Commercially important	Demersal otter trawl Beam trawl. (Anonymous, 2004) (Anonymous, 2006)

Table 2.1. 3rd panel

Component	**Reasons for monitoring**	**RV sampling methods and references**
Sharks, rays	Top predators Highly vulnerable to trawls, longlines Help to balance food web, prevent trophic cascades Commercial importance Many species IUCN red-listed or rare, biodiversity legislation	Occurrence in catches (Cortès, 2008) (Dulvy and Forrest, 2010)
Epibenthos (living on the seafloor)	Transfer energy from infauna, organic detritus Filter and clarify water Create physical habitat, shelter from currents Commercial crustacea and molluscs Food for fish	Beam trawl (Jennings *et al.*, 1999, Callaway *et al.*, 2007); (Brandt, 2006) Dredge (Brenke, 2005, Lewis, 2009) Video sled (Gray, 2010a)
Infauna (living in seafloor sediments)	Modify, aerate, and deepen sedimentary habitat Recycle and prevent accumulation of detritus Commercial molluscs Filter and clarify water Typically extremely diverse Food for fish	Benthic grabs (Eleftheriou, 2000, Schratzberger *et al.*, 2000, Rees *et al.*, 2008, Reiss *et al.*, 2010) Corers (Brandt, 2006)
Seafloor habitat	Bottom type is critical for species occupancy, biodiversity Seafloor is vulnerable to heavy trawling Egg depositories, nursery areas, essential fish habitat	Side scan sonar (Medwin and Clay, 1998) Video sled (Kenny *et al.*, 2003, Gray, 2010b)

Table 2.1. 4th panel

Component	**Reasons for monitoring**	**RV sampling methods and references**
Communities	Keystone species have vital functional roles Disturbed communities signal wider problems	Various data analyses on species lists, abundances/biomasses, see section 6.3.6
Seabirds	Fishery reduces food for seabirds Discards favour some seabird species Seabird bycatches eg. by longlines Several species are IUCN red-listed Biodiversity legislation Transfer of marine production to land	Observer on deck using binoculars (Tasker *et al.*, 1984) (Clarke *et al.*, 2003) (Hyrenbach *et al.*, 2007)
Marine mammals (whales, dolphins, porpoises, seals, etc.)	Mammal by-catches e.g. in seine nets Some species are IUCN red-listed, biodiversity legislation Some mammals control numbers of smaller predators	Observer on deck using binoculars (Buckland *et al.*, 2001, Buckland *et al.*, 2004, Shirihai and Jarrett, 2006, Boyd *et al.*, 2010)
Marine reptiles (turtles and seasnakes)	Reptile bycatches e.g. longlines, shrimp trawls Many species are IUCN red-listed Important for biodiversity	Occurrence in catches (Milton, 2001, Bache, 2002)

2.3.1 Seawater

Many marine ecosystems are best defined for EAF purposes in oceanographic terms. For example, a zone of nutrient enrichment caused by upwelling of sub-surface waters is likely to support a rich fishery within that zone, and fronts may cause localized accumulation of food and predators. Oceanographic currents and water densities can also affect migrations and seasonal refugia of some fish species. Low oxygen levels or salinities may be avoided by adult fish, and may kill fish larvae. Transparency is another important feature of seawater. Too much turbidity or plankton reduces light transmission for primary production and may impair visual hunting by some species. For these and other reasons, an understanding of the oceanographic features of an ecosystem is important for an EAF.

Whether or not oceanography should form part of an RV survey will depend on the nature of the ecosystem and the amount of RV time available. If the oceanography shows consistent patterns from year to year and is already quite well understood from past monitoring, occasional localized new sampling by an RV may not add much unless it is part of a wider, co-ordinated programme. Equally, if the oceanography is highly variable, eg. seasonally, results from the short period of an annual RV survey will provide little information about seasonal patterns and processes. On the other hand, RV surveys, preferably multi-seasonal, may be able to fill significant gaps in oceanographic understanding of some ecosystems by sampling at appropriate times and localities. RVs fitted with piped water systems feeding automatic analysers on board can sample large amounts of surface-water easily as they steam around the ecosystem. Sampling underlying water masses is carried out by lowering strings of water bottles at each station. Multi-sensor electronic devices can be lowered instead to reduce times on-station but they may not be as accurate or as reliable.

Autonomous and remotely operated underwater vehicles (AUVs and ROVs) can be used to collect oceanographic data instead, or in support, of an RV. See also the World Ocean Atlas at http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html.

2.3.2 Zooplankton and phytoplankton

Zooplankton play a crucial role in harvesting primary production by phytoplankton and thus making it available to the rest of the food web. They also control blooms of phytoplankton when nutrients and light are not limiting primary production. Production and succession of species of both of these components vary with climate, season, hydrography, light penetration, mixing and nutrients. Depending on season, zooplankton include the eggs and larvae of pelagically distributed fish, planktonic, and benthic species (Rees *et al.*, 2008). According to one writer, '*Ongoing plankton monitoring programmes worldwide will act as sentinels to identify future changes in marine ecosystems*' (Hays *et al.*, 2006). Sampling from RVs is usually with towed plankton nets, the samples being preserved for later analysis in a laboratory under a microscope. The time and taxonomic skills, and hence costs, required for analysis increase inversely with the mesh size of the plankton net. Quantitative interpretation of plankton sampling results can be problematic because of patchy distributions in the sea, diurnal vertical migrations, short life cycles, seasonal successions of species, variable sinking rates, and the fact that the standing crop is not necessarily related to the rate of production if that production is being rapidly consumed by planktivores.

Sources of information about plankton that are not dependent on an RV include remote sensing of chlorophyll concentrations using satellite images (Longhurst, 2007), and the continuous plankton recorder (CPR) towed behind ships of opportunity (Batten *et al.*, 2003). A recent text on plankton ecology and processes is by Kiorboe (2008).

2.3.3 Jellyplankton

'Jellyplankton' includes ctenophores and jellyfish. Environmental concern about them is quite recent (Lynam *et al.*, 2006, Richardson *et al.*, 2009). They are unselective consumers of zooplankton and sometimes fish, possibly showing well-developed foraging behaviour (Hays *et al.*, 2011), yet they have relatively few predators themselves. Large increases in populations can rapidly occur when prey is released by reduction of fish predators through fishing. A warming climate and eutrophication may also favour production of jellyplankton (Richardson *et al.*, 2009). The main concerns about large populations are that they compete effectively with fish for planktonic food, as well as consuming large numbers of fish eggs. A marine ecosystem that has become dominated by jellyplankton might therefore be unlikely to turn back quickly to a fish-dominated state. Jellyplankton have been reported as concerns for many seas, eg. the Benguela system west of southern Africa (Lynam *et al.*, 2006), the Baltic (Haslob *et al.*, 2007), the Black Sea (Daskalov, 2008), and the Yellow and Japan Seas (Stone, 2010). Monitoring methods for jellyfish using RVs may include acoustic systems, observations from an observer platform (Bastian *et al.*, 2011) and, possibly, occurrences in trawls and plankton nets. Jellyfish CPUE data from trawls are likely to have high variance because of shoaling, as for pelagic fish (section 2.3.5). Cleaning a trawl of jellyfish, as is essential after every haul if occurrences or CPUEs are to be collected, requires much time and labour. Jellyfish can also be monitored from low-flying aircraft (Houghton *et al.*, 2006).

2.3.4 Cephalopods

Cephalopods such as cuttlefish, squid and octopus may exist in competition with some fish species so population sizes may respond to changing commercial fishing effort. Cephalopods are sometimes targeted by fishers when other stocks are low. Jigging using lights to attract to the vessel is a common fishing technique for squid (Bjarnason and Carlesi, 1992). Some species are quite resilient to heavy fishing because of an annual life cycle. Species occurring in catches of an RV survey trawl should be recorded, but soft-bodied forms are likely to be damaged by trawl nets and difficult to process beyond simple counting. Also, size distributions found in nets often differ substantially from sizes found in the stomach contents of predators (Boyle and Rodhouse, 2005) implying that length distributions obtained on an RV are likely to be biased anyway. Populations of pelagic cephalopods can be assessed acoustically (Goss *et al.*, 2001). An alternative to an RV for monitoring cephalopods is to use catch data from observer surveys on commercial fishing boats, preferably jiggers to minimise damage to the catch.

2.3.5 Pelagic fish

In some parts of the world, pelagic fish are caught in large quantities by industrial-scale fishing fleets. This can impede the passage of primary production biomass to higher trophic levels, as in so-called ‘wasp-waist’ ecosystems (Cury *et al.*, 2000, Smith *et al.*, 2011). As a result, fisheries on valuable predatory species show lower yields, and seabird populations may be affected. Another consequence of reduced populations of pelagic species may be over-production of their zooplanktonic prey leading, in turn, to expansion of populations of ctenophores or other jellyplankton ‘thriving on the food no longer consumed by fish’ (Lynam *et al.*, 2006). See the ‘Jellyfish’ component (section 2.3.3). On the other hand, increased populations of certain pelagics may cause excessive predation of planktonic fish eggs, leading to poor recruitment and impeded recovery of predatory species, eg. sprat eating the eggs of cod in the Baltic (Casini *et al.*, 2008). Pelagic species can be monitored acoustically from an RV with regular tows of a pelagic trawl to confirm the identity of species found with the echosounder (MacLennan and Simmonds, 2010). Egg-production surveys (Stratoudakis *et al.*, 2006) are a second RV monitoring method for some pelagic stocks. They estimate the size of the adult stock from concentrations of planktonic eggs, spawning patterns, and fecundities. A third RV monitoring method for pelagic species swimming near the seafloor – as some do during the day – uses a high-headline demersal otter trawl. However, average catch per unit effort (CPUE) indicators for shoaling adults of pelagic species are seldom reliable because extreme results are common:- the trawl either catches very large numbers if the tow clips a shoal, or virtually none if it misses it altogether. Better may be to record ‘shoal present’ or ‘shoal absent’ using an arbitrary threshold number of fish to signify a shoal, and to analyse as occupancies (section 5.1.1). Trawling may be best timed and located so as to catch young fish before they aggregate as shoals. Recent articles on pelagic species, including RV survey methods, can be found in Checkley et al (2009) for example.

As alternatives to using an RV, stocks of pelagic species can be assessed from commercial landings statistics, or possibly from data collected by observers on commercial fishing vessels combined with automatic vessel monitoring systems (VMS). Aerial fish spotting has been used in California and Namibia.

2.3.6 Demersal fish

Demersal fish are categorized informally as round- or flatfish according to body shape. They form the principal targets of many commercial trawling and netting fisheries. As predators, demersal fish serve an important trophic role by helping to restrict population sizes of prey species, and by routing food energy from low trophic levels to higher predators such as marine mammals and sharks. Demersal species often change their feeding habits and trophic level as they get older and larger (Jennings *et al.*, 2002a). Roundfish tend to live on or near the seafloor, though they may rise up at night in step with vertical migrations of their prey. They tend to be best caught by an RV during the day using an otter trawl because of the wide towing path and the herding effects of otter boards and sweeps. Most flatfish, on the other hand, are generally best caught by heavy beamtrawls fitted with tickler chains to raise them out of the sediment and into the path of the net. The nature of the seafloor can strongly affect the efficiency of trawling. Trawls with a light footrope make good ground contact on smooth seafloors but cannot be used where there are rocks. Rockhopper trawls are fitted with large rollers on the groundrope to deal with rocks but fish can escape between the rollers. Lining or netting may have to be considered for sampling demersal species in very rocky areas or reefs. There is a large literature on RV demersal trawl surveys, eg. (Anonymous, 2004, Anonymous, 2006).

Non-RV sources of information on demersal fish are data collected at fish markets or by observers on commercial fishing vessels, and commercial CPUE data.

2.3.7 Sharks, skates and rays

Many species of sharks and rays are top predators, serving a similar trophic role as mammalian top predators. Sharks are particularly vulnerable to longlines if fitted with wire leaders that cannot be bitten through (Ward *et al.*, 2008). Large pelagic rays are also caught by this method. Some sharks and many rays are vulnerable to trawls, and some species are dependent on special habitats for reproduction, feeding, and migrations (Ellis *et al.*, 2008). Many sharks and rays are now being caught at low rates compared to historically, and several species are probably in danger of extinction even though, because information is lacking, they are not yet officially on the Red list of the IUCN (Dulvy and Forrest, 2010). For a summary of various conservation listings, see Ellis et al. (2008). A survey intended to gain information about sharks might use longlining or fixed nets to obtain reasonable capture rates, eg. as in the Bay of Bengal (http://goo.gl/6ibrc; http://goo.gl/kqmNO). Encounter rates for pelagic sharks in RV trawls are likely to be low, yielding little quantitative information. However, demersal skate and ray species are regularly caught by demersal trawls when present and could be monitored, as for fish, by trawling from an RV. For recent articles on the biology and ecology of sharks and their relatives, see Hamlett (1999) and Carrier et al. (2010).

Monitoring of sharks, skates and rays without using an RV can be carried out at fish markets and by observers on commercial fishing vessels, particularly longliners. Large surface-visiting sharks such as basking sharks can be surveyed aerially. Archival tagging is another option for studying these animals (Metcalfe *et al.*, 2008).

2.3.8 Epibenthos

Epibenthos are the animals living on the seafloor. Those living attached to the seafloor contribute to the micro-environment of the seafloor habitat (‘biogenic’) and are probably best monitored as part of a habitat component (Hobday *et al.*, 2007); see section 2.3.10. Those that are mobile form a trophic bridge between infauna and demersal species. They can also affect benthic ecological recruitment and restrict the succession of species by predation on settling larvae. Planktonic larvae of epibenthic species – which may arise in great numbers at certain seasons – compete with holoplanktonic species such as copepods (Lindley *et al.*, 1995) thereby changing planktonic communities and perhaps affecting development of fish larvae. Several epibenthic species have direct economic importance, e.g. crabs, lobsters, mussels.

Epifauna can be monitored using the main survey trawl intended to catch demersal fish. However, otter trawls, depending on ground gear and mesh sizes, tend to catch only small amounts of epibenthos. Beam trawls can take large amounts but the large meshes in the belly of commercial beam trawls may mean that catchabilities for some epibenthic species are low. A good solution on an RV survey, if feasible, is to make supplementary tows with a specially designed epibenthic trawl or dredge. See section 2.5.4. Trials may be needed to find the best design for local conditions. Whatever gear is used by an RV, catches of epifauna are likely to be strongly affected by the recent history of commercial trawling in the area.

2.3.9 Infauna

The infauna are a highly diverse group of species that live in the sediment of the seafloor, for example annelid worms, bivalve molluscs, and many other invertebrate phyla. Many species feed on organic detritus by filtering the water. The resulting clearer water can, itself, be important for other species (Breitburg and Riedel, 2005). Other infaunal species can digest organic matter from sediments and thus re-introduce food into the macro-ecological food web. Infaunal species contribute planktonic larvae that serve as food for other plankton and fish larvae (Rees *et al.,* 2008). Several infaunal species form burrows and, by moving water through them, aerate the sediments and permit aerobic life forms to live at greater depths in the sediment, thereby adding to the organic matter recycled to the water column from the bottom sediments. Deep-burrowing infaunal forms assist these processes by exchanging deep and shallow sediments. Benthic communities have been used as indicators of trawling pressure (Hiddink *et al.*, 2006b).

Monitoring of infauna on RV surveys is usually done with a benthic grab or corer that takes a bite of sediment at each location. The RV is not held up for a long time, but the infaunal samples take much time and skill to process because of the high variability between samples and the difficulties of identifying the many species typically found. Standardized sieving of the sediments is essential since more and more species can be found as mesh sizes decrease. Difficulties of identification also tend to increase inversely with size.

2.3.10 Seafloor habitats

Hobday et al. (2007) proposed classifying seafloor habitats according to three variables: substrate type, geomorphology, and structural fauna. Each of these can be further subdivided into standard categories that are relevant to the types of species living there. Simple keyword descriptors are listed in Table 2.2, Table **2.3**, andTable **2.4**. Examples of seafloor habitats are soft mudbanks, gravel covered by structural epifauna, rocky outcrops, and cold- and warm-water reefs. Physically structured benthic habitats are important as nursery and feeding areas, for laying eggs (e.g. herring), for protection from predators, and for biodiversity. Different types of habitat have different vulnerabilities to fishing gear, most notably to trawls. Removal of seafloor structure, both topographic and epifaunal, is a significant deleterious effect of trawling leading to less shelter from strong currents, less sedimentation of detrital food, less shelter from predators, and altered functional composition (Tillin *et al.*, 2006). For these reasons, seafloor habitats, especially any designated as marine protected areas (MPAs, http://www.wdpa-marine.org/#/countries/about) (Gubbay, 1995, Claudet, 2011) or essential fish habitat (EFH, http://www.habitat.noaa.gov/protection/efh/index.html) (Benaka, 1999) should be monitored as part of an EAF. Epibenthic trawls and dredges provide partial indications of habitat types if, for example, mud, gravel, or attached fauna are retrieved. However, they do not reveal the geophysical structure of the habitat. For this, acoustic or video imaging is necessary (Kenny *et al.*, 2003). Even then, interpretation of changes may be difficult to link with trawling (Hiddink *et al.*, 2006b) unless trawl tracks can be seen. Ideally, detailed information on commercial trawling effort between RV surveys will be available. A study of this type was reported by (Callaway *et al.*, 2002a, Callaway *et al.*, 2007).

Sedimentological and hydrographic information may be available for a marine ecosystem without special new sampling by an RV if general geological or hydrographic surveys have covered the area, eg. in relation to mineral extraction or environmental impact assessments for offshore constructions.

Table 2.2. Keywords for classifying substrate types of seafloor habitats**.** Modified from Hobday et al. (2007).

Substrate keyword	Short description
Soft mud	The finest mud or ooze; easily disturbed
Fine sediment	Fine and very fine particles
Sandy sediment	Sand and shells in high proportions
Gravelly sediment	Small pebbles and shells throughout
Cobbles and boulders	Large stones and rocks evident
Sedimentary rock	Consolidated, hard sedimentary rock
Solid rock	Consolidated rock lacking sedimentary structure
Biogenic reef	Biologically deposited rock, e.g. coral

Table 2.3. Keywords for classifying geomorphic forms of seafloor habitats. Modified from Hobday et al. (2007).

Geomorphic keyword	**Short description**
Flat, unrippled	Sediments lacking ripples due to currents, waves
Current-rippled	Sediments with directional rippling due to currents
Wave-rippled	Sediments symmetrically rippled by wave action
Irregular, low	Irregularities, < 10cm approx, often biogenic
Irregular, medium	Irregularities < 100cm approx
Subcrops	Dispersed, low protrusions of hard rock with sediment between
Low outcrops	Low outcrops, < 100cm approx, lacking holes or cracks
Craggy low outcrops	Low outcrops,< 100cm approx, with rough surfaces
High outcrops	High outcrops, >100cm approx, lacking holes or cracks
Craggy high outcrops	High outcrops,>100cm approx, with rough surfaces

Table 2.4. Keywords for classifying non-mobile benthic life forming physical structure on the seafloor. Modified from Hobday et al. (2007).

Biological keyword	**Short description**
Unencrusted	No physical structure attributable to life
Encrusted	Low encrustations, mostly <3cm approx, of sponges, low bryozoa, serpulids, barnacles, etc.
Overgrown	Medium height species, mostly 3 – 10cm approx, dominate physically, e.g. anemones, branching bryozoa, sponges
Highly overgrown	High species, >10cm approx, in sufficient density to reduce benthic visibility and current flows, e.g. soft corals, crinoids,
Bioturbated	Burrowing animals affecting quality of superficial sediments
Echinoderm beds	Dominated physically by asteroids, ophiuroids
Bivalve beds	Dominated physically by epifaunal bivalve species
Other named faunal type	Dominant structural epifauna (living on seafloor) that has linked epibenthic fauna, e.g. coral
Macroalgal	Macroalgae (seaweed) growth dominates physically; shallow, illuminated waters
Seagrass	Seagrass growth dominates physically; shallow, illuminated waters

2.3.11 Communities

Communities of species are an important component of marine ecosystems in all habitats because of the vital functional roles of some of the species and their dependence on others. Changes in the species compositions of species can be gradual and subtle, and neighbouring communities tend to merge into one another geographically, making them difficult to monitor individually unless there are marked changes of habitat, e.g. between sediment and rock. Also, communities are naturally variable with regard to species composition and density of habitation, making the interpretation of sampling results difficult. For discussion of the difficulties in relation to ecological risk assessment (PSA method), see Hobday et al. (2007). Communities are sampled and recorded automatically when species and habitats are identified, counted and, preferably, weighed at RV sampling stations. For that reason, the monitoring of ecological communities occurs at the data analysis stage and does not necessarily call for new sampling techniques.

2.3.12 Seabirds

Seabirds are valued aesthetically and as contributors to biodiversity though they are not numerous in in all marine regions. Many seabird species are declining in number due to loss of nesting sites, nest raiders such as rats, and food shortages, especially around breeding colonies where low stocks of surface-swimming pelagic species may prevent adults feeding their chicks. Certain species are also directly vulnerable to fishing gear, notably when they dive for fish in trawls or on baited longlines. Many species are known to be nearing extinction (http://www.iucnredlist.org/). They include most albatrosses, and several shearwaters and petrels (Onley and Scofield, 2007). On the other hand, some seabird species benefit greatly from galley waste, fish offal, and whole fish discarded by fishing boats. This leads to a changing balance of seabird species in the ecosystem. See Schreiber (2001), for example, for articles on biology and ecology. Monitoring of seabirds from RVs is usually carried out with ‘sight surveys’ using specially trained scientific crew with binoculars. Ships of opportunity may be used instead. Many species can also be monitored by surveys of nesting sites around breeding times.

2.3.13 Mammals

Many species of marine mammals are top predators. By eating smaller predators, their numbers are controlled and predation on mid trophic levels is moderated, thereby contributing to healthy populations of pelagic fish and helping to prevent trophic cascades. Marine mammals are also important for public interest and for biodiversity. Several species are IUCN red-listed. They can be at risk from purse seiners, netters, and fast pair trawlers. On the other hand, seals and other mammals may compete with fisheries by eating commercial species or their food, or they may damage fish captured by fixed nets, lines and traps. Marine mammals must come to the sea surface regularly to breathe, making them visible to watchers on an RV. Monitoring of mammals from RVs is usually carried out opportunistically by scientists watching seabirds but, in many geographic regions, encounter rates will be low and little analyzable data will be obtained. Marine mammals can also be monitored by aerial surveys, shore-based surveys and scat collections at haul-out sites of Pinnipedia (seals), passive acoustic listening buoys, and archival tagging (Metcalfe *et al.*, 2008). For recent articles on biology and ecology, see Hoelzel (2002), for example.

2.3.14 Reptiles

Seven species of sea turtle occur in the tropical and temperate waters of the oceans. All are red-listed by IUCN, mostly in the highest category: ‘critically endangered’. This is partly because of vulnerability to fishing nets and lines but, additionally, turtles suffer from theft of eggs, high predation on young individuals, and from pollution, eg. by floating plastics mistaken for food. Many species of seasnakes are found in tropical waters. Although often poisonous to man, they are valued for biodiversity and probably other ecological roles. They are vulnerable to certain types of fisheries, notably shrimp trawlers (Milton, 2001). Monitoring of marine reptiles from RV surveys is generally impractical because of low capture rates and the low, poorly visible profiles of free-living, surfacing individuals. When caught, reptiles should be released alive if possible after quickly photographing and measuring. Marine reptiles can sometimes be monitored without using an RV by divers, archival tagging, or by observer surveys on commercial fishing boats taking them as bycatch. There are several general texts on biology and ecology (eg. Lutz and Musick, 1996, Spotila, 2004).

2.3.15 Conclusions

An RV survey can feasibly monitor many components of a marine ecosystem including: water, plankton, jellyplankton, pelagic fish, demersal fish and skates and rays depending on the type of trawl used, attached and mobile epibenthos, infauna, seafloor habitats, and seabirds. However, this does not mean that monitoring of all or even most of them on the same RV cruise would be practical. Components less suited for RV monitoring are ctenophores, cephalopods, pelagic sharks, marine mammals, sea turtles, and sea snakes. Monitoring of ecological communities, another important component, can be considered at the data analysis stage provided that results for abundances and biomasses were collected for all or most species found at each station. Generally, the components that can be monitored by RV depend on the gears that can be deployed, the allowable times on station, the deck space, crew and equipment available and, in some circumstances, whether or not the survey can be conducted seasonally rather than just annually.

2.4 What sort of research vessel (RV)?

Practical factors that affect the amount of information and types of indicators available from an RV ecosystem monitoring survey (EMS) include:

- The amount of time allowable for sampling at each station
- The sampling devices that can be deployed on-station or whilst steaming
- The amount of sample processing that can be done on deck or, after the survey, on land
- The training and expertise of the scientific sampling crew
- The quality of shelter and working conditions for scientists on deck
- The weather, and the seaworthiness of the RV
- Steaming times between stations, and access by the RV to all parts of the ecosystem
- The seasonal timing of the survey.

The size of the RV is relevant to most of these factors. Small RVs are limited to inshore waters and relatively calm weather, have limited accommodation for scientists, and lack safe deck space and other facilities for scientific work. Large RVs, on the other hand, cannot access shallow waters, can work in somewhat worse weather with larger scientific crews, and have more space and facilities for work on deck and in cabins. Large RVs may be able to steam faster between stations but fuel costs rise substantially with speed. The high overhead costs of large RVs usually means that they are kept busy with projects throughout the year. This can restrict their availability for an EMS within the season preferred for monitoring indicators of reproductive potential and growth, or for sampling seasonally migrating species. This reasoning warns that a large and expensive RV is not automatically the best option for an EMS. The different types of RV suitable for an EMS are discussed in the sub-sections below. Points made are summarized in Table 2.5.

Table 2.5. (2 panels). Types of research vessel (RV) suitable for an ecosystem survey, the restrictions typically arising, and general advantages and disadvantages. GFS = groundfish survey for commercial species; AS = acoustic survey; EMS = ecosystem monitoring survey.

Type of RV	**Restrictions**	**Advantages**	**Disadvantages**
Share RV with GFS for commercial species	Fixed cruise track of GFS Fixed time of year of GFS Trawlable habitats only Types of sampling gear may be restricted by time on-station No shallow water work	Low cost for use of large RV May permit bird/mammal sight surveys May permit acoustic surveys of benthic habitats Support from fishery biologists Good for hydrographic sampling with bow-thruster positioning	Course and season may be poor for ecosystem monitoring Limited sampling time at each station May need night-time work Changed trawl and inter-calibration can disrupt EMS time series
Share RV with an acoustic survey (AS) for commercial pelagic species	Fixed cruise track of AS Fixed time of year of AS No demersal trawling Limited times on-station	Good for bird/mammal sight surveys Good for acoustic surveys of benthic habitats Good for hydrographic and plankton sampling Bow-thruster positioning	Course and season may be poor for ecosystem monitoring Limited sampling time at each station May need night-time work Demersal fish cannot be sampled

Table 2.2. 2nd panel

Type of RV	**Restrictions**	**Advantages**	**Disadvantages**
A purpose-built RV	Competition for season with other projects No shallow water work	Wide range of sampling techniques including all above Many scientists on board Good deck and lab space Bow-thruster positioning	High costs Inefficient use of RV resources if some are unused during an EMS
Chartered fishing vessels as RVs	Limited deck space No labs May be inshore only Probably one fishing method only No bow-thruster Poor visibility for sight surveys of seabirds and mammals	Cheaper than purpose-built RVs Different regions can be sampled at the same time Involves fishing industry and improves acceptance of EMS Brings in local knowledge Random sampling of vessels could prevent intercalibration problems	Lively sea motion Vessels may change catching powers between cruises Extra safety checks needed Hydrographic sampling may not be feasible in rough weather Sight surveys may not be feasible One survey may need sequential cruises with different sampling devices
Multiple purpose-built RVs	Competition for season with other projects No shallow water work	As for single RV Different regions can be sampled at same time	High costs Co-ordination overhead Difficult to change design

2.4.1 An RV shared with a groundfish survey (GFS)

Groundfish surveys (GFSs), as mentioned in the Introduction (section 1), are demersal trawl surveys used to estimate CPUE abundance indices of demersally swimming commercial fish species. Usually, the codend of the trawl is fitted with a fine-mesh liner intended to catch young fish that will recruit to the commercial fishery in the coming year or two. Since demersal trawls are poorly selective for species, many varieties of fish are caught that are likely to be of interest for an EMS. Additionally, time may be available at each trawl station for sampling with other sampling devices, depending on the distance to be covered each day and the weather. Other ecosystem monitoring techniques might be carried out while the RV is steaming between trawl stations, eg. sight surveys for seabirds and mammals, acoustic surveys of seafloor habitats. A general constraint when using GFSs is that the cruise track and timing may not be that preferred for ecosystem work.

Fish-related ecosystem indicators derived directly from catches made by the main GFS trawl include CPUEs, length frequency distributions, and others discussed in section 5.1. However, the GFS trawl will be specialized for catching commercial species and may catch indicator species poorly. Frequent occurrences of small numbers of a species in hauls do not necessarily indicate that that species is highly catchable when present; sporadic catches may just arise because of the large areas towed over during a GFS. Similarly, an indicator species having the same shape as a commercial species is not necessarily equally catchable; it may live in a more sheltered habitat, for example. The effect of poor catchabilities of certain species is to increase the variances of indicators, as discussed in section 6.1.2.

A well-recognized problem with GFS trawling arises when the RV itself, or the trawl gear, must be updated or otherwise altered for practical reasons. Catchabilities of different species and size groups could then be affected, leading to a re-scaling of catch-per-unit-effort (CPUE) indices relative to species abundances or biomasses. Before-after comparisons, parallel towing, or modelling studies can be applied to try to intercalibrate the two different RV-gear states (Anonymous, 2006) but, even in the best of circumstances, the step-change in CPUE time series is difficult and costly to estimate and may depend on strong assumptions. Intercalibration is a larger problem for EMSs than for GFSs because more species must be considered. Ecosystem indicators based on CPUEs are not the only ones affected. Presence-absence rates may also vary with different trawls, particularly for species that are only marginally catchable. This can lead to step changes in diversity indices, and to different, possibly spurious, assessments of rarity in biodiversity studies. Size-dependent indicators will also be affected by different size-selectivity properties, as will reproductive indicators because maturation is related to size. For these reasons, the need to intercalibrate a GFS trawl could seriously disrupt EMS time series. Trawl design for EMSs is discussed under ecosystem sampling techniques in section 2.5.3.

When deploying ecosystem sampling devices other than the main GFS trawl, speed of working is important to avoid delaying the vessel unduly. Grabs, corers, and water samplers can be worked quickly. Long tows of plankton nets or benthic trawls may not be acceptable to a GFS cruise leader, particularly at deep stations requiring much warp to be paid out and retrieved. Time-consuming ecosystem sampling methods may, however, be allowed at night if GFS trawling is only carried out in daylight, as is often the case because of diurnal vertical migrations of many fish species. However, the RV must be crewed and lit sufficiently for operating the sampling gear safely at night.

2.4.2 An RV shared with an acoustic survey

Acoustic surveys are used to estimate biomass of shoaling commercial pelagic species. The RV generally zig-zags over the area believed to be occupied by the species recording the strength of echos received by a calibrated echosounder in order to estimate the number and density of shoals. At intervals, a midwater trawl must be fished to estimate species compositions. The need to keep the RV moving on acoustic surveys favours sight surveys for seabirds and mammals but may restrict times stopped on-station for special ecosystem sampling work, as on GFSs (above). Acoustic surveys, in Scotland for example, have successfully incorporated hydrographic and plankton mapping, as well as acoustic seabed classification using single and multi-beam systems. Demersal trawling is not usually possible on acoustic surveys because of the need to keep using the midwater trawl.

2.4.3 A purpose-built RV

A vessel purpose-built for scientific work, depending on its cost, is likely to have some or all of the following facillities for ecosystem monitoring:

- Large gantries and winches for different fishing techniques, e.g. otter and beam trawling.
- Davits and small winches for other sampling techniques such as grabbing, coring, side-scan sonar, and water sampling.
- Multi-function water samplers for dipping from a davit.
- Piped water samplers for measuring surface water quality while the RV is steaming.

- Acoustic and video equipment for mapping benthic habitats.
- Comfortable accommodation for several scientists.
- Space on deck and sheltered laboratory cabins for catch sampling, and processing.
- Observation platforms for sight surveys; exterior wings of the bridge may serve for these.
- Other electronic nautical equipment for depth sounding, water and ground speed, accurate navigation, positioning, and safety.
- A bow-thrust propellor for accurate positioning in wind and currents.
- Low underwater noise signature (Mitson and Knudsen, 2003) but see Ona et al. (2007).

An RV equipped to map benthic habitats is especially valuable for EMSs because previous GFS work may not have discovered the full extent of reefs, nursery areas and other essential fish habitat or havens of biodiversity that could be vulnerable to commercial fishing. A bow-thruster is valuable on an RV for maintaining a vertical wire angle when sampling with water bottles or dipped devices; a shallow angle, aside from reducing the intended depths of sampling, may prevent messenger weights from tripping bottle closures at depth. Since RVs at sea are typically pressed for time, devices that reduce times spent on-station are valuable, eg. multi-function dip devices (measuring conductivity, temperature, depth and other variables), and autonomous equipment that may be left at the station for recovery later, such as benthic landers and incubation devices for respirometry and productivity studies.

A more expensive suggestion for a new RV is to include a helicopter landing pad. This would enhance synoptic sampling capabilities and permit aerial surveys. Helicopters have high operating costs but can sample large areas very quickly if only a single dip or observation is required at each station. This may tip the economics in favour of helicopters for some studies, eg. ichthyoplankton surveys.

2.4.4 Chartered fishing vessels as RVs

One or more commercial fishing vessels, preferably operating on or near their fishing grounds, can be chartered or otherwise made available as RVs for ecosystem survey work. At least one scientist should be onboard to carry out sampling work. Partnership surveys already use fishing vessels for collaborative work between the fishing industry and scientists (Chouinard *et al.*, 1999, Armstrong *et al.*, 2008). Compared to a purpose-built RV, the cost savings of chartered fishing vessels are likely to be un-ignorable and may permit more than one vessel to be used at a time, allowing a greater geographic spread of stations to be sampled on each day. Involvement of the fishing industry with the survey helps to improve acceptance of the results and brings in useful, local marine knowledge and experience.

Disadvantages of chartered fishing vessels, particularly small ones, are that working conditions tend to be more challenging, and deck space that is safe for working, with good shelter and hand-holds, may be minimal. Small auxiliary winches with adequate warp capacity for deep seafloor sampling and hydrology are unusual on fishing vessels, as are bow-thruster propellors. Navigation and acoustic instrumentation could be constraining, and there may be poor all-round visibility for seabird and marine mammal sight surveys, depending on the size and height of the vessel. It follows from these disadvantages that ecosystem indicators measurable on a chartered fishing vessel could be restricted to basic observations and measurements on the catches. There may be facilities for deployment of sampling devices other than a fishing trawl but they should not be accepted without careful consideration of safety and usability in poor weather. Scheduling of different types of sampling for sequential cruises contributing to each survey may be a better option depending on the possible effects of the intervening time lags.

Maintaining constant fishing power is important when commercial fishing vessels are used as RVs. Scientists should preferably supply a fixed, standard design of fishing gear to all vessels being chartered. They should also supply a fishing protocol that is acceptable on the different vessels so as to diminish skipper and equipment effects on fishing power. The protocol should, at the least, deal with

- use (or, more likely, non-use) of fish finding equipment,
- gear rigging, shooting, towing, and hauling techniques, warp-out to depth ratios,
- the times and locations of fishing, and
- responses to poor weather, ripped nets, and equipment failures.

As much time and staff resources as possible should be allowed for drawing up such protocols to the satisfaction of everyone who might become involved. Protocols used for groundfish surveys are available and may contribute text adaptable for an EMS using chartered fishing vessels. Catch sampling protocols, see section 4, may need special attention for commercial fishing vessels lacking deck space or motion-compensated balances for estimating raising factors.

Commercial fishing vessels present special intercalibration problems. Although one vessel may be chartered year after year, the owner is under no obligation to maintain the vessel constant with respect to fishing power. New engines or gear could both affect this substantially. Further, the vessel may not be available when it is needed, so forcing use of another vessel with, probably, a different skipper.

An idea for diminishing intercalibration problems with commercial fishing vessels is to charter a random sample of them from the fishing fleet on each occasion. The names of those vessels willing to take part and acceptable for the work could be put into a hat and drawn independently for each repetition of the survey. Statistically, mean and variance of fishing power should then be reasonably constant over time even if membership of the population of available vessels gradually varies. Large numbers of vessels are not essential, either in the pool or as the sample set of RVs, but having larger numbers would be expected to reduce the variance of fishing power from time to time, as would a standard fishing protocol and gear type. Considering that even highly-resourced groundfish surveys are prone to variance of fishing power due to the effects of weather, cruise leader, fishing skipper, etc., the variance introduced by randomly choosing RVs may not be especially serious. It has the special advantage of spreading the financial benefits of chartering equably around the fleet.

Other issues arise when using fishing vessels as RVs. Safety is one. Before contracting a vessel, it should be checked for good maintenance, particularly of life-saving and communications equipment, bilge alarms and pumps, deck machinery and warps. A scientist should never be left unwatched on deck. Low railings on many commercial fishing vessels increase the risk of falling overboard. Wearing a compact, automatically inflating life-jacket fitted with an automatic distress radio beacon (EPIRB) is advisable for work in such circumstances (Course *et al.*, 1999). Reduction of chartering costs by allowing the vessel operator to sell catches is another possible issue. The contract should be carefully written so that financial incentives do not encourage a search for big catches when scientifically objective fishing is needed.

2.4.5 Multiple RVs

Some marine regions, for example the North Sea, are covered by several co-ordinated GFSs. High densities and frequencies of ecosystem sampling are then possible across a large marine area. Some acoustic and planktonic egg surveys, usually for commercial pelagic species, may also make use of co-ordinated RVs. RV surveys can be co-ordinated so as to take place during different quarters of each year (Anonymous, 1998). This allows seasonally varying indicators to be monitored if required. Also, the additional measurements in time assist the fitting of time-series models and may allow long-term trends to be identified earlier than can be achieved with annually spaced measurements. There may be exceptional scope for acoustic monitoring of benthic habitats, bird or mammal watching, or other ecosystem sampling during these multi-RV cruises. Co-ordination of timing, coverage, and gear specifications of different RVs is just as important for ecosystem survey work as it is for commercial fish sampling and was achieved for the North Sea by Callaway et al. (2002a).

Using two or more RVs for an ecosystem survey may, paradoxically, be cheaper than one. Occupying a high-specification RV for straightforward fishing and acoustic duties is wasteful when fairly ordinary fishing vessels can complete the same work for lower costs. A more efficient plan may be to use the RV sparingly for the duties that only it can carry out, such as special oceanographic or acoustic studies, and to support it with one or more fishing vessels performing trawling, acoustic, or grabbing surveys. Other advantages of this plan are improved synoptic sampling, access to shallower waters and, depending on circumstances, inclusion of the fishing industry for better fishing skills and improved acceptance of the results.

2.4.6 Conclusions

Several types of vessel can be used for ecosystem work. A low-cost option is to combine the EMS with a GFS already undertaken for assessing commercial stocks. However, times on station may have to be short, the EMS is then restricted to the cruise plan of the GFS, and catchabilities for indicator species may be poor. A piggybacked EMS may also be adversely affected by decisions to change the RV or main GFS trawl, requiring intercalibration studies. Purpose-built RVs are expensive and offer the most facilities for EMSs but competition with other projects for RV time may prevent choice of the best season for the EMS, and a sophisticated RV may not, in fact, be needed for all EMS work. Habitat mapping and oceanographic studies are two important functions of RVs but many are too big to visit shallow waters. Chartered fishing vessels tend to be cheaper than purpose-built RVs but many suffer from limited deck space, excessively active sea motion, lack of height for sight surveys, and uncontrolled modifications by the owner that create intercalibration problems from year to year. Random selection of vessels from a fishing fleet could get round intercalibration problems and would spread financial benefits evenly around the industry. Multiple RVs can be co-ordinated for an ecosystem survey allowing sampling over wider areas and at different places. Costs can also be saved by using specialist RVs only where they are essential, and leaving fishing duties for cheaper fishing vessels.

2.5 What sort of ecosystem sampling devices?

A wide range of sampling devices can be deployed from an RV during an EMS but each has its own requirements for equipment, deck space, cabin space, crew support, technical expertise, and time on-station. The following notes discuss practical aspects of specific sampling techniques worth considering for an EMS. They are summarized in Table 2.6. Please also refer back to the methodological references in the last column of Table 2.1. Detailed protocols on several aspects being developed for the Census of Antarctic Marine Life, available at www.caml.aq, may also be of interest.

Table 2.6 (3 panels)**.** Ecosystem sampling techniques that may be deployable from an RV, what they sample, their needs, and issues typically arising. All techniques require an operating protocol to standardize sampling.

Technique	**What it samples**	**Needs**	**Issues**
Piped seawater sampling	Surface temperature, conductivity, oxygen, chlorophyll pigments, nutrients	Bubble-free water supply Analysis in a lab, preferably with auto-analyzers	Samples surface waters only Contamination by RV Bubbles in rough weather Calibration and maintenance of analyzers
Nansen bottles with reversing thermometers	Temperature, conductivity, oxygen, chlorophyll pigments, nutrients at depth	Light davit and winch, messenger weights Bow-thruster Storage racks, bottles, analysis equipment	Maintaining a vertical wire in windy weather Accurate analyses and calibrations
Dipped electrode array	Temperature, conductivity, oxygen, pH, turbidity to moderate depths	Light davit and winch Bow-thruster Calibration and maintenance of electronics at sea Storage for multi-core wire	Maintaining a vertical wire in windy weather Accurate analyses and calibrations Electrical connectors
Plankton sampling	Plankton biomasses Plankton biodiversity Fish eggs and larvae Benthic eggs and larvae	Light towing point and winch Plankton sampler, netting Flow meter on sampler Constant towing speed	Incomplete size selectivities depending on mesh size Towing speed, technique Clogging of meshes

Table 2.3, 2nd panel

Technique	**What it samples**	**Needs**	**Issues**
Otter trawling for fish	Mainly demersal roundfish Some flatfish and pelagic species	Trawling winch and crew Small trawl preferred Monitoring of trawl geometry Catch-sorting table and deck space 2+ scientists depending on trawl size	Trawl design and technique Grounds and depths unsuited to the trawl Bottom contact, herding of fish Time of day, trawl speed Catch sampling for large catches Adequate engine power to tow at standard speed everywhere
Beam trawling for fish	Mainly demersal flatfish Some roundfish Variable epibenthos	Trawling winch Small trawl preferred Catch-sorting table and deck space 2+ scientific crew depending on trawl size	Tickler chains, stone matting Grounds and depths unsuited to the trawl. Validity of benthic sampling Catch sampling for large catches Engine power, towing speed
Epibenthic beam trawling or dredging	Attached (sessile) fauna Mobile fauna Some sediment	1 scientist, taxonomic skills High-capacity winch Standard, length-marked warp Sorting sieve, lab Spare trawls Bottom-contact sensor	Bottom contact Distance towed on bottom Time needed at deep stations Confusable species

Table 2.3, 3rd panel

Technique	**What it samples**	**Needs**	**Issues**
Benthic grabbing	Infauna Sediment Some epifauna	1 scientist, taxonomic skills Light winch and davit Sorting sieve, lab Preservation bottles, fluid	Effect of sediment type on grab volume Time to sort and identify species including after cruise Confusable species
Active acoustic techniques	Seafloor morphology, depth Attached epifauna Fish shoals	1 scientist, acoustic skills Towing facilities for sidescan Onboard electronics	Wave action Data reduction Identification of echoes
Passive acoustic techniques	Vocal invertebrates, fish, mammals Noise pollution Ecosystem noises	Development of listening techniques Quiet vessel or free-floating hydrophones	Recognition and interpretation of sounds Wave, current and wind noise Noise pollution
Sight surveys	Seabirds Marine mammals Basking sharks Jellyfish (possibly)	2 scientific observers, taxonomic skills, for shiftwork High observation platform Standardized, tested technique	Course or activities of vessel may be poor for a good survey. Poor visibility causing identification difficulties Confusable species

2.5.1 Water sampling

Surface waters can be monitored almost continuously for conductivity, temperature, turbidity, and nutrients using a piped seawater system connected to an auto-analyser. One scientist will be needed to keep the system operational and calibrated. A piped supply could be temporarily rigged on a fishing vessel but practical problems of contamination and bubbling could be challenging.

Subsurface water sampling may be carried out with Nansen reversing bottles (or similar) clipped to a weighted, depth-marked line lowered from a davit. The bottles are fired by messenger weights. Water samples for analysis are filled from each bottle as it is returned to the surface, quickly to avoid temperature changes and loss of gas from solution. A storage area for the sample bottles is needed. A reversing thermometer and an unprotected thermometer on each Nansen bottle accurately measure temperature and depth when the bottle is fired. Details of these time-honoured devices are given by Holden and Raitt (1974, section 7). The RV must be held in position while the Nansen string is out to prevent excessive wire angles caused by drifting. In windy weather, a bow thruster and accurate navigation system are important on the RV.

Sub-surface water sampling may be carried out more quickly, though perhaps less accurately, using a frame to which electrode sensors are attached, eg. for dissolved oxygen, pH, conductivity, turbidity, depth, and chemical determinands. Calibration and maintenance at sea are time-consuming skilled tasks, and the whole system may have to be put out of action when one component fails. Electrical connectors can be especially difficult in salty environments. Depending on how data are transmitted to the ship, facilities may be needed to wind and store all of the long, multi-core wire that is lowered over the side with the electrode frame. Some electronic systems are fitted with water bottles to collect samples for analysis. Agreed oceanographic sampling and calibration methods should be described in a protocol.

2.5.2 Plankton sampling

Plankton samplers are relatively light sampling devices requiring a davit, winch and warp. They may be deployed at constant or undulating depths, or hauled up from depth at one location. Towing should be at a constant speed so that the proportion of fast-swimming animals escaping in front of the net is standardized so far as possible. The net should be fitted with a flow meter to measure the volume of water filtered which might be affected by clogging of the meshes. A flow meter aids quantitative comparisons of results though, as mentioned previously, high variability is to be expected for plankton samples at the best of times. Given high variability, intensive sampling both spatially and in time are likely to be needed to discern trends. A recent text on plankton sampling and related matters is by Suthers and Rissik (2009). An older reference by Holden and Raitt (1974) provides still-useful advice. Plankton sampling on an EMS should be covered by a protocol. The specification should include design of the sampler, netting and meshes, towing speed and method, estimation of the volume of water filtered, and sample preservation.

2.5.3 Trawling for fish

Demersal trawling on an EMS hosted by a GFS will be governed by the GFS fishing protocols (eg. Stauffer, 2003, Anonymous, 2009, Anonymous, 2010). Consistency of design, rigging, and towing technique are just as important for EMSs as they are for GFSs since CPUEs, size and species selectivities, and even presence-absence proportions will be affected by these factors. Most survey trawls are either otter or beam trawls, the latter being better when demersal flatfish are the priority. Midwater trawling is used to verify species compositions during acoustic surveys but is seldom used by itself for CPUE estimates.

If there is an opportunity to select a trawl design purely for catching demersal and low-swimming pelagic fish as part of an EMS, the following features would be ideals to aim for:

- Simple structure unlikely in future to need redesign and intercalibration.
- Short or no sweeps. Effective trawl width is then less affected by variable herding.
- Constant geometry despite varying depths and water speeds.
- A high headline, especially if the demersal trawl is the only sampler of pelagic species.
- Consistent ground contact despite wave motion of the RV, and different ground types.
- Rapidly shot and hauled; does not fish at these times.

Achieving all of these ideals is, perhaps, impossible but a Norwegian project reported progress towards them (Anonymous, 2005, section 2.2).

A survey trawl does not have to be large, nor must it necessarily be towed for long periods (Pennington and Vølstad, 1991). Large catches mean that catch sampling must be more frequent, adding a component of sampling variance (Cotter, 1998) and extra work on deck. Smaller trawls need less engine power to tow and are quicker to deploy, set, and mend when torn. However, the trawl must be large and heavy enough to sink rapidly and to maintain good bottom contact despite wave motion of the RV. Also, short, frequent tows waste time on winch work at deep stations and, for otter trawls, the proportion of towing time when the net is fishing in a stable configuration may be too low compared to the times taken for the net to stabilize on reaching the seafloor, and to collapse on haul-up. Depth-related variations of fishing power can easily arise from variable net geometry; a common problem is for an otter trawl to spread more widely with a lower headline at depth. Warp-out to depth ratios are important for configuration and bottom contact, and sensors on the gear, transmitting acoustically to the RV, permit estimation of configuration and effective towing times. Towing into the tide is beneficial for achieving constant trawl geometry. A consequence is that the ground direction of the towing path at a station varies on each visit, thereby randomizing effects of local ground types on catches at the station. This should help to reduce bias in randomized and grid survey designs (section 3.2). A recent study of variables affecting otter trawl behaviour for surveys is by Weinberg et al. (2008).

Trawling speed is another important consideration if not already fixed by a GFS protocol. Ground speed is most relevant for flatfish and other demersal species that lie close to the bottom. Water speed is more relevant for actively swimming species. When a multi-vessel RV fleet is used for an ecosystem survey, all must have sufficient engine power to achieve the selected standard towing speed into the strongest likely tide. An EMS protocol for a trawl could be derived from, or styled after a GFS protocol. It should include, trawl design and rigging, towing variables, use of net monitoring sensors, determination of towing time and distance over the ground, criteria for rejecting tows, methods of repair, and catch sampling (section 4).

2.5.4 Epibenthic trawling and dredging

Seafloor epibenthos can be sampled with various trawls and sledges that yield a worthwhile impression of attached and mobile epifauna not obtainable with fishing trawls, benthic grabs or corers. A lightweight beamtrawl design, has been used informatively in UK waters (Jennings *et al.*, 1999, Callaway *et al.*, 2007). A slightly heavier, steel-sled design (Ward *et al.*, 2003), and a much heavier sled intended for rough terrain (Lewis, 2009) have both been applied successfully in Australian waters (Ward *et al.*, 2006, Currie *et al.*, 2008). Another sled used in Antarctic waters is given by Brenke (2005). Lightweight designs can suffer from ‘flying’ over the bottom resulting in uncertainties about the effective distance towed. Relevant factors are the weight of the trawl and warp, ground and water speeds, roughness of the seafloor, depth, and warp-out to depth ratio. Light trawls also require significant winching times at deep stations. Heavier sampling devices may, therefore, be best but they are more expensive to build, require bigger winches and a bigger RV to operate.

Epibenthic sampling additionally requires a seawater hose for sieving and washing, a well-lit sheltered working area for sorting catches by low-power microscopy, plus facilities for preserving and storing specimens, eg. for confirmation of identity. The protocol for epibenthic sampling should cover design of the trawl or sledge, fishing technique, criteria for rejecting tows, the influence of tide and weather, processing of the catch including sieve mesh sizes, standardized naming for species that are not easily distinguished, and training and verification of taxonomic skills of those sorting the catches.

2.5.5 Benthic grabbing and coring

Benthic grabbing using, for example, a Day grab, yields a large suite of species for monitoring an ecosystem. It requires a suitable davit with safe, railed space around it to push out and retrieve the heavy grab over the side. For some sediments, coring may be preferable (Brandt, 2006). Sample processing facilities required on an RV are the same as are needed for epibenthic sampling, above, except that sieve meshes are usually finer. Sieving and sorting of benthic samples is time-consuming. Identifications may not be completed at sea, leaving preserved samples to be sorted through and identified later. Aside from the extra costs involved, this may delay production of the ecosystem report, leading to lower interest in it. Protocols should specify the design of the grab or corer, criteria for rejecting samples, and the other aspects listed for epibenthic sampling, above.

2.5.6 Active acoustic techniques

Biomasses of shoaling pelagic fish species are best estimated by active acoustic methods combined with midwater trawling to verify species compositions for the returning echoes (MacLennan and Simmonds, 2010). Sidescan sonar, multi- and single-beam echosounders (Kenny *et al.*, 2003) are useful for monitoring seafloor habitats. A sidescan fish is towed behind the RV whereas echosounding techniques are installed in the hull of the vessel. Installed echosounders have potential to monitor while the RV is steaming. Large volumes of data are then produced which may have to be sampled for manageability. All these details should be standardized for an EMS monitoring programme in a working protocol. Oceanographic acoustics is discussed by Medwin and Clay (1998).

2.5.7 Passive acoustic techniques

Passive acoustic techniques, i.e. listening using hydrophones, have been advocated as potentially valuable for ecosystem monitoring (Cotter, 2008) though they await development for routine use. Many marine species, including fish and invertebrates, make sounds that can be heard from long distances underwater and that can sometimes be identified, eg. http://www.fishecology.org/soniferous/justsounds.htm. Libraries of underwater sounds exist (Ranft, 1997) to help. Censusing and distributional studies may sometimes be possible especially when aggregations of known species are occurring, but many technical problems can arise, eg. selecting the best frequency bandwidth, interfering noises made by wind, self-noise from water movement over the hydrophone, shipboard noises, wave-caused bubbles under the ship, and noise pollution from shipping etc. Free-floating hydrophones, if they can be recovered, might be deployable from RVs.

2.5.8 Sight surveys

Scientists systematically watching[6] from an RV can record seabirds, marine mammals and any other large surface-dwelling animals such as basking sharks. Seabirds are surveyed using either a fixed-width observation region, or a line transect method that models detection at different distances from the ship (Buckland *et al.*, 2004, Thomas *et al.*, 2004, Hyrenbach *et al.*, 2007). Possibly other visible species, such as large jellyfish, could usefully be estimated by similar methods. Watchers can do their job best if situated well above the sea surface in a sheltered, panoramic observation platform, eg. the exterior wings of the bridge, or the deck above. Verified taxonomic competence is essential. A team of at least two watchers working in shifts is best for maintaining alertness, particularly if days are long. With only one watcher, available watching periods could be sampled. An element of randomness is then desirable for reducing possible time-of-day biases. Watching protocols should specify the training and assessment of watchers, describe the watching routine, and clarify what to record for species that are likely to be confused when seen at a distance, perhaps in poor visibility.

2.5.9 Conclusions

The first choice of sampling technique for an EMS is likely to be demersal trawling which is suited to most RVs and chartered fishing vessels. A small trawl fished briefly at many dispersed stations is better for learning about the ecosystem as a whole than a large trawl towed for long periods at a few stations. There are, however, practical lower limits to trawl size and tow length. In addition to trawling, oceanographic and plankton sampling may be feasible and appropriate depending on what is already known about the ecosystem and what is needed to implement an EAF.

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[6] This could alternatively be called ‘observing’ but, in fisheries circles, ‘observers’ is a common term for scientists that accompany commercial fishing trips.

Acoustic techniques such as single- and multi-beam echosounders and sidescan sonar are effective for monitoring benthic habitats. Epibenthic or benthic sampling is also needed at intervals for groundtruth. The latter are informative techniques in themselves for biodiversity, ecological, and community studies and indicators. Various small trawls, dredges, grabs, and corers are available for this work. They require appropriate winches, sample sorting facilities, and expertise in benthic taxonomy. Epibenthic samples are generally quicker to process than infaunal samples.

Sight surveys for seabirds and mammals is feasible from RVs having a suitably panoramic observation platform, raised above sealevel. Increasing jellyplankton populations is of concern in some regions and might be monitored by watching or catching methods, though the latter are made laborious because of the difficulties of cleaning the trawl after each tow. Passive acoustic listening has been advocated as an additional way of monitoring vocal marine animals. However, techniques require development for monitoring purposes.

All sampling methods required detailed protocols so that different scientific crews can standardize their work on every RV monitoring cruise. Taxonomic skills and thorough training in all sampling techniques are critical for EMSs. The occurrence of confusable species should be expected and dealt with by naming them in standard ways.

3 ECOSYSTEM SURVEY DESIGN

Ecosystem monitoring surveys (EMSs) carried out in collaboration with groundfish or acoustic surveys must make the most of the fishing stations and course chosen to meet their priority objectives of estimating stocks of commercial species. Ecosystem sampling is then opportunistic and survey design is hardly an issue. Designing an independent EMS, on the other hand, raises several issues addressed in this section.

A preliminary note on some terminology preferred in this report is needed. Generally, 'region' refers to geographic areas, so the 'surveyed region' is the geographic area just enclosing all of the sampling stations chosen for a survey, possibly with holes where localities are inaccessible for sampling. Sometimes, however, the time dimension should be remembered as well because RVs tend to travel slowly relative to marine distances such that results at one edge of the surveyed region may differ from those at the opposite edge not only because of their geographic separation but also because of the seasonal difference between the dates of sampling. Similarly, species and fisheries may also vary their regions of presence or activity over time. For these reasons, the word 'domain' is used to refer to a region plus an associated period of time even though, for operational reasons, the time dimension may have to be ignored.

The first task of designing an EMS is to locate the survey domain with respect to the defined ecosystem (section 2.1). The next is to choose a survey design. Three statistical designs are put forward. One, based on randomly located stations, is intended for reliable estimation of indicators as summarizing statistics, eg. the mean or median, for the whole survey domain, or for specified sub-domains. The second, based on an even grid of stations, is intended when spatial modelling, eg. contouring, is the primary objective. Since both designs have weaknesses when applied for the other purpose, a third, compromise design, using a lattice of square sampling strata, is proposed. None of these designs is 'optimal' in the sense of producing as much information per unit cost as possible. Optimization is likely to be fruitless for an EMS because a design good for one species will almost certainly be disastrously inefficient for many others. Instead, general utility for most priority species, low bias, adaptability for regional estimation or modelling, and practicality are all treated as more relevant than statistical efficiency for designing an EMS.

3.1 Choosing the survey domain

The survey domain of an EMS may not match the boundaries of the ecosystem if (i) the ecosystem is too big to contemplate sampling throughout, eg. it is an ocean; (ii) if parts of it are inaccessible, eg. they are too rocky, deep or steep; or (iii) there are reasons for positioning some sampling stations outside the named ecosystem anyway, eg. to deal with migrating species.

Knowing the relationship between the survey domain and the domains occupied by the individual species being surveyed can be important for interpreting survey results, as well as for understanding why average catch rates for some are much more variable than for others. The region occupied by a species at any point in time varies due to migrations, expansion or contraction of the population, or because different stages of the life cycle occupy different places. Figure 3.1 illustrates some possible relationships between survey domains and a species' domain when migrations occur. Total enclosure of a species by a survey is easiest to interpret, though results may still depend on the whereabouts of the species with respect to the pattern of sampling stations. Partial overlap is less straightforward because the sub-population monitored inside the survey domain may differ from that outside, causing bias in results for that species. Migrations across the survey boundary, eg. with season, year, and/or age (Trenkel and Cotter, 2009), can add variance to the survey results as well, particularly if the migrations themselves vary in relation to the seasonal time period of the EMS. Estimates of abundance- and size-related indicators could be strongly affected. Precision is worst when the overlap between survey and species domains is small, with only a small number of sampling stations present within the overlap.

Bounding the survey domain so as to minimize bias and variance arising from partially overlapping domains of priority species could be assisted by developing a 'Species database' holding details of the regions occupied seasonally, preferred habitat types, and migrations of each species. For simplicity, irregularly shaped regions could be simplified to rectangular enclosures, bounded by N and S latitudes and E and W longitudes marking the limits of the actual boundaries, perhaps with one set of four points for each quarterly season to allow for seasonal migrations. Candidate survey domains can then be quickly tested to see which species are likely to be enclosed, which overlapped partially, and which would be overlapped variably depending on migrations. Such a database would also form a valuable resource in its own right and could be updated as the survey time series lengthens, possibly leading to marginal revisions of the survey domain. Table 3.1 suggests fields for a Species database, including others mentioned later in this report.

Choosing the best season or seasons for an EMS also needs care. For priority species and certain biological indicators, the seasons of migrations, reproduction, recruitment, and growth may affect whether the survey is informative or, at worst, misleading. Compromises and trade-offs between species are likely. Allocating available RV-days across different seasons, rather than to one seasonal cruise in each year is another option to consider. Fewer stations would be fishable on each cruise but more types of indicator may be measurable over the year giving, perhaps, a more informative survey overall. Concerning terminology again, in this instance, one repetition of a ‘survey’ consists of more than one ‘cruise’.

The definition of the survey domain in the EMS protocol may exclude different types of ground or depths, or may include them subject to sampling with different types of catching device so as to catch priority species with best efficiencies. For example, an otter trawl might be rigged differently for hard and soft, or shallow and deep grounds. Intercalibration of the different gears and configurations would not usually be feasible for all species. However, since catchabilities and size selectivities differ from species to species even for a single type of gear operated in one way, using different sampling gears for different types of ground, provided it is done consistently for every repetition of the survey, would not add much to the problems of interpreting EMS results but would allow more of the ecosystem to be sampled consistently. So, for example, swapping a dredge for a grab at certain stations may be a practical way of retrieving constant volumes of sediment. The EMS protocol should state if certain regions or stations are to be sampled with particular types of gear so that it is done in the same way on every repetition of the survey.

Figure 3.1. Effects of migrations, symbolized by $\rightleftharpoons$, on the relationship of a survey domain (solid line) to a species domain (broken line). (i) Enclosing; migration shifts centre of gravity of the species. (ii) Enclosing; migration shifts the region occupied by the species. (iii) Partially overlapping; migrations vary abundance within the survey domain. (iv) Non-enclosing; migrations also vary abundance within the survey domain.

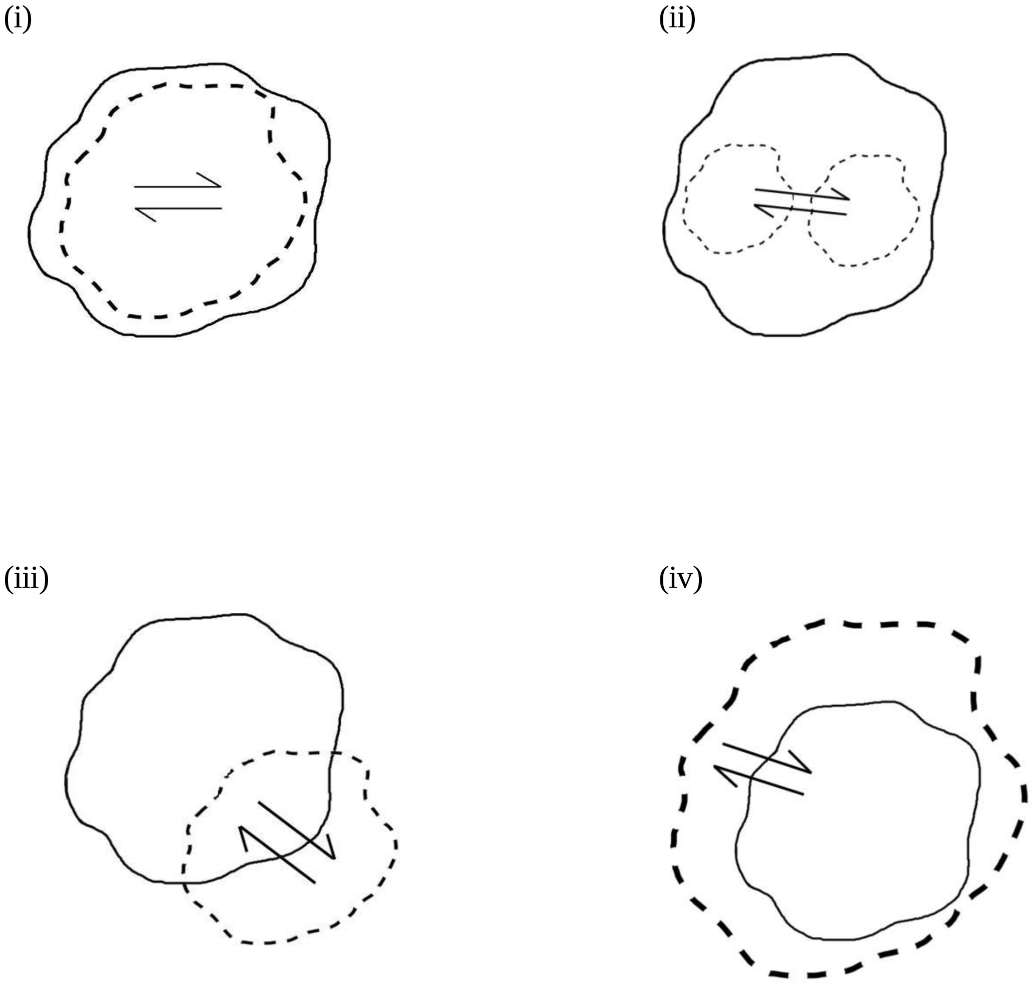

Table 3.1 List of fields for a Species database to support an RV ecosystem survey. Geographic fields might be repeated to record different locations seasonally.

Field	Field	Field
FAO 3-letter code	Common name	Scientific name
Description and illustration	Ecosystem component (Pelagic, demersal, epibenthic attached, epibenthic mobile, etc)	Northern limit
Southern limit	Western limit	Eastern limit
Habitat preference keyword	Migrations	Catchability: survey trawl (Hi, Med, Lo)
Catchability: epibenthic trawl (Hi, Med, Lo)	Catchability: benthic grab (Hi, Med, Lo)	Vulnerability to commercial trawling: (Hi, Med, Lo)
Vulnerability to commercial netting: (Hi, Med, Lo)	Vulnerability to commercial longlining: (Hi, Med, Lo)	

3.2 Statistical terms and inference

Having decided the survey domain, sampling stations must be allocated within it. The term 'sampling unit', taken from Sampling Theory, is used here to mean the smallest practical unit of sampling for any gear, eg. the multi-species catch of a trawl, the mixed contents of a grab or water bottle, etc.. The term, 'sample set' is used to refer to a collection of *N* sampling units. [The word 'sample' is avoided when there can be ambiguity between a sampling unit or a sample set.] 'Sampling' is used to refer to the process of collecting a set of sampling units by an EMS.

Fish and benthic survey design is often controversial (e.g. Anonymous, 2004). Nevertheless, Sampling Theory implies that we may infer the properties of a marine region from the properties of a set of *N* sampling units with either of two contrasting approaches (eg. see Thompson, 1992):

- Design-based inference: It assumes a randomized statistical design but nothing about the nature of variation in the population. It serves best when regional estimation of summarizing statistics, eg. means or medians, are the priority.
- Model-based inference: It assumes a mathematical model of spatial variation and, perhaps, other factors such as temperature, but assumes nothing about the sampling design. It serves best when a model of spatial variation, eg. a set of fitted contours, is the priority.

Of course, both approaches are ideals: sampling is never perfectly randomized in practice, and models never fit real variation perfectly. The contrast between them raises the possibility of a third, compromise approach referred to here as lattice-stratified sampling. All three are discussed in the sub-sections below but, firstly, another approach, referred to as 'Station-based sampling' is described because of its popularity. Arguments for dismissing it from further consideration are given. More statistical matters are covered in a later section on data analysis (section 6).

3.3 Station-based sampling

'Station-based' sampling refers to the practice of taking replicate sampling units at each visited station so that, by using analysis of variance, a 'within-station' standard error can be estimated and applied to abundances, biomasses, or other measures made at any single station. The main assumption underlying station-based sampling is that a fixed statistical distribution and variance parameter are common to every station and, therefore, are worth estimating. Reasons to doubt this assumption are:

- High spatial heterogeneity and patchiness are typical in marine environments at all scales.
- The population of possible sampling points at a station is poorly defined because it varies with the accuracy of navigation, wire angles, wind and currents, and the direction of towing in the case of a trawl.
- The number of sampling units taken at each station is typically small, e.g. 3 to 5, meaning that neither the constant variance assumption nor the validity of any transformation applied to achieve it can be verified.

If the assumption of a fixed statistical distribution at every station is in serious doubt, there is no point in estimating a station-based variance because it itself is expected to vary throughout the sampling domain. Additionally, a major practical drawback of replicate sampling is that fewer stations can be sampled with the available RV resources. Consequently, the survey captures less of the spatial and temporal variability existing within the survey domain. For these reasons, station-based sampling is not recommended.

3.4 Design-based regional estimation

‘Regional estimation’ refers to estimation of parameters defined for a specific domain, *R*, from sampling units located within it. *R* could either be the survey domain itself, or a single stratum (subdivision of the survey domain), with an associated time period spanning the time period of the survey. In practice, the time dimension may be ignored for operational reasons. The word ‘regional’ estimation is used here because it is used in Geostatistics. The parameters could be means, medians, variances, or others.

Design-based regional estimation requires that sampling stations be located at randomly chosen space-time co-ordinates. Station co-ordinates, northings and eastings, are picked with a table of random numbers (the uniform distribution of Statistics), rejecting those that fall outside the survey domain, eg. beyond the boundaries, or on unfishable ground previously excluded from the survey domain (section 3.1). Station co-ordinates should be freshly randomized for each repetition of the survey so that the residual errors will average to zero over time. If this is not done, the residual error associated with each repetition of a survey must be assumed constant and not a function of the value of any measure found, a weakness of the design. Repeated use of a single random selection of stations is most accurately referred to as a fixed-station design.

Randomizing in time is usually not practicable for an RV that, because of limited speed and high fuel costs, must visit the next adjacent sampling station, more or less in sequence. If so, timing must be assumed to have no effect on measured results, as may be true for some indicators but not others such as indicators of reproduction and growth which could be highly seasonal (section 5.1.4). Depending on the configuration of stations and distances between them, there may be opportunites for randomizing the cruise track without undue additional expense and time. If so, they should be used. A different cruise track for each repetition of a survey is desirable for avoiding enduring confounding over a time series between timing and locality of sampling.

The true regional parameters of *R* are defined as sums for countable populations such as fish, and as integrals over area and time for continuous variables such as concentrations in water, or sedimentary properties. See Box 3.1**.**

Randomization of sampling within *R* confers the benefit that estimates of *R*'s parameters are expected, from Sampling Theory, to be unbiased, meaning that histograms of repeated estimates, ie. made from different sets of *N* randomly located stations, are centred on the defined parameter. In addition, increasing *N* causes the statistical distribution of the sample mean, $\bar{y}$, to tend toward the Gaussian (normal) shape with variance reducing in proportion to *N* in accordance with the Central Limit Theorem (Feller, 1968), provided that results at each station are kept independent (section 6.2.5). The value of *N* needed to achieve reasonable approximation to Gaussian depends on the probability of occurrence of extreme positive values of *y*; there can be no standard guidelines.

The most basic design for a regional survey is simple random sampling (SRS). It permits straightforward estimation of means, variances, medians or other quantiles etc. using formulae from textbooks. A disadvantage is that it usually gives an uneven spread of stations within a region, possibly prompting criticism that the sample set is "unrepresentative", or that it favours some species more than others depending on their domains. It can also cause practical difficulties with catch-processing work because of unequal steaming times between adjacent stations. Stratified random sampling (StrRS) can be designed to provide a more even spread of stations. The survey domain is divided into sub-domains, called strata, having similar areas. Each is sampled at the same rate, ie. it receives the same number of sampling stations per unit of area. This is 'proportional allocation'.

If, alternatively, evenness is not so important, strata may be designed to enclose and isolate major features of the ecosystem such as habitat types, depth ranges, or zones of upwelling. The strata may then have very different areas. Selected strata receive higher sampling rates to reflect their importance and expected variance. This strategy may be maximally informative about the effects of the features but may diminish precision for other important estimates not linked to the features, and could still suffer from irregular steaming times between stations.

The number of strata used in a survey is a compromise for a given total of N stations. More strata offer increased spatial definition but the number of stations in each is reduced, leading to reduced precision of estimation. A small number of strata, on the other hand, improves precision but decreases spatial definition. However, the latter strategy improves the Gaussian approximation offered by the Central Limit Theorem because fewer strata mean fewer parameters to estimate and higher degrees of freedom for estimating variances. Restraining the numbers of strata therefore seems the more dependable and informative strategy for regional estimation even if, at first sight, a survey appears to offer less spatial detail as a result. Large numbers of strata can be thought of as a luxury only justifiable if there are resources for large numbers of stations to be sampled in each.

The weighting of regional strata for calculation of StrRS estimates of mean values for the whole survey domain (Cochran, 1977) depends on how estimates are calculated in each stratum (Cotter, 2009b). For countable populations such as fish and benthic invertebrates, the measure on each fish, say, can be averaged over all fish in a stratum. This is called the ‘mean over fish’. Alternatively, the measure can be averaged for all the fish at each station, and the stratum mean estimated as the mean of the station means. This is called the ‘mean over stations’. The two estimators are explained in more detail in Box 3.1. For over-fish estimation, the strata are, for logical consistency, weighted by the numbers caught in each. The stratum weights would then vary from species to species, as may seem reasonable. For over-stations estimation, the strata are weighted by area. The areas should be accurately measured. Weighting of strata for uncountable populations is simpler than for countable populations because there is no clustering of unmixed individuals in a sampling unit. See Box 3.1. Area-based stratum weights are therefore appropriate for uncountable measures such as temperatures, concentrations, etc.. Having decided the best stratum weights, means, variances and other summarizing statistics can be estimated straightforwardly and without bias using textbook StrRS formulae (Cochran, 1977, Thompson, 1992). The distributions of means for the total survey domain, like those for the strata, approach normality for large N by the Central Limit Theorem.

Box 3.1. Defining and estimating parameters for populations monitored by an EMS

Countable populations

'Countable populations' in aquatic environments refers to animals such as fish. Two approaches and a compromise have been suggested (Cotter, 2009b) for defining the parameters of countable populations, the gist of which is below.

One approach is to define regional parameters as if individuals of the population are the sampling units. So, for the mean of variable, *y*,

$$\bar{Y}_{pop} = N^{-1}\sum_{j=1}^{N} y_j \tag{1}$$

for which the statistically consistent estimator is found 'over fish' (or whatever animal it is):

$$\bar{y}_{fish} = \frac{\sum_{i=1}^{n_{stn}}\sum_{j=1}^{n_i} y_{ij}}{n_{fish}} \tag{2}$$

n_{stn} is the number of stations indexed by i, n_i is the number of fish caught at each, and n_{fish} is the total number caught. Estimator (2) is an average weighted by the number of fish caught at each station. It implies that zero catches are irrelevant, that the best estimate is obtained by sampling at stations where the species is common and, when the survey is stratified, that the strata should be weighted by numbers of fish caught, assuming that they are the best available estimates of relative population sizes.

The other approach is to define a regional parameter in a geographic sense with the survey domain divided into a grid of A small plots treated as sampling units. Then, if there are n_a fish in the a'th plot, and

$y_a = \sum_{j=1}^{n_a} y_{aj}$,

$$\bar{Y}_{geog} = \frac{\sum_{a=1}^{A} y_a}{\sum_{a=1}^{A} n_a} \tag{3}$$

Definitions (1) and (3) are identical in value but, since individual animals cannot usually be sampled independently, (3)fits better conceptually with the catching of clusters of animals in a net or other device deployed at a station by an RV. The statistically consistent estimator is 'over stations':

$$\bar{y}_{stn} = \frac{\sum_{i=1}^{n_{stn}} \bar{y}_i}{n_{stn}} \tag{4}$$

In contrast to estimator(2), estimator (4) weights the mean value at each station equally regardless of the number of fish caught. It implies that n_{stn} should exclude stations where catches are zero; the estimate is then for the mean of y over that part of the species domain within the survey domain. Estimator (4) also implies that many stations should be spread around to capture geographic variation and, when the survey is stratified, that the strata should be weighted by areas.

As a compromise, a mixed-model estimator has been suggested:

$$\overline{y}_{mix} = \hat{\rho}\overline{y}_{stn} + \ 1-\hat{\rho}\ \ \overline{y}_{fish} \tag{5}$$

where $\hat{\rho}$ is the within-catch correlation estimated by fitting a mixed model to results by station. If quantiles, eg. the median, are preferred as summarizing statistics because they minimize the influence of outlying (extreme) results, the same weighting considerations apply. For details, see Cotter (2009b).

Uncountable populations

Continuous variables such as concentrations can be thought of as ‘uncountable’ populations for sampling purposes. Regional parameters can be defined as integrals over the region, R. Let the area of R be A_R. Then, for example:

Mean: $\mu_R = A_R^{-1}\int_R y.dA$

Variance: $\sigma_R^2 = A_R^{-1}\int_R\ y-\mu_R\ ^2 .dA$

Median: $\tilde{\mu}_R$ for which $\int_R\ y \le \tilde{\mu}_R\ .dA = \int_R\ y > \tilde{\mu}_R\ .dA$

Sampling units usually only provide one measurable value, y_i at station i, for a continuous variable because the content of the sampling unit, eg. a bottle, is mixed before measurement. Therefore within-sampling-unit correlation is not a problem and estimators can be taken from standard sampling texts (eg. Thompson, 1992). For example, the estimator for μ_R is, as usual,

$$\overline{y}_R = \frac{\sum_{i=1}^{n_{stn}} y_i}{n_{stn}} \tag{6}$$

Estimates of the mean using (6) improve in precision as the number of stations located independently and randomly within R increase. They also tend to the normal distribution under the Central Limit Theorem, allowing confidence limits to be estimated from standard errors. Sample medians can be dealt with using binomial confidence limits (Conover, 1971, Cotter, 1985) which also get narrower as N increases.

3.5 Model-based estimation with a grid of stations

For model-based estimation, the survey domain is imagined as an uncountable population of points, on each of which one or more variables, eg. density, can be measured. Values of the variables are governed by a mathematical function, called a model, of spatial co-ordinates and, maybe, other factors, eg. temperature or season. Estimation of the model's parameters depends on it adequately simulating all spatial and factor-related variation. Then the values observed on a set of *N* sampling units should form residual errors falling around the fitted model with a random, non-spatial pattern. No assumptions about the sampling design are made because, by definition, all variation is in the model and none can be caused by 'biased' sampling. Contours and other general spatial models suitable for gridded stations are available in global information system (GIS) software packages. See also the open-source R system (Bivand *et al.*, 2008) and a review of digital mapping methods in fisheries science by Eastwood et al. (2008).

The most obvious choice of survey design for model-based inference is a regular grid of stations spread as densely as RV resources allow across the survey domain. Then the model is estimated with the same density of information in every locality. The starting point and orientation of the grid – it does not have to align with the compass points – can be randomized for each repetition of the survey in order to average out, or expose factors unwittingly omitted from the model. However, there are only 2 degrees of freedom, possibly causing a large between-repetition variance.

Many scientists are happy to estimate means, medians, variances and other descriptive statistics from grid surveys but they risk bias from the restriction on randomization imposed by the grid, in particular from trends over the domain, and from cyclical variability having periods 'aliased' with the distance between lines of stations in the grid (Cochran, 1977). See Figure 3.2 for an explanation. Also, degrees of freedom are less than a count of the number of stations in the grid because of serial dependence of results at neighbouring stations. Using the number of stations to estimate a regional variance, for example, would give an estimate that is biased too low. A particular problem from using a regular grid for an EMS arises for a species with a falling population that contracts its species domain into favoured, localized habitats falling between stations in the grid and, thus, not reached by the EMS.

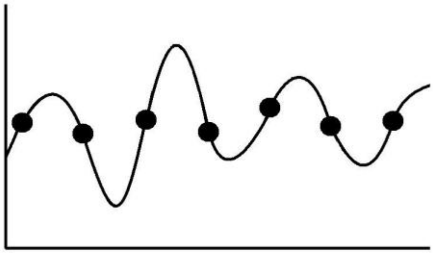

Figure 3.2. Aliasing of a systematic, one dimensional sampling grid (dots) with variability of the true indicator value (solid line) fluctuating with a wave length comparable to the grid interval. Much of the variability is lost because of the regular spacing between observations.

3.6 A compromise design: a lattice of strata

A lattice of equally sized square strata over the survey domain with equal numbers of stations randomly located in each square provides a compromise between randomization and even coverage. [The strata could be rectangular rather than square but then sampling intensity is less in one dimension than the other.] Locating at least two stations randomly in each square is one possibility. It allows standard errors of means for the whole survey domain to be estimated with standard StrRS formulae. At the same time, results in each square are available for spatial modelling, perhaps using just the estimated mean of each square as if it were located at the centre. A long-standing example of a lattice-stratified GFS is the co-ordinated international bottom trawl survey of the North Sea. See http://goo.gl/GWW41 .

As with any compromise, there are drawbacks however. Precision of StrRS formulae is reduced by the need to estimate two parameters, mean and variance, for every stratum; and modelling precision is less than for a grid because randomization means that different parts of the survey domain contribute different densities of information for fitting the model.

A preferable strategy may be to locate only one station in each square of the lattice, then to analyse the whole sample set of stations as SRS, instead of StrRS. This would give the maximum geographic spread of stations while each point in the survey domain has an equal probability of observation. For the purposes of SRS, this is not quite the same as giving every possible sample set of *N* stations an equal probability of observation, as SRS estimation formulae require for elimination of bias (Thompson, 1992). The difference is the restriction on randomization attributable to analysing the lattice-stratified design as an SRS, instead of as a StrRS. It seems a subtle difference that is unlikely to cause much bias, and certainly less than a grid design in which randomization has, at most, 2 degrees of freedom, as discussed above. In summary, a lattice design with one station per square has the valuable advantages for an EMS of providing even coverage, opportunities for spatial modelling, and simple, though slightly biased estimation by SRS formulae.

3.7 Conclusions

Ecosystem surveys differ in several respects from groundfish surveys focussed on commercial fish species. Ecosystem surveys enclose the domains of some species but only overlap those of others, potentially adding bias and sampling variance to results for the overlapped species, particularly if there are few stations in the overlapping region. Bounding the survey domain before designing the survey should take into account the distributions of priority species and could be assisted by a Species database holding distributions, migrations, and habitat preferences for each species. Retrievals could then quickly show which species will be enclosed, and which merely overlapped by candidate survey domains. The database would also serve as a store of species knowledge. An ecosystem monitoring survey is likely to use several different sampling devices so the boundaries of the survey domain should also take into account access, and adequacy of sampling on different types of seafloor by them. The season of an EMS must be carefully chosen because many indicators are sensitive to seasonal growth, temperature, migrations, and reproductive cycles.

Different catching devices are unlikely to be intercalibrated for different catchabilities for each species, implying that caution is needed when interpreting or using multispecies data from an EMS.

Replicate sampling at individual stations is not recommended because of the environmental heterogeneity typically existing, and the need to spread as many stations as possible widely around the survey domain. Instead, regional estimation with design-based, randomized sampling schemes is proposed for estimating means, medians, or other parameters defined for specific marine regions or domains. Standard errors and confidence limits are justified by large samples and the Central Limit Theorem with minimal dependence on unsafe assumptions, e.g. constant standard errors at different stations. Sampling may be stratified so that evenness of coverage is better than for simple random sampling, or so that major features of the ecosystem, eg. different habitats, are isolated if this is thought to be more informative for EAF. The number of strata should be low with many stations in each for maximum precision and dependability of EMS results. Care is needed in choosing stratum weights and station allocations.

Model-based estimation is proposed when EMS results will be analysed by fitting a model, eg. contours. Provided that there is confidence that the model includes most significant variation, stations can be set out in a regular grid so that equal densities of information are used for fitting the model over each part of the survey domain. The grids should be re-positioned at a randomly chosen starting point with a random orientation for each repetition of the survey. Summarizing statistics, eg. the mean, can be estimated from gridded survey data but there is a risk of bias because of the strong restriction of randomization.

A compromise between randomized and grid designs is obtained with a lattice of equally sized, square strata with one station per square. Design-based estimation uses simple random sampling formulae as if there were no strata, and spatial modelling benefits from an even spread of stations across the survey domain. The strengths of a lattice-stratified design appear to outweigh its weaknesses for a multi-species, multi-objective EMS.

4 PROCESSING CATCHES AT SEA

An RV ecosystem monitoring survey (EMS) may operate two or more catching devices, eg. a demersal trawl and a grab, and may yield tens or hundreds of species of interest from each. Sorting, identifying, quantifying, and taking measurements on many priority species therefore requires significant scientific labour. Since this work, along with other duties at each station, must normally be completed by the time the next catches are ready to be brought on board, catch processing may have to be restricted so that the same set of tasks can be completed reliably at *every* sampled station despite foreseeable problems such as bad weather, net repairs, and exceptionally large catches. This cautious approach to setting the amount of work is important because the final product of an EMS, namely time series of measures and indicators, are generally much more informative if they do not suffer from missing values and erratic precision, both of which would be caused by inconsistent catch processing. A consequence is that, when catches are light and everything is going well, the scientific crew may have a little spare time . . . for non-routine duties.

The first two sub-sections below briefly consider the initial cleaning and sorting of catches into species, whether taken by trawls or other catching devices. Figure 4.1 schematically illustrates these initial processing stages applied to the catch of an otter trawl.. The third sub-section considers sampling of species or size groups for estimation of indicators. The fourth puts forward ideas for matching indicators to the level of catch processing and for getting the most information from them.

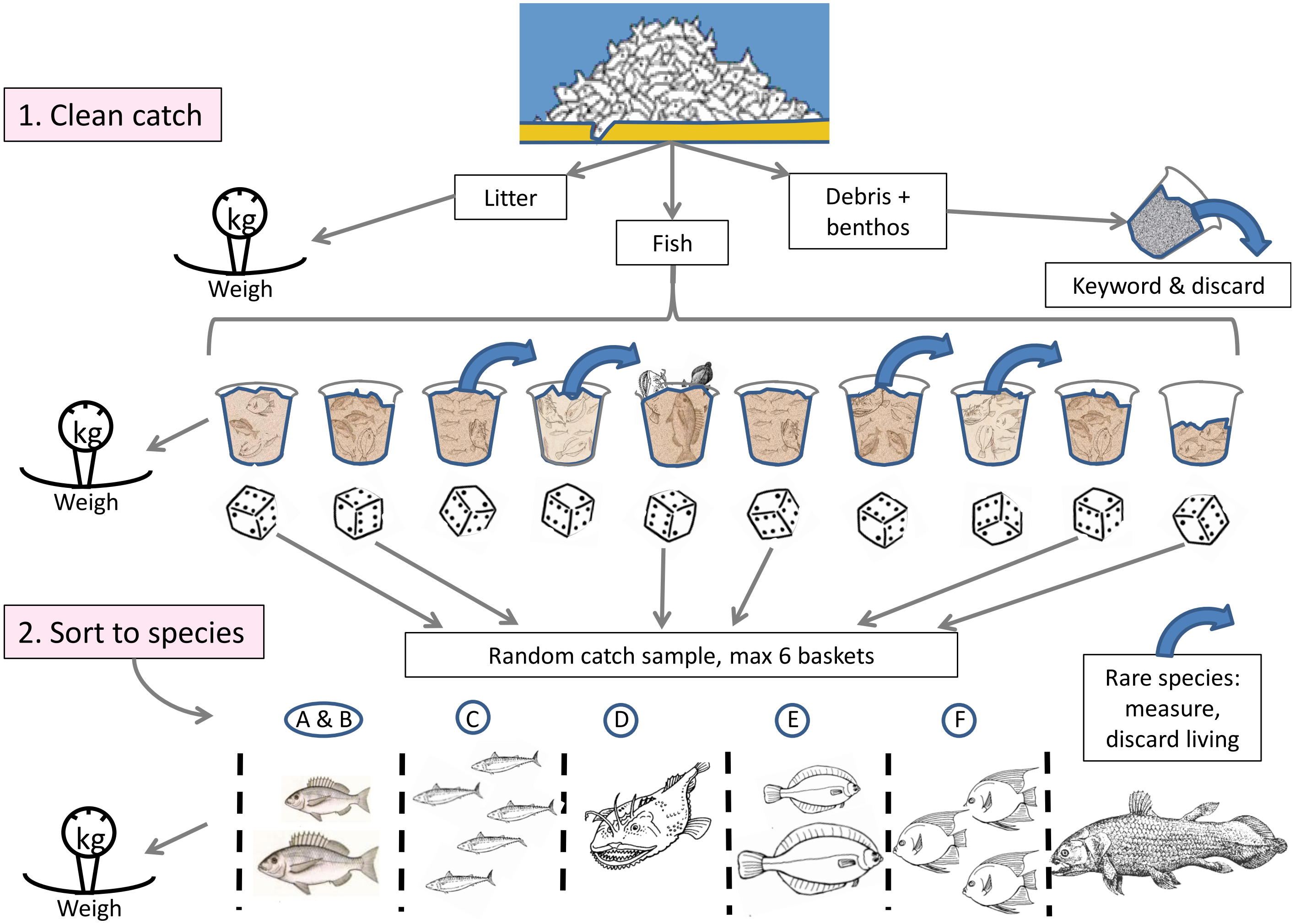

Figure 4.1 Scheme for initial cleaning and sorting of an RV trawl catch. Dice represent random selection of baskets to make up the maximum catch sample volume (MCSV), here set to 6 baskets. See text. Species A & B represents a mix of two similar species. Suggested keywords for debris and benthos are given in Table 2.2. Fish clipart from http://www.arthursclipart.org/seafish/seafish.htm.

4.1 Cleaning the catch

Living biological material in a catch should firstly be separated from sediment, rocks, dead shells, and any other debris either initially or as part of the processing to separate species. 'Debris' could sensibly include living material for which the catching device was clearly never intended, eg. sundry epibenthic species caught in an otter trawl, or occasional large fish taken in a small epibenthic trawl. Few if any inferences can be drawn from such occasional occurrences. Quantifying sediments and rocks caught would also be an unproductive use of time, though descriptive keywords could be helpful for mapping benthic habitats. See Table 2.2, page 35. On the other hand, keeping a record of quantities and types of litter items is relevant for an ecosystem survey (Galgani *et al.*, 1995, Galil *et al.*, 1995)[7]. Material other than litter can be washed overboard but only when the vessel is not trawling. Biological material should only be discarded when sight surveys for seabirds will not be disturbed.

4.2 Separating species

The next stage of processing is separation of the biological material by species. A strong sorting table or channel lined with stainless steel sheet is ideal. Poor standards of identification remarked upon for European GFSs (Daan, 2001) underline the magnitude of the taxonomic task for an EMS for which identification of many more species is important. Scientists should be thoroughly trained *and* objectively tested in the necessary branches of taxonomy before being permitted to name species on an EMS. Training and testing should be outlined in the catch-processing protocol.

Species identification is time-consuming when biodiversity is high so complete identification may not be feasible at every station. The catch-sampling protocol could specify a list of all species to be processed on the EMS; specimens of unlisted species are merely preserved for later identification so as to control the need for *ad hoc* taxonomic research during catch processing. In addition to saving time, a list should prevent inconsistent processing of unusual species on some cruises but not on others as a result of the personal interests of those who happen to be on board. Such inconsistencies could give misleading indications of the recurrences of species.

When sampling a large catch, the chance of finding a rare species increases with the amount of catch searched, particularly if the species is small or unobtrusive. Setting a 'maximum catch-sampling volume' (MCSV) in the catch-processing protocol is suggested as a way of dealing with

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[7] See also http://www.chrisjordan.com/gallery/midway/#about

occasional very large catches consistently and within time limits. 6 randomly drawn baskets is shown as the MCSV in Figure 4.1, but the MCSV should generally be as large as catch-sorting resources allow. Then the total catch, or the MCSV, whichever is the smaller, would be searched thoroughly at every station for rare species at the same time as it is sorted into species. An MCSV could help to standardize the apparent catchabilities of rare species, leading to better standardized occurrences, CPUEs, and diversity measures.

Species that are not easily identified are likely to occur frequently on ecosystem surveys, either singly or as mixes of two or more species that are hard to separate. Many of the difficult groups and combinations are foreseeable, given experience, and standard procedures for dealing with them should be prepared for catch-processing protocols. A mix of two or more similar species can be collected when sorting a large catch, and the ratio of the species estimated by detailed examination of a randomly drawn sample set from the shuffled mix. The size of the sample set needed will depend on whether the ratio of species is all that is required, or whether LFDs are required for each species individually. See Figure 4.2. Perhaps not all species' mixes merit this extra work and, if not, a standardized, common taxonomic name for any individuals of the group of confusable species should be written into the protocol. The same applies to single species that are hard to identify to the species level; the acceptible taxonomic name should be specified in the protocol, eg. '*Genus sp*'. Inconsistent naming, as inevitably occurs among different workers not guided by agreed naming rules, is likely to result in the species group being lost or confused in a database.

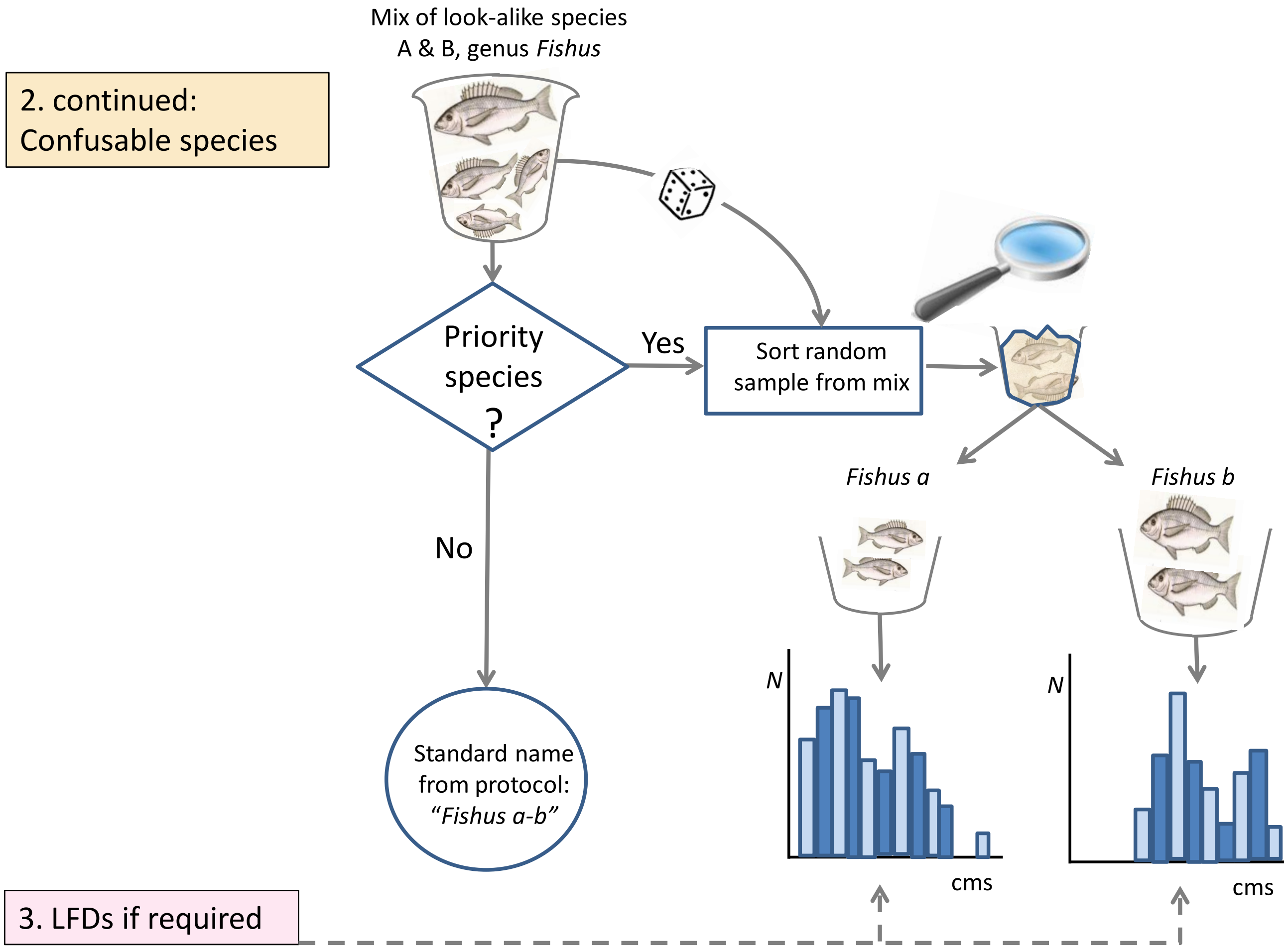


Figure 4.2. Scheme for separating a mix of two imaginary, look-alike species, *Fishus a* and *Fishus b*, in order to estimate the proportions of each in a hypothetical catch made by an RV. The dice represents random selection of fish. The volume of sample required depends on whether just percentage composition, or length frequency distributions, shown lower right, are needed. Fish clipart from http://www.arthursclipart.org/seafish/seafish.htm

4.3 Sampling species' catches for length-frequencies (LFDs)

Having sorted a catch into species, priority species can be processed further for the purposes of estimating biological indicators on them. The simplest, informative biological indicator to measure is size because it is linked with growth, age, behaviour, reproduction and, sometimes, trophic level. Measurement of sizes for selected species is therefore the next logical stage in catch processing. The extremities of each species that define its size for measurement should be defined in the catch-sampling protocol. For fish, this is usually the length though that must be specified as the fork length, total length, standard length, maximum length, etc. Shellfish and crustacea also have standard lengths (Holden and Raitt, 1974). The following text refers generally to ‘length’ or ‘size’.

Often the catch of a species has a few large individuals and many small, or some other obvious grouping of sizes. This is of no consequence if every individual is processed. On the other hand, if the catch is sufficiently numerous to require sampling for length measurements, sampling stratified by size can be beneficial for constant sampling precision across all sizes. The sampling fraction is low for the most numerous size groups, while it is 1 in the scarce size groups, ie. every member is measured. The idea is illustrated hypothetically in Figure 4.3 where three size strata are shown. Estimates in each stratum must be raised separately by the reciprocal of the sampling fraction to estimate the LFD of the catch. Stratified random sampling formulae are given by Thompson (1992) and Cadima et al. (2005) for example.

Size stratification is easy to implement when there are obvious gaps in the size range because individuals are unlikely to be mis-stratified. Sizes falling along a continuum from big to small require a little extra time and care to sort accurately into separate strata. There need only be sufficient strata to isolate the rarer length ranges for different sampling rates.

The procedures for drawing animals from a catch randomly for size measurements are important if biases are to be avoided. Taking conspicuous animals from the top of the catch, or “representative” animals, and other conscious plans are to be avoided so that sampling is de-personalized. Ideally, each animal in the catch should have an equal probability of being in the sample set. A pragmatic approximation to a random sample set is to sample systematically every *k*’th fish that is processed without regard to size. The random sampling procedure should be described in the catch-sampling protocol, along with containerization of the catch if needed, shuffling procedures, and estimation of raising (also called ‘expansion’) factors from relative volumes or weights of catch and sample set.

Weight-based raising factors are likely to be the more accurate, especially for irregularly shaped species of different sizes that do not pack down well in a container.

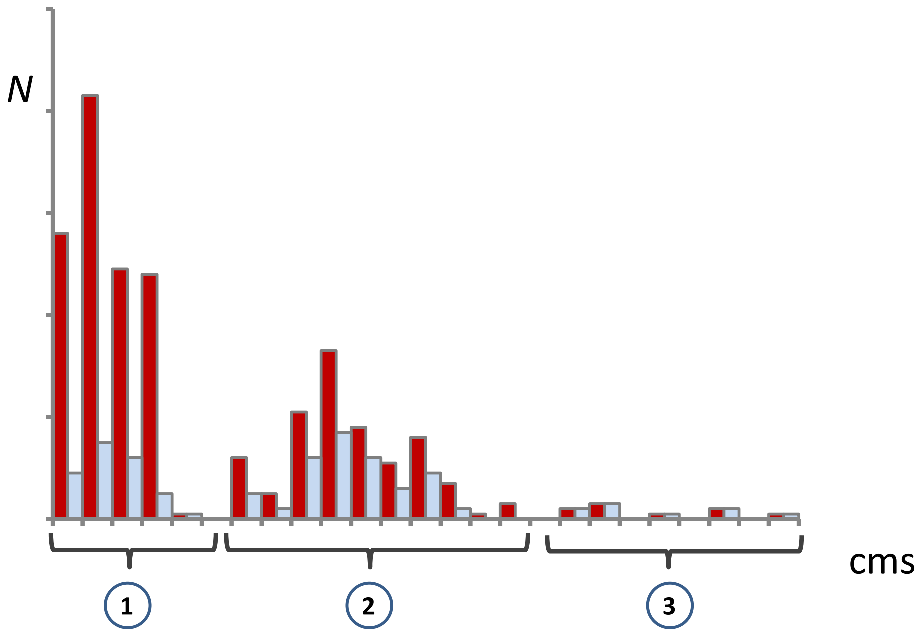


Figure 4.3. Estimating a length frequency distribution by length-stratified random sampling from an imaginary RV catch of one species, eg. a fish. Red bars: numbers at length in catch; blue bars: numbers-at-length drawn from the binomial distribution to illustrate an imaginary sampling from strata 1 to 3 taking 1 fish per 5 fish caught, 1 per 2 fish, and 1 per 1 fish (= no sampling) respectively.

4.4 Size-stratified sampling for biological indicators

Many biological indicators are functions of length, eg. maturity-, weight- and age-at-length. If caught animals have already been measured individually to estimate the LFD, as suggested above, collection of individuals of different lengths for estimation of the length-related variable is most easily carried out using regularly spaced length strata, eg. every 1 cm. This 'double sampling', as it is called (Thompson, 1992), will also provide the widest spread of lengths. For age-related indicators, the largest size groups should generally receive the highest sampling rates because there tends to be most uncertainty about the ages of large fish due to their slower growth. Otherwise, taking the same sized sample set from each length stratum is an easy scheme to implement. However, this is quite an active field of statistics with modelling and Bayesian methods available in connection with market sampling of commercial landings (see references in Cotter and Pilling, 2007).

Record keeping at all stages of catch processing should maintain the links between different indicators or measures and the individual fish or samples of fish on which they were measured. The links are important for raising factors, for checking back where a sample came from, as well as for correlation studies and modelling.

4.5 Conclusions

The processing of catches on an ecosystem survey, whether from the main trawl or some other catching device must be planned to suit the resources of space, time, and scientific crew available. Formal catch-processing protocols are essential for every gear. They should cover the separation of litter, rocks and other debris, sorting into species including rarities and confusables, size stratification options, and the drawing of animals at random for unbiased estimation of indicators. A maximum catch-sampling volume (MCSV) is proposed for when catches are too large to be searched throughout for occurrences of rare species or size groups of a species. Scientific crew should be trained in taxonomy and tested before being authorized to make identifications at sea since poor identifications cannot be verified later and could seriously undermine an EMS. Protocols should specify and name in a standard way any restricted identifications that are acceptable (eg. to genus or family level). Procedures should be described for estimating quantities of difficult-to-separate species, and for naming groups of unseparated mixed species. Catch samples for size- or age-related indicators are most easily drawn using the length strata created when the length frequency distribution is estimated. This should provide a reasonably constant coefficient of variation across the size groups, though higher sampling rates in the larger groups may be advisable for some indicators because of the wider range of ages among larger individuals.

5 WHICH INDICATORS?

Potentially, hundreds of indicators can be calculated from an EMS but presenting results for all of them to an EAF management committee could provoke confusion. The best selection will be linked to the high-level goals of the committee and the general and operational objectives (GOs and OOs) developed from them for each ecosystem component or unit of concern (Hobday *et al.*, 2007), as schematized in Figure 1.1, page 17. For example, management may wish to prioritize foodweb structure, protection of TEP species or, more pragmatically, to maintain the economic and social benefits of fisheries. These must be translated by scientists into OOs for each species or component of concern, then matched to informative indicators that can feasibly be monitored by an EMS or other means, and compared with performance criteria thought to signal successful management (Fletcher *et al.*, 2005, Anonymous, 2011).

This section of the report provides three different groupings of RV ecosystem indicators. The first is derived 'bottom-up' from the logical sequence of catch processing tasks on an RV, completion of which at every station will depend on resources of time and staff. The second and third are 'top-down' 'wish-lists' for monitoring the effects of fishing, and for monitoring and building up knowledge about the ecosystem generally. Managers of the EMS have the challenging role of selecting what is feasible from what is desirable.

5.1 Indicators from different levels of catch processing

The stage of catch processing that can be consistently achieved for each catching device deployed by an EMS may exert a strong influence on the number and types of indicator available. One scientist working on a small, lively trawler might be expected to produce species lists for every fished station and not much more, whereas a team of scientists on a large RV could produce species lists, length-frequency distributions, and several other biological indicators for a range of species from different catching devices. This subsection discusses feasibility and informativeness of catch-based indicators according to stages of catch processing. A sequence of catch processing varying by species according to priorities set by the EAF committee is schematized in Figure 5.1.

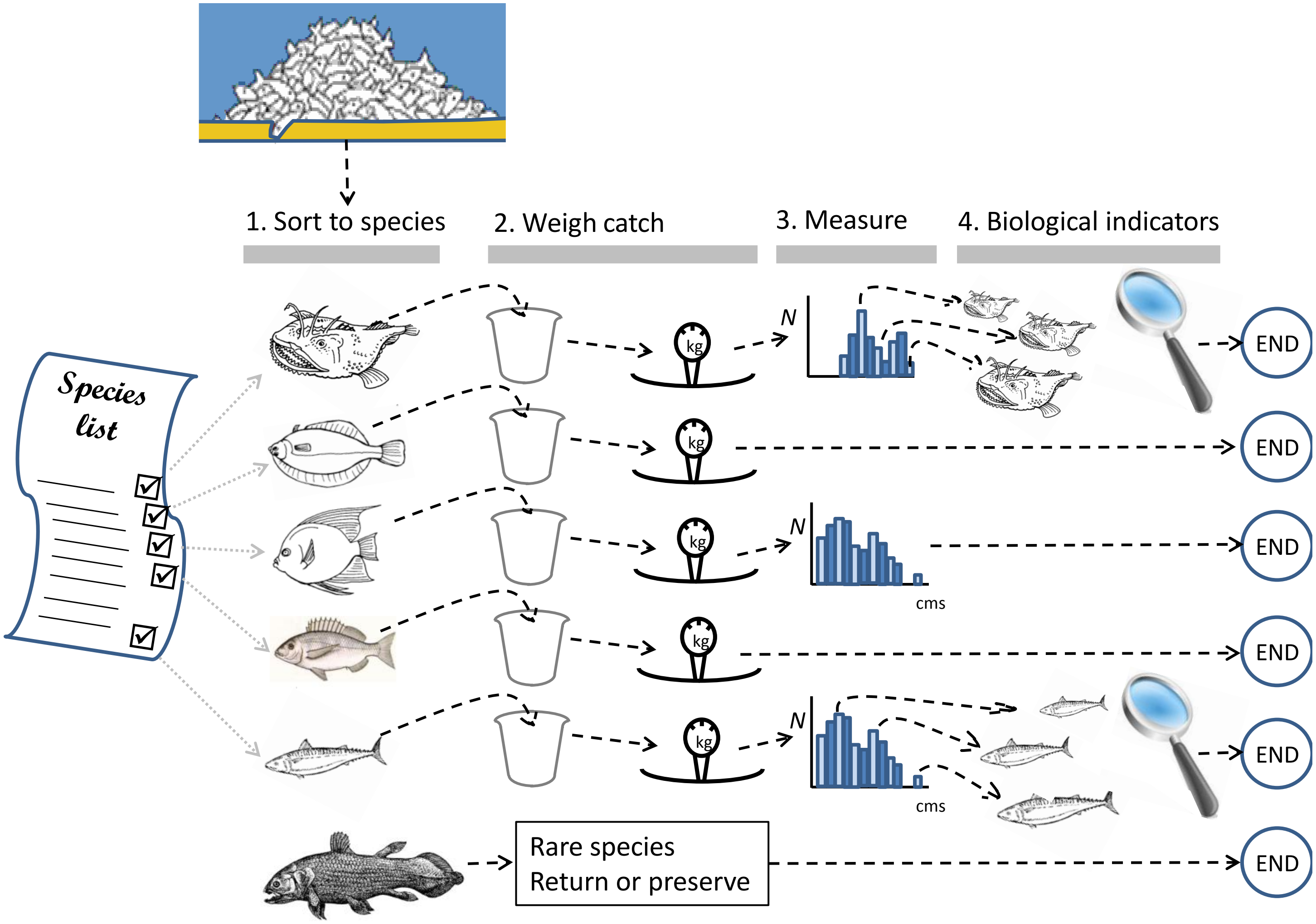


Figure 5.1 A suggested catch processing scheme in which species are identified if listed, all of them are weighed as total catch, some of the weighed species are measured, and some of the members of each length class are taken for other biological indicators (age, condition, maturity, etc.). Selections of species at each stage should be guided by priorities in the catch-sampling protocol for the catching device.

5.1.1 Indicators from species lists

The simplest processing of catches taken on an EMS should, at the least, provide lists of species found at each station fished. As discussed in section 4.2, the species might be ticked on a list intended to simplify identifications at sea, or they might include all species found and identified. For epibenthic and benthic samplers, the number of species found and the time taken to sort them depends strongly on the mesh size used to sieve the catches, e.g. 5 or 10 mm internally (Callaway *et al.*, 2002b), or finer for infaunal sampling using a grab (Schlacher and Wooldridge, 1996).

‘Occupancies’ (eg Cotter *et al.*, 2008, eg Patten and Smith-Patten, 2011) are a type of indicator estimable from species lists by station. The occupancy for a species within a region or stratum is defined as the proportion, *p*, of stations fished there where at least one individual of that species is found. Declining occupancies of a species over time may signal a regional extirpation problem, the seriousness of which will depend on whether the species domain is only partially overlapped, or fully enclosed by the survey domain (section 3.1). If the species has an important trophic role as, for example, some pelagic species do in ‘wasp-waist’ ecosystems (Bakun, 2006), declining occupancies may indicate a developing change in the food web. Increasing occupancies could indicate a stock recovery, an invasive species or, again, a changing foodweb. Either way, a clear change of a species’ occupancy is a signal worth investigating for causes such as commercial fishing, climate, etc. See

Figure 5.2 for examples of occupancy trends measured from the North Sea. Notice that the change of survey trawl type in 1992 did not strongly affect the series, suggesting an advantage of occupancies over CPUE data for assessing declining presence. Box 5.1 describes a Bayesian method for smoothing occupancies.

Occupancies can be developed into a multi-species indicator (Cotter *et al.*, 2008). To maximize sensitivity to changing presences of species, the measure should only be derived for species known to have been caught in the first few years of a survey, or at other times of plenty. The index, referred to here as the Bayesian occupancy index (BOI), for year *y* and for all $s = 1, \ldots, S$ included species is

$$BOI_y = \sum_s p_{y,s} \Big/ S \, .$$

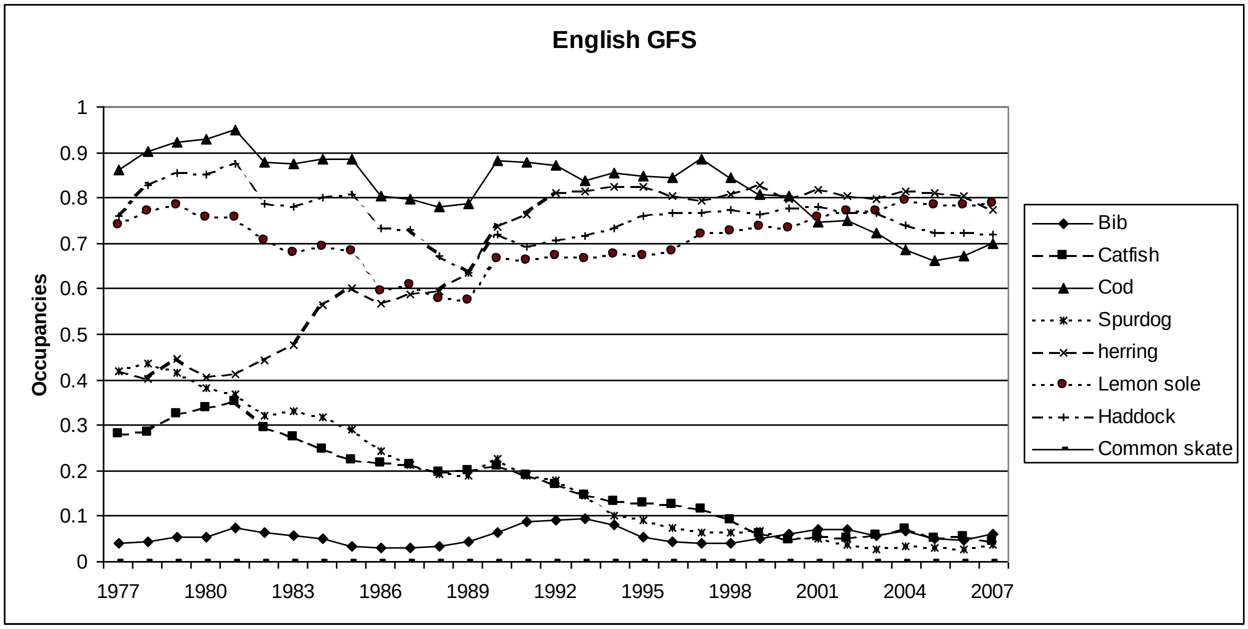
It decreases from 1 to 0 as species are found at fewer and fewer stations. Note that sporadic rarities have low $p_{y,s}$ and so have relatively little influence on changing values. Also, that species trending in different directions are confounded.

A survey-based indicator comparable in some ways to the BOI except that it is based on CPUEs is the threat indicator for marine fish (Dulvy *et al.*, 2006). It was designed for assessing extinction risk in relation to IUCN criteria. Dulvy et al (2006) estimated the threat index for a selected group of species with known vulnerabilities to fishing or other environmental factors. The same approach would aid interpretation of the BOI.

Related to occupancies is the spatial indicator called ‘positive area’ (Woillez *et al.,* 2009). The ‘area of influence’ around a station is the area made up of points in space that are closer to the station than to any others. The positive area is the sum of the presence at each station weighted by area of influence. Positive area can be plotted geographically and, for some applications, may be preferred to the occupancy.

Species richness (number of species) is another possible indicator for species lists produced by ecosystem surveys. However, it loses information about the geographic distributions of species, implying that it is less informative about changes to an ecosystem. Richness is, nevertheless, a widely used measure of biodiversity.

Figure 5.2. Occupancies (proportion of fished stations occupied) for selected, contrasting species caught by the English groundfish survey (EGFS) of the North Sea. The survey trawl changed from a Granton to a GOV from 1992. 75 to 80 stations were fished annually. Copy of figure 5.4.1c in (Cotter *et al.*, 2008, Defra, UK government).



Box 5.1. **Bayesian smoothing of occupancies**

Let n be the number of stations fished in year y, o the number occupied by a species, and a the balance where it was absent: $a = n - o$. Then $p = o/n$ is a random variable having the beta distribution:

$$beta\left(p \mid o,a\right) = \frac{\left(o+a-1\right)!}{\left(o-1\right)!\left(a-1\right)!} p^{o-1}\left(1-p\right)^{a-1} \quad \text{for} \begin{cases} 0 \le p \le 1 \\ 0 \le o \le n \end{cases}$$

It can serve as a 'prior' distribution for p in the next year, and becomes a 'posterior' distribution after next year's results have been analysed using the Bayesian equation. In this case, a beta prior with parameters o_y and a_y in year y gives rise to a beta posterior with parameters $\left(o_y + o_{y+1}\right)$ and $\left(a_y + a_{y+1}\right)$ having expectation $\frac{\left(o_y + o_{y+1}\right)}{\left(n_y + n_{y+1}\right)}$ (Schmitt, 1969). In other words, the number of stations at which the species occured and the number fished can simply be added over a fixed number of previous years to find the posterior distribution of p in the current year. A period of 4 years, as for a moving average, was selected for Figure 5.2 to give reasonable smoothing.

5.1.2 Indicators from quantified species lists

A second stage of processing a catch after identifying species is to estimate how much of each was taken, whether as a total number, volume, or weight. Quantities caught per unit effort (CPUE) have long been used as indicators of the population sizes of commercial species of fish, but caution is needed before relying on them for non-commercial species. CPUE indicators may show high variance arising from (section 6.1):

- poor catchability
- rarity of occurrence
- poorly known effort (eg. for a 'flying' epibenthic trawl), or from
- small area of overlap between the survey domain and the species domain.

CPUEs are usually measured as real values (eg. '3.7') but variance can be very high, leading to spiky time series. Log transformation reduces the deviance of high values and thus smooths CPUE time series. A constant must be added to allow logs of any zero CPUEs occurring. The size of the constant is arbitrary and affects the apparent variance of the log series. Zeros could be omitted by defining CPUE as ‘given that one or more fish were caught’ as for the mean-over-fish, section 3.4. Another solution would be to down-grade CPUEs from real values to ordered categorical values after division of catch by effort. Examples are ‘Lo, Med, Hi’, or logarithmic bins: ‘0 – 3’, ‘3.1 – 10’, ’10.1 – 30’, etc. Ordered categorical CPUEs are expected to show more stable regional averages than real-valued CPUEs because they smooth out exceptionally large values and high variance. However, results become dependent on the bin sizes used. Yet another smoothing technique for CPUE time series is Lotka’s intrinsic population growth rate, ie. the slope of the trend line fitted to a time series of log abundance indices. Advantages and disadvantages are discussed by Cotter et al. (2009).

Various spatial indicators, such as those listed in

Table 5.1 (Woillez *et al.*, 2009), may aid interpretation of CPUEs by analysis of variation spatially. By using them, responses to effects of fishing and other factors can be reduced to small sets of indicator values relating to specific aspects of the geographic distributions. Some spatial indicators are themselves amenable to multivariate analyses (e.g. Petitgas and Poulard, 2009). The tabulated spatial indicators are insensitive to zero values and thus are unaffected by stations outside the species domain. One, the global index of co-location, might be appropriate for measuring the spatial distinctness between the domain of a species and that of a fishery characterized by spatial effort data. This might help an assessment of the potential effect of the fishery on the species.

The main problem with CPUE time series in an EMS is that there are too many to interpret consistently. Multivariate statistical methods such as principle components analysis (PCA) (Jackson, 2003) may allow the number of time series to be reduced to only 2 or 3; most sampling variation will be found in the higher PCs. A more direct approach is to subset the CPUE series of different species *a priori* according to the responses they are expected to show to fishing or other factors of interest, as suggested by Dulvy et al. (2006) in connection with their threat indicator. This should improve the uniformity of responses, making results easier to interpret. Informative groupings might be related to direct effects of fishing, or to trophic roles eg. as top predators, planktotrophs, etc. Stable, interpretable groupings of CPUE series, each group revealing different aspects of ecosystem functioning, could serve conveniently to communicate key results from an RV ecosystem survey.

Modelling is another way of handling multiple CPUE series. A few examples from the many published are trophic models (Cury *et al.*, 2000, Christensen and Walters, 2004, Dunne and Williams, 2009), size-based models (Shin and Cury, 2004, Shin *et al.*, 2005, Pope *et al.*, 2006, Andersen and Pedersen, 2010, Barnes *et al.*, 2010), and benthic models (Hiddink *et al.*, 2006a). A general problem with such models, as for some multivariate analyses, is that pre-requisite assumptions may be difficult to defend in a compliance-monitoring situation, though they may be acceptable for research. Other comments on modelling real data can be found in section 6.3.4.

Multispecies CPUEs can be used for calculating diversity indices relating to communities. However, these summarizing statistics will be strongly affected by variable selectivities and catchabilities for different species (sections 6.1.1, 6.1.2), and they lose the links between stations and species' identities. They may therefore be poorly sensitive to effects of fishing or other factors. Multispecies CPUEs can also be used in conjunction with data on trophic level of each species to estimate the ‘marine trophic index’ (MTI) (Pauly and Watson, 2005) but investigations have not supported its use with RV surveys because of (i) the small range of trophic levels encountered by a single trawl type, (ii) the relatively small number of stations fished compared with commercial fisheries (for which the MTI was designed), and (iii) difficulties estimating trophic levels, some of which need substantial adjustments for fish size (Jennings *et al.*, 2002a, Cotter *et al.*, 2008, Branch *et al.*, 2010). Stable isotope analyses and size-based indicators appear to be better tools for investigating trophic relationships from RV surveys (eg. Jennings *et al.*, 2002b). The threat indicator of Dulvy et al. (2006) is another method for multispecies CPUEs. It estimates extinction risks.

Table 5.1. Various spatial indicators suitable for use with indicators formulated with catch per unit effort. Selected from table 1 of Woillez et al. (2009).

Spatial indicator	Measures
Centre of gravity	Mean location of a population
Inertia	Variance of the location of individuals
Anisotropy	Elongation of the species domain
Spatial patches	Patchiness at a large scale
Spreading area	Distribution in space taking into account density of populations
Equivalent area	The notional area of the species domain if all individuals were equally spaced apart.
Global index of co-location	Spatial distinctness of two species' domains

5.1.3 Indicators from size-measured species

After catches have been separated into species and quantified, the next level of processing is usually to measure and/or weigh individuals of each species. Populations of fish species subjected to commercial fishing pressures tend to show reduced proportions of large individuals because of their vulnerabilities and increased numbers of exposures to nets. Size – usually length – measures can therefore make useful indicators of fishing effects but not for all species, e.g. those living cryptically among rocks, or which tend to be discarded alive by fishers.

Benthic species have different sensitivities to fishing. A few species are known to be vulnerable, e.g. large clams and sea urchins are vulnerable to beam trawls. Attached structural fauna, e.g. sea pens, are vulnerable to most towed gears. On the other hand, many small mobile species are not directly vulnerable to fishing. Their sizes might be more influenced by mobility of sediments, food shortages, depth, etc. (Kaiser, 1998). For benthic species, therefore, prior assessment of vulnerability to fishing, or other factors of interest, is important before committing scarce shipboard resources to measuring their sizes. The vulnerabilities could be stored in the species database, proposed in section 3.1, on a ‘Hi, Med, Lo’ scale for each different type of commercial fishing in use in the ecosystem. See Table 3.1.

The average sizes of populations of many species are strongly influenced by recruitment of numerous, very-small individuals at certain times of year, as well as by fishing and growth. Length percentiles[8] estimated regionally can help to separate changes of recruitment, measured by L25, from changed numbers of older individuals, measured by L50, and changed numbers of large breeding individuals, measured by, say, L75 (suggestions of V. Trenkel) (Cotter *et al.*, 2009). In this way, the multi-dimensionality of a length-frequency distribution is reduced to three variables, making interpretation easier. For fished species, a small L25 implies good recruitment, while a small L75 may signal heavy fishing. L25s are expected to fluctuate from year to year, but L75s respond quickly to increased fishing, yet slowly to reduced fishing because L75s depend on growth of older fish. The weighting method used to estimate size quantiles – whether ‘over fish’ or ‘over stations’ – should be stated (section 3.4 and Box 3.1).

Length- or other size-based measures can be averaged over species caught on RV surveys to create ‘composite’ or ‘community’ indicators. One, the ‘ICES large fish’ indicator, estimates the weight of all species of fish over a cut-off length designed to minimize sensitivity to occasional high recruitment events (Anonymous, 2007b, Anonymous, 2007a). Another, the ‘proportionate length indicator’, transforms the lengths of all individuals to proportions of the maximum length for the species, thereby creating a common scale of measurement across species (Willis *et al.*, 1993). The two indicators are complementary. The first measures fish of any species weighted according to the numbers in the RV catches; the second measures large individuals of each species where each species gets the same statistical weight. The second also gauges reproductive capabilities of the species assemblage because of the finding from life-history studies that length at maturity is approximately 0.66 for teleosts and 0.73 for elasmobranchs of maximum length (Charnov, 1993, Jensen, 1997, Dulvy *et al.*, 2004). Example applications to results from North Sea RV surveys are shown in Figure 5.3. Clear declines can be seen in both indicators suggesting that they are responsive, presumably to fishing though this cannot be proven on that evidence alone. A third community length indicator calculable from RV surveys is the well-known size spectrum in which

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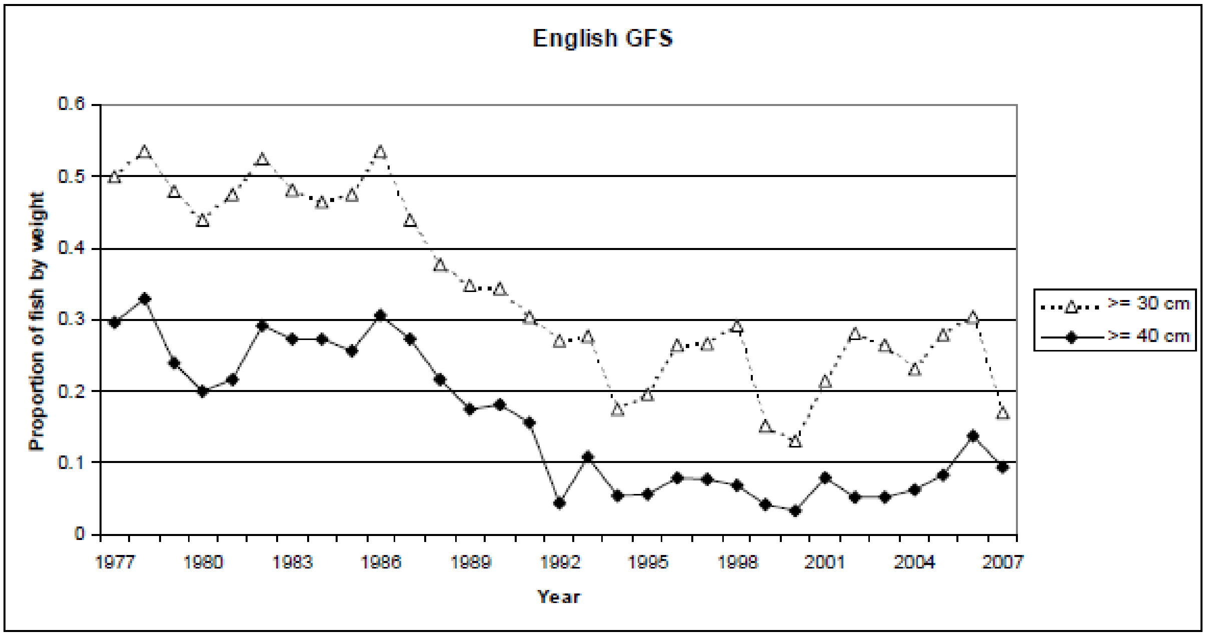
[8] Quantiles or percentiles mark proportions of a statistical distribution. Eg. 25% of a population are shorter than the 0.25 length quantile (= 25th percentile), and 75% are longer. The 0.5 quantile is called the ‘median’.

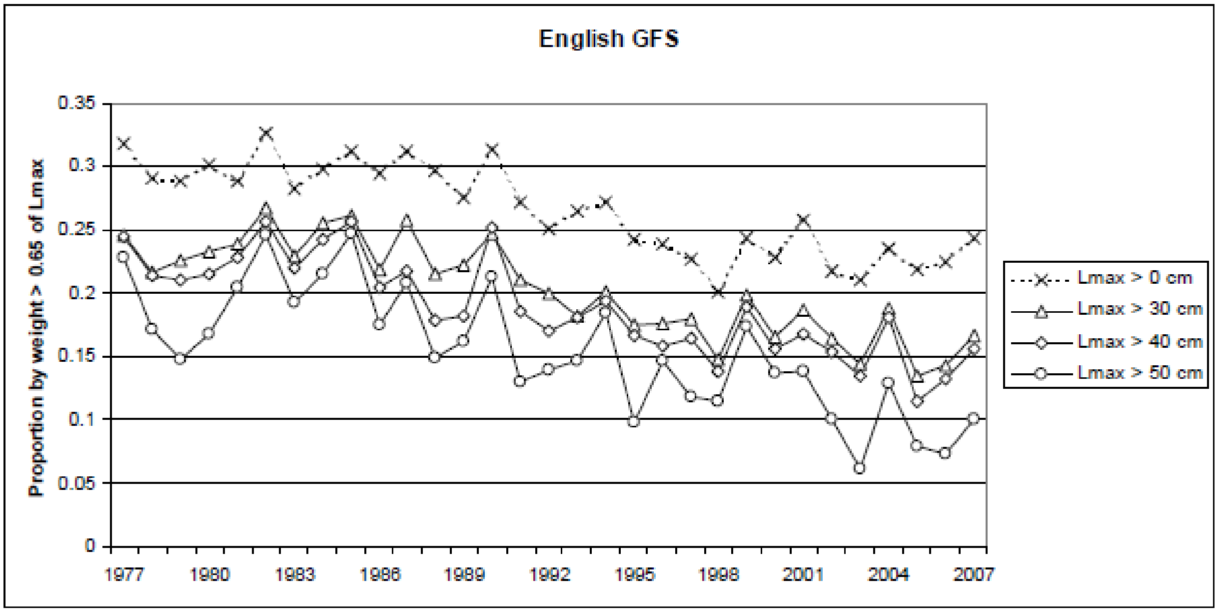
catches of all species are sorted into logarithmic length bins. Average CPUE tends to decline with length and with greater steepness for heavily fished communities (Bianchi *et al.*, 2000, Pope *et al.*, 2006). There are other community length indicators worth checking for applicability (Jennings and Dulvy, 2005).

Figure 5.3. Two length-based community indicators estimated from the English groundfish survey of the North Sea. Other details as in Figure 5.2. (a) The ICES (2007) indicator for the proportion by weight of individual fish of all species exceeding stated cut-off lengths. (b) Proportion of fish that exceed 0.65 of Lmax for the species having Lmax > stated lengths. Copies of figure 4.3.1c in (Cotter *et al.*, 2008, Defra, UK government).

(a)



(b)



5.1.4 Other biological indicators

When identification, quantification and measurement of a catch can be completed reliably for all required species at every station, opportunities exist for estimating other biological indicators although, since several are highly dependent on season, the EMS must be taking place in the correct season. Fish or other animals might be sampled from quantified species groups (section 0) or from the subsequently measured samples (section 5.1.3). Alternatively, whole groups could be used without sampling. If sampled, bias with respect to size can be avoided either by stratifying by size or by careful randomization (section 4.3). Sampling adds a component of variance to indicator values but may be essential if there are many species to process and/or the chosen biological measures are time-consuming to collect.

One informative biological measure is the weight of individuals of a species, obtainable if a sensitive, motion-compensated balance is on board. Weight-at-length or ‘condition’ can indicate recent environmental conditions for growth. Low condition may imply too much competition for available food and, perhaps, impaired reproductive capabilities (Shin *et al.*, 2005, Cotter *et al.*, 2009). Key species of an ecosystem that are affected in this way would be worth investigating further, if possible, since there may be an ecological link with fishing. Condition appears to be easier to monitor than growth which would either require repeated surveys to sample clearly identifiable year classes in the length frequency distribution, or tagging and weighing of individuals.

Age is only obtainable for some species caught on an EMS, though study of otoliths can addtionally reveal information about stocks and migrations (Campana, 2005). Removal of otoliths, scales, or other age-marked parts is a quick job for several species, but reading them requires time, skill and, for many non-commercial species, some preliminary research to verify that visible rings do indeed mark years or seasons. High demands for age reading could significantly delay publication of results from an RV survey, so reasons for measuring many ages should be sound. Size-, weight-, and maturity-at-age are all potentially informative indicators of how a species is faring. Relationships discovered with year classes may indicate density-dependent effects on growth and reproduction.

Reproductive indicators measurable with RV surveys include indices of spawner abundance (‘SSN’) and biomass (‘SSB’); gonadosomatic index (GSI), and length- or age-at-maturity. GSI, meaning gonad weight as a proportion of body weight, is the most sensitive to timing of the survey relative to the spawning season of each species (Cotter *et al.*, 2009) and therefore may only be warranted for high-priority species meriting a specially-scheduled survey. SSN, SSB, and length- or age-at-maturity should only be assessed when maturing of the gonad is clearly in evidence, usually in the months just before breeding. Maturity of older individuals is usually easiest to assess, though maturity staging in general, especially for non-commercial species, can be problematic especially when different numbers of stages are defined by different authorities. Scientists making maturity assessments should be trained, as for taxonomy. Age-at-maturity has been reported to decrease in response to fishing, and young fish have been found to produce less viable eggs with shorter spawning periods than older fish of some species (Trippel, 1995, Rochet *et al.*, 2000, Trippel, 2003). Length-at-maturity can be related to length quantiles to indicate the proportion of breeding adults in a population. These findings support the relevance of reproductive indicators for EAF if they can be measured on an an appropriately timed RV ecosystem survey. For further discussion of reproductive indicators, see Kjesbu et al. (2003) and Witthames and Marshall (2008).

5.1.5 Conclusions

Selection of ecosystem indicators may have to allow for the gears being fished and practical constraints on RV ecosystem surveys. Depending on facilities on board, catch processing generally involves firstly, species identification, then quantification, then length measurements and, finally, additional sampling for biological measures. Catch-based indicators can be graded to correspond to these different levels of processing, and it does not necessarily follow that, because an EMS must use only a small RV with small numbers of scientific crew, little useful information will be derived from it.

Indicators for species lists include occupancies, spatial positive area, and the Bayesian occupancy index (BOI). They appear to be particularly suitable for rare and poorly catchable species. Species richness and diversity are not recommended as ecosystem indicators for monitoring because they delete spatial information. Indicators for species whose total catch has been quantified by weighing or counting are mostly CPUE-based though, for many non-commercial species, CPUEs are likely to be poorly measured because of poor catchabilities and other reasons. *A priori* groupings of species by expected sensitivities to fishing or other factors is important for reducing the number of potentially confusing trends when examining CPUE time series. Intrinsic population growth rate, spatial indicators, and multivariate techniques can smooth them and reduce their dimensionality. The threat index assesses extinction risk from survey CPUEs. Modelling may also play a role providing that pre-requisite assumptions are acceptable for formal monitoring purposes. Indicators not recommended for RV CPUE series are richness, diversity, and mean trophic level.

Quantiles are recommended as indicators for species whose sizes – usually lengths – have been measured. The L25, L50, and L75 (or other) quantiles can be used to reduce the multi-dimensionality of length-frequency distributions while still distinguishing abundant recruiting classes from newly mature animals and older broodstock. Size may not be worth measuring for species not subjected to size-selection by commercial fishing gear. Sizes can be used to create composite community indicators that have been shown to vary over time, probably as a result of fishing.

Indicators of biological functioning tend to be highly vulnerable to bias from the season of the survey, and are sensitive to unintentionally size-selective sampling of catches. Weight-at-length or bodily condition can indicate growing conditions and perhaps density-dependent effects of strong year classes. Poor condition is of concern because it implies poor reproductive capabilities. Age determinations require time, skill, and verification, and could delay publication of RV survey results. Reproductive indicators like SSN and SSB should only be assessed by RV surveys occurring in the months just before spawning. Other reproductive indicators like GSI are even more sensitive to season. Length- or age-at-maturity is useful for estimating breeding proportions in a population and thus may be useful indicators of the long-term security of a species.

A summary of a suggested 4-level hierarchy of catch measures for demersal trawling with different RV resources is shown in Table 5.2. It ranges from identifying and quantifying a standard list of species as the first priority, to measuring all species and disecting some of them for age- and maturity-related indicators. A summary of a suggested hierarchy for epibenthic beam trawling or dredging is shown in Table 5.3. A hierarchy of feasible infaunal sampling could also look like Table 5.3 but with smaller mesh sizes, e.g. 2 and 1 mm instead of 10 and 5 mm.

Table 5.2. Suggested hierarchy of sampling using a demersal fishing trawl on an ecosystem survey depending on resources offered by the research vessel (RV). Catch sampling may be necessary for large catches at any level. FV = chartered commercial fishing vessel. PBRV = purpose-built RV. 'List' is from a formal protocol. List A has more species than list B.

Level	RV resources	Expected sampling
1	Small FV; 1 or 2 scientists	Demersal fish: list-A species sorted and quantified by volume or counting
2	Medium fishing vessel; 2 scientists	As (1) + rarities identified or preserved
3	Medium/large vessel; good sorting facilities; 2+ scientists	As (2) + list-A species counted and measured for lengths
4	Large trawler or PBRV; good sorting facilities, 4+ scientists	As (3) + list-B species disected for age, maturity, etc.

Table 5.3. Suggested hierarchy of feasible sampling using an epibenthic beam trawl on an ecosystem survey depending on resources offered by the research vessel (RV). For infaunal sampling using a grab, substitute smaller sieve mesh sizes, e.g. 2 and 1 mm. Other details as for table 5.2. See Callaway et al. (2002b).

Level	RV resources	Expected sampling
1	10-mm sieve; poor sorting facilities; 1 epibenthic scientist	Epibenthos; list-A species sorted and quantified approximately (eg. 1 – 9, 10 – 99, 100 – 999 individuals, etc.)
2	10-mm sieve; good sorting facilities; 1 epibenthic scientist	As (1) + rarities identified or preserved
3	5-mm sieve; good sorting facilities; 2 epibenthic scientists	As (2) + extra species on 5 mm sieve; more accurate counts if effort well measured
4	5-mm sieve; good sorting facilities, 2 epibenthic scientists	As (3) + list-B species measured or weighed

5.2 Indicators for monitoring effects of fishing

Table 5.4 is intended to assist the selection of indicators and groupings of sensitive ecosystem components for monitoring and managing the impacts of commercial fisheries. Several notes, linked by superscript numbers to entries in the table, are meant to amplify the abbreviated contents of the table. The term ‘parameter’ is used for naming properties of ecosystem components thought to have a true but unknown value for a population in an ecosystem at a given time. Then, by analogy with the same terms in Statistics, the indicator is an estimator for the parameter. Values of the indicator should be proportional to or, at least, show a monotonic relationship with values of the parameter. Sources of data other than RV surveys exist for calculation of several indicators. These are noted in the last column of the table but without any assessment of their relative merits; they would depend on local circumstances.

Table 5.4 was prepared from the output of the FAO expert committee referred to in the Acknowledgements.

Table 5.4 (3 panels below). Options for monitoring the impacts of fishing on aquatic ecosystems. Those marked ^{S} require that monitoring be carried out in the correct season. Table prepared by FAO expert committee, 29-31 August 2011.

Abbreviations: A = age; ADCP = Acoustic Doppler current profiler; AFD = age frequency distribution; AUV = autonomous underwater vehicle; B = biomass (total, or spawners only); CPUE = catch per unit effort; CTD = conductivity, temperature, depth; EIA = environmental impact assessment; Est. = estimated; L50 = median length; LFD = length frequency distribution; MBES = multi-beam echosounder; N = abundance; nm = nautical mile; RV = research vessel; spp. = species (plural); SSB = spawning stock biomass; T = temperature; VMS = vessel monitoring system (for locating commercial fishing vessels).

Superscript-numbered notes:

1. 'Ecosystem components' are intended as widely understood groupings of the essential parts of an ecosystem. Previous use was by Hobday et al. (2007).
2. 'Parameter' refers to the true – usually unknown – variable or value in the ecosystem.
3. 'Estimator or indicator' refers to a variable thought to show a proportional or monotonic functional relationship to the parameter.
4. It is assumed that appropriate davits/gantries, winches, and sorting facilities are available as a minimum on the RV.
5. 'Alternative data sources' refers to sources other than RVs. Fishery-independent alternatives include platforms, satellites, AUVs. Fishery-dependent alternatives are those associated with commercial fishing.
6. Sustainable populations must include a sufficient proportion of individuals large enough to be capable of breeding.
7. Spatial indicators not sensitive to zero values are defined by Woillez et al. (2009).
8. 'Observer' here means a person observing fishing on a commercial fishing vessel at sea.
9. The 'Operational objectives' column found in Table 5.4 has been omitted from Table 5.5.
10. An 'occupancy' is the proportion of fished stations occupied by at least one individual of a species.
11. Size structures, weights, abundances, and occupancies[10] depend on accurate effort measures and size selectivities.
12. Total particulate matter (TPM) = inorganic matter, particulate inorganic matter (PIM) + particulate organic matter (POM). They can be measured fairly easily but separating the living component is difficult.
13. Seabird surveys from RVs: recent references are by Clarke et al. (2003), and Hyrenbach et al. (2007). See also Tasker et al. (1984).
14. Distance sampling surveys for mammals and seabirds: recent references are by Thomas et al. (2004), and Buckland et al. (2004)
15. Habitat sampling: a recent reference is by Kenny et al. (2003).
16. Genetics: a recent European research project is presented at http://fishpoptrace.jrc.ec.europa.eu/ .

Table 5.4 panel 1. See notes and abbreviations above

Monitoring impacts of fishing

Ecosystem component[1]	**Operational objective**	**Parameter[2]**	**Estimator or indicator[3]**	**RV survey data or method**	**At-sea equipment & procedures[4]**	**Alternative data sources[5]**
'Fish' including target species, bycatch, and other bony fish, sharks, skates, rays	Maintain stock biomass at sustainable levels, eg. B_{MSY} or SSB > preset levels	Total biomass of population	Estimate or index of biomass	Density (N or B.area^{-1}) collected through: - CPUE[11] - Echo-integration - Egg production[S], mainly pelagic spp.	CPUE: Standardized sampling (eg. fishing) gear and gear monitoring, measuring boards, motion-compensated scales, otolith collecting Echo-integration: Acoustic equipment Midwater trawl Egg production: Standardized plankton sampler and midwater trawl, Maturity-staging tables	Catch and effort data from commercial fisheries
		Length/weight /age structure of population[6]	Sampled frequency distributions, quantiles, eg. L25, L50, L75)	Length / weight/age measurement of RV catches[11]	As for CPUEs, above	Sampled frequency distributions & quantiles from commercial catches
		Reproductive ability	Maturity ogive SSB	Maturity[S] at length or at age in RV catches	As for CPUEs, above Maturity staging tables	Port and observer[8] catch sampling[S]
		Spatial-temporal distribution	Spatial densities Spatial variation of LFDs, AFDs Centre of gravity inertia, etc.[7] Average CPUE	Station-based point estimates of density (N, N-at-A, N-at-L)[11] - CPUE - Acoustic	As for CPUEs or Echo-integration, above	In some cases, from combining observer+ Vessel Monitoring System (VMS) data

Table 5.4, panel 2. See notes and abbreviations above

Monitoring impacts of fishing

Ecosystem component[1]	**Operational objective**	**Parameter[2]**	**Estimator or indicator[3]**	**RV survey data or method**	**At-sea equipment & procedures[4]**	**Alternative data sources[5]**
'Fish' (continued)	Maintain genetic integrity and diversity	Stock structure	Degree of genetic isolation[16]	Samples collected following standard genetic protocols	See note[16] for protocols	Samples collected following standard genetic protocols
Threatened spp. (sea birds, mammals, etc.)	Minimize fisheries impacts on these species	Distribution (by species) Abundance(by species)	Sightings.nm^{-1} Sightings.region^{-1} Occupancies[10,11]	Sightings[13,14] Catches Photo identification	Observation post Binoculars Camera Identification guides	For some species: - Aerial surveys - Shore-based surveys of colonies - Observers on commercial vessels
Habitat (sea floor integrity)	Minimize adverse impacts on benthic habitats	Habitat/Biotopes sediment particle size Geomorphology Topography, depth Hydrographic features (T,S,O, currents) Habitat stability Benthos structure and function	Classification and mapping (biotic and abiotic) [15] Mapping of reference sites	Acoustic bottom backscatter, Sediment and biota sampling (macro, mega, info-, epi- in-fauna, motile, sessile), rapid assessments	Acoustic mapping: - Echosounders (preferably multi-beam, MBES) - Underwater video - Side-scan sonar Groundtruthing: - Grabs (mainly for infauna) ; Corer - Epibenthic trawl - Dredges	Geological surveys, Hydrographic surveys, Free international hydrographic databases World Ocean Atlas EIA by industries Biological traits

Table 5.4, panel 3. See notes and abbreviations above

Monitoring impacts of fishing

Ecosystem component[1]	Operational objective	Parameter[2]	Estimator or indicator[3]	RV survey data or method	At-sea equipment & procedures[4]	Alternative data sources[5]
Ecosystem structure & function (food web)	Maintain ecosystem structure and functioning Ecosystem services	Abundance/biomass of key species, eg. for predator-prey relationships	Ecosystem modeling Diversity measures ABC curves Size spectra	Seasonal estimates of primary production^S Stomach content analyses Stable isotopes	As for ‘fish’, above See also plankton sampling, below	Large fish abundance indicator from commercial landings Remote sensing of chlorophyll by satellite^S

5.3 Indicators for monitoring the ecosystem

Table 5.5 is intended to assist growth of understanding of the ecosystem being fished, given an initial characterization based on available knowledge (section 2.2). Improved understanding may point to better fishing strategies for sustainability and improved yields, and to better management policies and indicators. Operational objectives are omitted from the table because managerial decisions are not expected in direct response to improving knowledge. Many ideas are listed. They are meant to be options; monitoring all of them would not just require a large RV and crew but also much time at sea at different seasons. Notes to the table are as for Table 5.4.

Table 5.5 was prepared from the output of the FAO expert committee referred to in the Acknowledgements.

Table 5.5 (6 panels below). Options for monitoring aquatic ecosystems, given an initial characterization of the system based on available knowledge. Those marked ^{S} require that monitoring be carried out in the correct season. For abbreviations and superscript-numbered notes, please refer back to **Table 5.4**. Table prepared by FAO expert committee, 29-31 August 2011.

Ecosystem monitoring[9]					
Ecosystem component[1]	**Parameter**[2]	**Estimator or indicator**[3]	**Research survey data or method**	**At-sea equipment & procedures**[4]	**Alternative data sources**[5]
Water	Physico-chemical properties (T, conductivity, O_2, transmission, pH)	Measures of CTD, O_2, light transmission, pH	Piped, under-way systems Dip stations Water-bottle stations Towed undulators	Thermosalinographs Multi-function dip devices (eg CTD carousels) Sampling bottle systems Secchi discs	Hydrographic surveys Free international hydrographic databases World Ocean Atlas EIA by industries Satellites Deployed moorings AUVs
	Nutrients (N,P, Si, micro-nutrients)	Nutrients (N,P, Si, micro-nutrients) ^{S}	Water bottles Piped under-way systems	Water bottles	Some hydrographic surveys
	Water mass distribution	T-S profiles	CTD stations; Underwater undulating samplers	Hydrographic CTD (accurate to 3 decimal places)	Hydrographic surveys Free international hydrographic databases, World Ocean Atlas
	Currents and circulation	Eulerian & Lagrangian measures of velocity	ADCP, Seabed drifters	ADCP, Seabed drifters, Current-meter moorings	Hydrographic surveys Current-meter moorings, Free international hydrographic databases, World Ocean Atlas Models

Table 5.5, panel 2. See abbreviations and notes under table 1 above

Ecosystem monitoring[9]					
Ecosystem component[1]	**Parameter**[2]	**Estimator or indicator**[3]	**Research survey data or method**	**At-sea equipment & procedures**[4]	**Alternative data sources**[5]
Sea bed	Habitat/biotopes: Sediment charac-teristics, eg. particle size, organic matter, carbonate Geomorphology, Topography, depth Hydrographic features eg. T,S,O, currents, Habitat stability Benthos structure, function	Classification and mapping (biotic and abiotic), Mapping of reference sites	Acoustic bottom backscatter, Sediment and biota sampling (macro, mega, info-, epi- infauna, motile, sessile)[11], rapid assessments	Habitat classification and mapping: Acoustic mapping: - Echosounders (preferably MBES) - Underwater video - Side-scan sonar Groundtruthing: - Grabs; Corer - Epibenthic trawl - Dredges	Geological surveys, Hydrographic surveys Free international hydrographic databases, World Ocean Atlas, EIA by industries, Biological traits
Benthic fauna	Biomass by taxonomic categories	Infauna, epifauna weighings (dry, wet, organic)	Grabbing, Coring, Benthic trawling and dredging[11]	Grabs, corers, trawls, dredges, sledges Sorting facilities on deck Standardized sieves Motion-comp. balances	None
	Community structure	Abundances, Diversity Size structures	Results from grabbing, coring, benthic trawling/dredging[11] Visual/video	Grabs, corers, trawls, dredges, photographic sledges, TV sledges; Sorting facilities on deck Standardized sieves	None
	Production	O_2 consumption of cores [S]	Experiments on deck; Biomass results; Benthic lander systems	Corers, respirometric system Benthic lander systems	From biomass/production ratios
	Population dynamics for key species	Age, size compo-sitions; Abundances, recruitments	Age and size compositions[11]; Abundances[11]	Various age-ing and measuring equipment depending on species	Landings data for commercial spp.

Table 5.5, panel 3. See abbreviations and notes under table 1 above

Ecosystem monitoring[9]					
Ecosystem component[1]	**Parameter**[2]	**Estimator or indicator**[3]	**RV survey data or method**	**Alternative data sources**[5]	**At-sea equipment & procedures**[4]
Plankton	Biomass of phytoplankton, Phytoplankton production, Species composition, Vertical and spatial distribution	Biomass ^{S}: - Chlorophyll a - Derived from biomass, POC Production ^{S}: - *In situ* or simulated *in situ* incubations Species composition: - Counts - Spectral composition /colour	Measures from water bottles Fluorescence measures In situ light levels	Remote sensing satellites, Meteorological information, Continuous Plankton Recorder (CPR)	Water bottles, Fluorescence meter, Incubation facilities, Microscopes, Optical plankton counters, Towed optical systems, Analytical flow cytometer (AFC)
	Biomasses of zooplankton (categorized as micro, meso, macro, gelatinous)	Biomass ^{S}: - Wet & dry weights by category/sizes Production and population dynamics for key spp ^{S}: - Rate measures (eg. egg production, moulting, metabolism) Species composition: - Size spectrum - Taxonomy - Functional groupings	Measures from water bottles, plankton nets, Optical systems, Acoustic systems, Stomach analyses of zooplankton grazers, eg. small pelagics	Coastal and moored plankton stations Continuous Plankton Recorder (CPR)	Water bottles, Plankton nets, Optical systems, Acoustic systems, Microscopes, Towed optical systems, Continuous under-way fish egg sampler

Table 5.5, panel 4. See abbreviations and notes under table 1 above

Ecosystem monitoring[9]					
Ecosystem component[1]	**Parameter**[2]	**Estimator or indicator**[3]	**RV survey data or method**	**At-sea equipment & procedures**[4]	**Alternative data sources**[5]
Plankton continued	Biomass of organic particulates excluding living zoo and phytoplankton (so far as can be separated)[12 S]	Particulate organic carbon (POC) Particulate organic matter (POM) Particle size spectrum of organic fraction Dried and ash-free weight	Mainly collected from water bottles.	Filtration and weighing in a laboratory	Coastal and moored plankton stations
	Mass of inorganic particulates[12]	Ash weight Size spectrum	Mainly collected from water bottles.	Filtration and weighing in a laboratory	Coastal and moored plankton stations
Demersal and pelagic fish, crustaceans (non-burying), and cephalopods	Total biomass	Estimated biomass	Density (N or B/unit area) collected through: - CPUE[11] - Echo-integration - Egg production, mainly pelagic spp.	CPUE: As in table above for CPUE Echo-integration: Acoustic equipment Midwater trawl Egg production: Standardized plankton sampler and midwater trawl, Maturity-staging tables	Catch and effort data from commercial fisheries Aerial surveys, Visual surveys
	Length/weight/age structure	L/W/A frequencies, quantiles	Est. L/W/A frequencies, quantiles from catches[11]	Measuring boards, Otolith taking equipment Calipers Motion-compensated scales	Size compositions of landings Port and observer sampling

Table 5.5, panel 5. See abbreviations and notes under table 1 above

Ecosystem monitoring[9]

Ecosystem component[1]	Parameter[2]	Estimator or indicator[3]	RV survey data or method	At-sea equipment & procedures[4]	Alternative data sources[5]
Demersal and pelagic fish, crustaceans (non-burying), and cephalopods continued	Feeding	Diet (composition, total weight of stomach content)	Stomach sampling	Disection equipment, Microscope, Motion-comp. fine scales	None
	Reproductive ability	Est. SSB/ Maturity ogive [S], Length quantiles	Maturity [S] at length or at age in RV catches Histology Gonad, liver W	Measuring boards, Maturity-staging scales, Otolith collecting Fixatives Motion-comp. fine scales	Port and observer[8] sampling of commercial catches
	Spatial and temporal distribution	Spatial densities for N or B, Spatial variation of LFDs, AFDs Centre of gravity , inertia, etc.[7] Average CPUE	Point CPUE estimates of density (N, N-at-A, N-at-L)[11]	As for CPUE or Echo-integration, above	In some cases, from combining observer+VMS data Tagging
	Ecotoxicology	Concentrations in tissues	Tissue samples	Disection equipment Freezer storage	Port and observer[8] sampling of commercial catches
	Health/condition	Parasites Diseases Weight/length	Histopathology Visual inspections Condition factors [S]	Motion-compensated fine scales Microscope Measuring board	None
	Stock structure	Degree of genetic isolation[16]	Standardized genetic sampling	Freezer storage	Port and observer[8] sampling of commercial catches using standardized genetic protocols

Table 5.5, panel 6. See abbreviations and notes under table 1 above

Ecosystem monitoring[9]					
Ecosystem component[1]	**Parameter**[2]	**Estimator or indicator**[3]	**Research survey data or method**	**At-sea equipment & procedures**[4]	**Alternative data sources**[5]
Marine mammals, Reptiles, Sharks, large rays, Rare species IUCN Threatened, endangered or protected species (To be released as soon as possible)	Abundance	Sightings	N per time, or distance, or area[14] Occupancies[10,11] Photo identification Passive acoustics (mostly mammals)	Observation post Binoculars Camera Taxonomic guide Hydrophones	Arial surveys Shore-based surveys Passive acoustic buoys Scientific catch surveys Tagging Seal scat collection and analysis
Seabirds	Abundance	N per unit area	Distance sampling[14] Strip sampling[13]	Observation post Binoculars Camera Taxonomic guide	Shore-based surveys of colonies

6 ANALYSIS OF BIOLOGICAL DATA FROM AN ECOSYSTEM SURVEY

Physical and chemical oceanographic measures made on an RV ecosystem monitoring survey (EMS) can be used for regional estimation of summarizing statistics (section 3.4) or they may be collected in a database for modelling of oceanic and planktonic processes (Fox and Aldridge, 2008). Groundfish surveys are typically analysed routinely by a fish stock working group considering one species at a time. By contrast, the scope for statistical estimation and modelling of biological data obtained from EMSs is wide, with no concensus yet available on what a routine analysis might involve.

This section discusses the special problems of analysis posed by biological data derived from EMSs. Firstly, practical and theoretical constraints on analyses are listed and ways forward suggested. Secondly, statistical and modelling methods are very briefly discussed in relation to different types of data, eg. presence-absence, ranked, real-valued. Monitoring of the habitat and community components raises special issues that are discussed in two separate, additional sections.

6.1 Practical constraints on data analysis

This section lists some constraints on EMS data analysis posed by practical aspects of a survey.

6.1.1 Variable selectivities

Each catching gear in use on an EMS will exhibit different selectivities by size for different species. Consequently, many indicators must be tied specifically to one type of catching gear so that size-selectivity effects are constant, eg.

- Multi-species indicators such as diversity and community measures
- Size- and age-based indicators such as length-frequency distributions
- Abundances that are greatly increased by small individuals.

Concerning the selectivity of trawls, large individuals that do not pass through the mesh are often assumed to be 100% selected. However, the assumption may be invalid for species for which a trawl was not designed, that habitually swim above the headline or below the footrope, or that are strong enough to swim in front of the trawl. Some species are herded by a trawl, some not, a factor that further affects selectivities. Other towed fishing gear can also exhibit size selectivity additional to that of the mesh of the netting. The gear used to derive measured values that might be responsive to size selectivity should always be stated. A few ecological measures may be relatively independent of size-selectivity, eg. age-at-length, and maturity-at-age.

6.1.2 Low catchabilities

A species that is rarely seen on an EMS is either scarce or it is poorly caught. A low rate of occurrence increases CVs of estimated numbers (Cochran, 1977). Knowledge of low catchability therefore forewarns of a high CV for abundance-related indices such as CPUEs, and this knowledge may be as reliable or more so than CVs estimated by formula from occasional occurrences in catches. Relatively large catches taken at any time in the past suggest good catchability while, if *all* catches were small, poor catchability is likely, especially if the species is known from other information to be common in the ecosystem. Catchabilites of species by different gears can be stored as 'Lo, Med, Hi' in the species database suggested earlier. See section 3.1 and Table 3.1.

6.1.3 Effort dependence

Many measures made on a catch depend strongly on the effort applied to catch it. Effort is relatively well measured for some catching devices, e.g. heavy demersal trawls, but poorly for others, e.g. light epibenthic beam trawls, and grabs taking variably sized bites of sediment. Measures that depend on effort include:

- CPUEs, abundances and biomasses, including zero values
- Occupancies (section 5.1.1)
- Species lists and diversity indices

Qualitative measures, such as length frequency distributions, fish weight, and maturity-at-age, may be relatively independent of effort, though size selectivity remains an issue (section 6.1.1).

6.1.4 Low overlap of survey and species domains

A survey domain may enclose, partially overlap, or exclude a species domain. Bias and extra sampling variance can arise when there is only partial overlap, or there are only a few stations within the species domain, as discussed already in connection with choosing the survey domain (section 3.1).

6.1.5 Shoaling and clustering

Many fish species, notably pelagics, swim clustered together as shoals. Clustering of benthic species is also observed, sometimes as a result of localized spatfall. Patchiness of plankton is well-known and amounts to another type of clustering. Clustered species tend to be caught in large numbers or not at all, depending on whether the cluster is clipped by the catching device or not. Real-valued CPUEs estimated from such results usually have very high error variances and should not be used in data analyses. Better is to use presence-absence of a 'shoal' (or 'cluster') defined as > *N* fish (or benthic species) caught. Acoustic methods are generally better than CPUEs for estimating abundances of shoaling fish species (Simmonds and MacLennan, 2005).

6.1.6 Contracting species domains

Many species abandon unfavourable or marginal habitats as population sizes decrease, causing contraction of their species domains. Depending on the configuration of survey stations, sampling bias and variance may increase substantially as a result. Grids are worst in this respect because species have more opportunity to dwell in small habitations between lines of stations. Randomized configurations remain unbiased but variance increases because of decreasing numbers of occupied stations. If the species has high priority, re-stratification of the survey may be worthwhile.

6.1.7 Outliers and mistakes

Common occurrences on surveys at sea are unusually high or low measurements and sundry mistakes made by scientific crew members, often working under difficult conditions. Mistakes would sometimes be distinguishable if a comment box were supplied on data sheets so as to encourage the scientist making the measures to acknowledge exceptional values when they have been noticed and verified so far as possible. If the comment box is not completed, the chances are good that an outlying value is an error. Human transcription errors can be found with a 2-person read-and-check system in which computer printouts are compared with original source data. Computer databases should be set up with automatic checks for acceptability of inputs, though these will seldom be infallible. Species codes should return the full name of the species together with a picture, if possible, before data are entered for that species. This is especially important on ecosystem surveys because of the many species dealt with and the many opportunities for muddles. Only raw data, not calculated values should be stored, and the database should be designed with full relational structure so that no data item is stored more than once. Apart from saving storage space and data-entry time, corrections, when necessary, only have to be made at one location in the database.

6.2 Theoretical constraints on data analysis

This section lists some constraints on EMS data analysis implied by statistical theory.

6.2.1 Clustered, not random sampling

Nets and grabs catch clusters of animals, not random samples from the ecosystem. The variance of measures on a species therefore decreases more in proportion to the number of independent stations sampled than to the number of animals found at them. This is illustrated in Figure 6.1. For discussion of this issue, see Pennington and Vølstad (1994) and Cotter (2009b).

Results for different species caught in the same nets are not independent but are multivariate vectors with associated correlation matrices. Thus high/low values of a measure for one species may typically be accompanied by high/low values of another; the possibilities for pre-determined relationships among species are extensive. Part of a relationship arises from a real relationship between two species in the ecosystem, and part from the catching method (section 6.2.4 below). Relationships discovered among different species can be examined from different parts of the survey domain, or from other surveys, to try to cast light on whether they are more real than method-related.

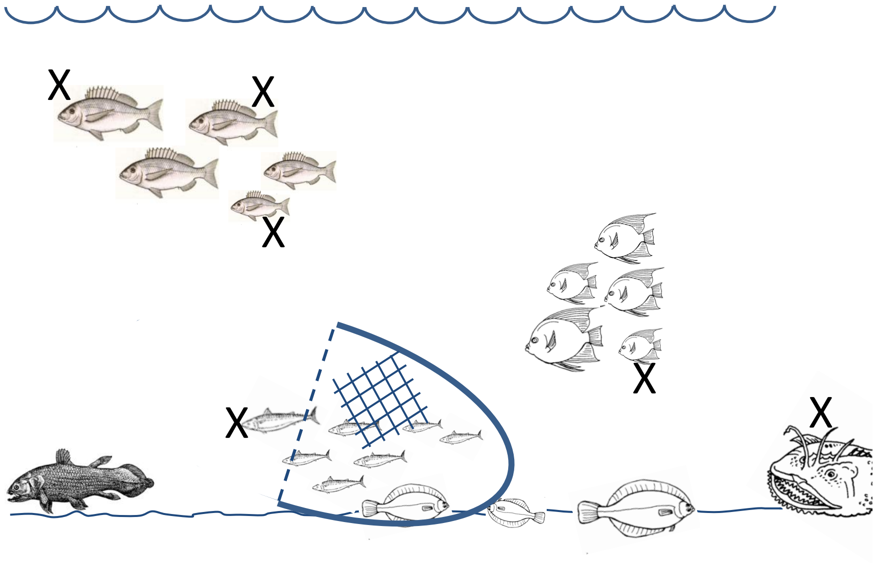


Figure 6.1. To illustrate that a sample set of fish caught in a net is clustered compared to a sample set picked with random co-ordinates, marked with Xs. Fish clipart from http://www.arthursclipart.org

6.2.2 Non-stationary variation

Spatial and temporal variation of biological, sedimentary, and hydrological variables is typically highly irregular in the sea with occasional extreme values. Consequently, assumptions of stationarity underlying many parametric statistical methods are unsafe, e.g. 'the mean and variance are constant'. Transformations of the data may give a good fit on one occasion but not another. Regional estimation of indicators with confidence limits (CLs) based on the central limit theorem, as discussed in section 3.4, does not depend on stationarity unless estimated values are later considered to apply outside the survey domain, a risky assumption.

6.2.3 Zero abundances

Ecological measures cannot be made at all stations if the right animals are not found there. Certain spatial indicators are not affected by zero values (Woillez *et al.*, 2009) and geographic distributions inferred from zero values can, by themselves, indicate declining fish stocks or climatic effects for example. The effects of zeros can be avoided by reporting indicator values 'given that the species was caught' along with the stations of capture, or as 'means-over-fish' which are estimates weighted by the numbers of fish caught (Cotter, 2009b). Zeros interfere with logarithmic transformation of real-valued measures intended to improve the validity of Gaussian (normal) approximations to the statistical distribution. An arbitrary constant can be added to zero values but analyses should be checked to see whether the Gaussian approximation is seriously affected by different choices of constant. A well-known, model-based approach to survey zeros is given by Pennington (1983). The treatment of zeros is often important and should be stated.

6.2.4 Covariances of signals and sampling errors

Variables measured by sampling on an EMS display variability for oceanographic or ecological reasons, as well as variability deriving from the chosen methods of sampling, measurement, and navigation. These are generally referred to as 'signal' and 'sampling errors' respectively. Covariance or correlation (= standardized covariance) occurs when variation in one variable tends to occur in association with variation in other. As a result, there is less information available from the two variables than if they were independent or, in other words, given results for one variable, those for the other can be predicted with precision depending on the degree of covariance.

Signal covariance arises

- Between quantitative or biological measures from different species because of shared influences of the ecosystem such as habitat, behaviour, feeding, climate, season, migrations, etc.
- Between different measures from one species because individuals share influences of genetic, physiological, and environmental factors.
- Between physical and chemical measures because of the heterogeneity of water and sediments; the closer the sampling points of two measures, the stronger the covariance tends to be.
- Between biological measures and physical and chemical measures.

Signal covariance is one way of measuring the true relationships among ecosystem variables. Ecosystem modellers estimate the relationships as mathematical functions.

Sampling covariance arises between different biological measures made on individuals taken from

- The same catch sample because of the manner of sampling the catch.
- The same catch because of its specific location and timing.
- The same catching device because of its specific selectivity properties and manner of deployment.
- The same cruise or survey repetition because of weather, crew, and any other influences on it.

Sampling covariance between physico-chemical measures arises from

- Sampling units collected at the same incorrect locations and times.
- Any analytical problems shared by the two measures.

Sampling covariance can distort the image of a signal provided by an EMS because sampling errors are linked to variation of the sampling errors for the other measure. Sampling covariance can also mislead by suggesting relationships between pairs of signals when the actual relationship is between the sampling errors. This problem can beguile into over-interpretation of EMSs and over-determined ecosystem models.

Covariance can also arise between signal and sampling error. An example would be when a large catch prompts use of a faulty catch-sampling procedure that consistently under- or over-estimates the quantity in the catch. Covariance of this type would cause exaggeration or damping of signals.

6.2.5 Covariances between stations

Measures made at one station depend on (= covary with) measures made at another when

- Animals from adjacent stations are pooled to increase sample sizes. Some age-length keys are compiled like this, causing numbers-at-age by station to become dependent and without necessarily benefitting precision (Cotter and Pilling, 2007).
- When stations are arrayed in a fixed-interval grid; positive serial correlation of results along the lines is likely to be found.
- When stations are randomly located in a regular lattice of strata (section 3.6); positive serial correlation would usually be less than for a fixed grid because of the randomly varying distances between stations.
- When sampling methods differ regionally for operational reasons or due to inadequate training of staff.

Independence of the results at each station means that each is providing information about the ecosystem not estimable from other stations. It is important for finding the correct degrees of freedom (= number of stations – number of fitted parameters) for estimating regional variances and covariances, for statistical tests relating to regional parameters, and for fitting models such as contours which require independent data points.

6.3 Quantitative methods for analysis of EMS results

A small selection of quantitative methods is presented below.

6.3.1 Presence-absence data

Binary presence-absence and occupancies (section 5.1.1) are useful for monitoring species whose abundance can only be measured with high sampling error, for example because

- catchability is low
- catching effort is poorly measured
- shoaling behaviour or clumped distributions occur
- the species is rare.

The idea is that the more abundant a species is within an ecosystem, the more stations it is likely to be found at, given that it is moderately rare.

To see why occupancies are useful for poorly caught species, suppose that a species is found at o out of n stations fished. Then, from the binomial distribution, the large-sample variance of the occupancy, $p = o/n$, is $\mathrm{var}(p) = pq/(n-1)$. It reduces to zero as the ‘true’ p decreases to zero. By contrast, the CV of the total abundance, a, of the species over all stations tends to infinity as $p \to 0$ (Cochran, 1977). p is therefore a much better measure than a for rare species. Occupancies can be estimated for each survey or stratum domain and plotted over time. A practical example showing their mostly low noise and responsiveness is in

Figure 5.2. The smoothed curves were derived from Bayesian ideas described in Box 5.1.

6.3.2 Ordered categorical data

Ecological measures in quantitative categories (e.g. ‘low’, ‘medium’, ‘high’; or ‘1 – 9’, ’10 – 99’, ‘100 – 999’, etc.) have more quantitative information than presence-absence but less than real-valued measures. These ordered categorical measures can be useful when real-valued measures are thought to suffer from substantial, possibly irregularly distributed sampling errors, e.g. because of bouncing trawls or variable corer volumes. Analysis and modelling of categorical measures is discussed in a general text by Agresti (1996).

6.3.3 Ranked data

The simplest way of dealing with real-valued ecological measures is with nonparametric statistics. They can be informative without reliance on strong assumptions, so they are most useful when variability is high and the data are not clearly distributed according to a standard distribution such as the Gaussian or lognormal distributions. The following notes are summarized from Cotter (2009a) where more references can be found. A sample set of real measures is first put into numerical order and ranks (1, 2, 3, . . . , N) are assigned.

The ordered measures can be summarized regionally using quantiles, usually the sample median, conventionally the middle value for odd n or the average of the two middle values for even n. Confidence limits are found using the binomial distribution. They get smaller as sample size increases, as for the Central Limit Theorem applied to the mean. The median is slightly smaller than the mean for skewed distributions such as the lognormal. It is less affected than the mean by occasional large values in samples and may therefore have tighter, binomial confidence limits than the mean has, based on the Central Limit Theorem. Quantiles can be interpreted in terms of areas or time periods. For example, an ecosystem survey domain can be split into two equal areas where measures are $\leq$ or $>$, respectively, the median value estimated from a cruise.

The median provides simple tests of trend in a time series with no assumptions about models, transformations, residuals, etc.. In one test, consecutive measures are differenced, e.g. at lag 1: $X_2 - X_1$, $X_3 - X_2$, etc.. Then the median of the differences is zero when there is no trend, and a significance test is provided by binomial confidence limits. A related median test is available for before-after studies, and for comparisons of one stratum with another.

Greater detail on trends are obtainable with statistical methods that make full use of data orderings. Kendall’s tau and Spearman’s rank correlation method test correlations between a measure and the times of measurement. Jonckheere’s method accommodates multiple observations at each time. The aligned-rank test and the Dietz-Killeen test are for multivariate indicators. This and other nonparametric tests find the probable direction of trends, up or down. Cochran’s Q tests whether all indicators are responding similarly over time, and the Runs test responds to serial correlation around a quantile or trend.

6.3.4 Real-valued measures

Real-valued measures, eg. ‘length 21.3 cm’, are typically analysed with parametric statistical methods. Transformations, such as taking logarithms, may be necessary to encourage conformity with standard statistical models such as the Gaussian distribution, or to improve the approximation to Gaussian provided by the Central Limit Theorem. All the same, regional medians may prove more stable and interpretable than regional means of transformed measures.

One of the main advantages of real-valued data is the opening up of modelling possibilities for understanding and utilizing the results of ecosystem surveys. Contouring of indicator values over stations is a general way of modelling. It can be carried out with various algorithms, e.g. Kriging, using Geographic Information System software (GIS). Different patterns of contours can be obtained with different algorithms, so residuals should be checked. References to specialized types of model are given in section 0. Multispecies modelling in a fisheries context is reviewed by Pinnegar et al. (2008). An ambitious, comprehensive, whole-ecosystem model, including socio-economic submodels, is called Atlantis. It has been applied to many fished marine ecosystems globally (Fulton *et al.*, 2011).

Fulton et al. (2011) advise on the benefits and constraints of ecosystem modelling. From a statistical viewpoint, the appeal of new predictions and insights must be balanced against the danger of building model structure more elaborately than can be supported by available data and knowledge. This is called over-determination or over-parameterization. It causes the model to become unstable when one or more inputs are changed slightly; the model may also over-emphasize the effects of trivial processes. Models can also be over-aggregated spatially, leading to excessively simplistic conclusions. Fulton et al. (2011), citing Box (1979), state that ‘the art of modelling is to represent a system in the simplest form consistent with realistically capturing its essential dynamics and behaviour’.

An important statistical aspect of monitoring indicators concerns whether they comply or not with limits or reference values. This is part of the large subject of Statistical Quality Control (SQC) (Montgomery, 2009). Marine ecosystem work appears to pose more challenges than the industrial processes for which SQC methods were developed because variances and covariances of indicators can be much more extreme, and time series tend to be short. The CUSUM method is particularly suited for real-valued ecological indicators; see Mesnil and Petitgas (2009) for applications to ecological indicators measured from trawl surveys. Making sense of many indicators moving in different directions is a further challenge. Petitgas (2009) discusses a simple approach to multivariate CUSUM charts. Numerous papers discuss applications of multivariate techniques more generally to marine ecological data. Though good for research, they may not be so effective for formally monitoring performance of ecosystem indicators because strong assumptions about statistical distributions and large sample sizes may not be tenable.

6.3.5 Analysis of habitat indicators

Many benthic habitats are vulnerable to fishing gear on account of their fragile physical structure. They may consist of soft mudbanks, reefs, or regions populated with attached epibenthic fauna. Structure of benthic habitats can be monitored using acoustic and video techniques (Kenny *et al.*, 2003) supported by epibenthic or infaunal sampling. The critical questions are

- Do the data collected signal a derioration in the habitat, no change, or an improvement?
- If a deterioration, is it linked with fishing or any other manageable factors?

A suggested way to deal with the first question is to break the sampling points or tracks into small quadrats and make an assessment in each using a cut-off value. For example, ‘structured habitat present in < 30% of a 10 x 10m quadrat = poor’. Quadrats should be located randomly so far as possible or, if points fall along a linear track, a lattice of sampling strata could be overlayed and a small number of points chosen randomly as sampling units from each square stratum. The lattice design was discussed in section 3.6. A binary categorization of quadrats into ‘poor’ or ‘good’ habitat could be assessed statistically over time as suggested above for occupancies by species. See section 5.1.1. Triple or higher categorization would require multinomial methods (Agresti, 1996).

The second question above might be dealt with by collecting commercial fishing-effort data by large scale quadrats, eg. longitude-latitude rectangles, possibly using data from vessel monitoring systems (VMS) (Eastwood *et al.*, 2008) . Comparisons between trawling effort and benthic communities in the same localities have been achieved by Rijnsdorp et al. (1998) and Zühlke et al. (2001). Annual assessments of fishing effects might be made by testing change-of-indicator with change-of-fishing-effort as pairs in each surveyed rectangle using a nonparametric test of independence such as Kendall's tau or Spearman's rank correlation (Hollander and Wolfe, 1973).

6.3.6 Community indicators

Ecosystems consist of communities of species having mutually supportive functional roles. Several community indicators have already been mentioned and it seems that there are few that make special demands for the time of an RV ecosystem survey because the indicators can be estimated from data already collected. Community size-based indicators like the proportion of large fish, the proportionate size, and size spectra were put forward in the discussion of size-based indicators. A community having a big proportion of large individuals will have the foodweb controlled by top predators, will support secure reproduction of many species and, more practically, will give protection to commercial fisheries against recruitment failures. Multi-species CPUE series may also be valuable as community indicators providing that they are amenable to interpretation. Subsetting into different functional groups would be beneficial for this, as discussed in section 0. Wide-scale plankton monitoring may also cast light on community responses (Longhurst *et al.*, 1995, Beaugrand, 2005). Other potentially informative community indicators are *k*-dominance curves (Lambshead *et al.*, 1983) which indicate whether one or two species are dominating a community, and ABC curves (Warwick, 1986) which indicate whether the dominant individuals are large- or small-bodied. Community indicators in second place for reasons discussed in section 5.1.1 are species richness, species diversity, and the marine trophic index.

6.4 Conclusions

Several theoretical and practical constraints should be considered when analysing EMS data. Many statistical and modelling methods are available for ecosystem measures of different types according to precision, eg. presence-absence, ordered categorical, ranked, and real-valued measures. Nonparametric statistical methods can be informative without making major assumptions about the data. Modelling methods open up more structural possibilities but make stronger assumptions and are dependent on the analyst identifying the model that represents the system in its simplest yet most realistic form.

Monitoring changes in the structure of habitats can be carried out by classifying habitat quality according to an arbitrary, but objective scale in randomized quadrats, or at random points in a lattice of quadrats; the proportion of quadrats showing damage provides an indicator of habitat change. When local-scale fishing effort is known, changes in habitat quality may be related to changes of fishing effort in each quadrat using a nonparametric correlation method.

Community indicators can mostly be calculated from abundance, size, and weight data collected by an ecosystem survey. Subsetting into different functional groups would assist interpretation of community indicators. The proportion of large fish, the proportionate size, size spectra, multi-species CPUE series, *k*-dominance and ABC curves, may all be valuable for indicating the health of marine communities using RV surveys. Useful wide-scale supplementary information may be available from satellite monitoring and continuous plankton recorder tows.

7 APPLYING EMS RESULTS FOR AN EAF MANAGEMENT

This section consists of notes on current issues for EAF fisheries management. Sometimes the EAF will represent a development of single-species management procedures, as widely carried out around the world. Resistance to new management policies suggested by the results of an EMS may ensue because of the perceived security and practical advantages of the previous single-species management system including, particularly, routine implementation and well understood input data. These two advantages could beneficially be carried over so far as possible when seeking to apply results of an EMS for the purposes of an EAF.

An EMS involves many species, indicators, and oceanographic measures. A significant risk from this diversity is that management advice derived from an EMS lacks the structure and dependability of single-species advice. There can also be issues of timing, quality control, and understanding with new forms of advice (Apostolaki *et al.*, 2008). The following features of an EMS are suggested to help win acceptance:

(1) The EMS should follow an annual routine, ie. it is primarily for monitoring, not for research unless special scientific work is requested and separately funded.

(2) The monitoring tasks, indicators, and performance measures should, if administratively possible, be agreed by all influential parties in advance of EMS surveys, taking into account national and international commitments to conservation, as well as RV resources and expense.

(3) The EMS should, so far as possible, supply the same body of results in the same format every year, mostly as time series or changing maps. Dependability, consistent presentations, careful descriptions of methods, and estimated levels of precision are all important for acceptability.

(4) Policy inferences should preferably be evident merely from graphic presentations of results with standardized statistical techniques used in a supporting role. Dependence on strong technical assumptions, *ad hoc* adjustments, and black box models could rapidly become obscure and distrusted when there are many species and indicators to deal with at an EAF committee.

(5) Any procedures for modifying input or output controls on fisheries based on EMS results from (4) should be agreed in advance, though they might be re-negotiated for future years to reflect improved understanding of the ecosystem. This links back to (2) and should help to prevent nasty surprises at EAF committee meetings. The agreed procedures will probably involve social and economic time series as well as those from an EMS, as is consistent with the EAF.

Concerning (5), two ways to convert EMS monitoring results into decisions about fishery controls are the reference point system, and ecological risk assessment for fisheries. In both cases, an EAF committee, starting from status quo fishing, would probably wish to turn its attention first to the most pressing issues gauged either by the reference points or the perceived risks. The following notes about the two systems are meant to be impartial.

Reference points can be set as point values which should preferably not be crossed, upwards or downwards as appropriate, by critical EMS time series. There may be two types, one a target, the other a limit (Caddy and Mahon, 1995). Either type will probably need subjective decisions about the values to use, eg. based on earlier periods of fishing history when the ecosystem was deemed healthy and productive. Many reference points may be needed to protect all the vulnerable components of an ecosystem. This implies that the ecosystem is tied down like a tent with pegs and stays when, in reality, it is naturally highly variable. A problem that has perhaps not received enough consideration is that testing compliance with reference points requires statistical quality control (Montgomery, 2009), as already mentioned (section 6.3.4). High precision of the tests should not be expected because of typically high variances and short time series for EMS indicators, so there are high risks of making poor decisions. Somewhat less demanding for EAF than reference points are reference directions of time series, ie. a reversal of trend from bad to good. However, statistical confirmation of a reversal of trend takes a long time (Jennings and Dulvy, 2005) so supporting reference points may be necessary as well. No actual values for reference points are suggested in this report. It is envisaged that EAF committees managing fisheries and RV surveys will wish to set their own reference points or directions, taking into account local circumstances and needs.

The second potential management framework for an EAF, ecological risk assessment for the effects of fishing (ERAEF), was developed in Australia in response to early legislation calling for protection of ecosystems there (Hobday *et al.*, 2007, Astles, 2008). The general idea is that all the components of an ecosystem, and all potentially harmful aspects of commercial fishing (and other influences if required), are systematically considered to find the most important and damaging effects, given agreed and detailed ecosystem and socio-economic objectives for managing the fishery. This is analagous to dealing first with the points ‘where the shoe pinches’. A preliminary stage is a risk-screening process, called ‘Scale, intensity, and consequence analysis’ (SICA), in which individual units of all ecosystem components are briefly considered as being at low, medium, or high risk from a comprehensive list of all the foreseen effects of fishing, given the expected scale and intensity of fishing. The risks judged to be highest are passed on to ‘Productivity, susceptibility analysis’ (PSA) in which species are assessed for their ‘productivity’ – meaning ability to recover from fishing – based on life-history characteristics, and their susceptibility to fishing based on availability to the gear, the likelihood of encounters, size selectivity, and post-capture mortality rates. The highest risks from PSA may be passed on for more intensive study or modelling. A short review and summary of ERAEF is given by Cotter and Lart (2011). General problems with ERAEF are that it is only semi-quantitative, it depends on discovering all of the most pressing risks, and it does not take into account actual fishing effort or catches. An EMS feeds into ERAEF by supplying updated values of critical indicators so that performance relative to operational objectives and perceived risks can be assessed.

8 CHECKLIST FOR AN RV ECOSYSTEM SURVEY

The list below summarizes and suggests an ordering of tasks for planning an RV ecosystem survey.

1. Prepare a background report on oceanography, fauna and flora, commercial fisheries, and any other influences (section 2.2).
2. Fill a species database (Table 3.1) for the ecosystem.
3. Advise the EAF committee on definition of the ecosystem to be managed, the goals of management, and on setting the general objectives (GOs) for ecosystem components, indicators and performance measures (section 2.1).
4. Develop operational objectives (OOs) and associated indicators for the priority units (species, or parts) of ecosystem components from the GOs decided at (3).
5. Set priorities for all underwater components to be surveyed (section 2.3) taking into account goals, GOs, and OOs flowing from the EAF management committee .
6. Set priorities for all surface-dwelling components, including seabirds, marine mammals, and perhaps other components to be watched from the EMS (sections 2.3.12, 2.3.13, 2.3.3) .
7. Assess RV options taking into account available fishing and sampling techniques, deck and cabin space for working, the number of RVs required, safety and accommodation (section 2.4).
8. Choose and standardize fishing and other ecosystem sampling devices to be deployed (section 2.5). Document all associated procedures in a protocol for each device.
9. Choose the survey domain taking into account catching and sampling techniques to be used in different localities, species distributions, catchabilities on the survey, and vulnerabilities to commercial fishing, so far as possible (section 3.1). Document in the survey protocol the geography and timing of the survey domain in relation to the ecosystem agreed at (3), recording reasons for choices made.
10. Choose the statistical survey design (sections 3.4 to 3.6), documenting reasons for the choices in the survey protocol.
11. Choose indicators and performance measures to be applied to each ecosystem component being surveyed; standardize the measures needed and the calculations to be made. (section 5). Document in catch or other sampling protocols associated with each deployed sampling device.

12. Initiate discussions/negotiations at the EAF management committee on the interpretations and implications of indicator movements as slopes, relative to reference values, or as changing risks. (Section 7). Decide how indicators and performance measures will be archived, processed and published. Document in an EMS analysis protocol.
13. Finalize and agree the protocols needed to standardize the survey design, fishing and other sampling, catch processing, data checking and archiving, lists of species to be identified (if closed lists will be used), how to deal with confusable or unidentifiable species, etc. (Section 4).
14. Train EMOs in catch processing and taxonomic skills. Train specialized EMOs for watching, acoustic work, etc. Familiarize with relevant protocols. Test and certify their competence to high standards.

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