Selective Fishing and Balanced Harvest in Relation to Fisheries and Ecosystem Sustainability

S. M. Garcia, (Ed.)

About IUCN

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges.

IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, NGOs, the UN and companies together to develop policy, laws and best practice.

IUCN is the world's oldest and largest global environmental organization, with more than 1,000 government and NGO members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 60 offices and hundreds of partners in public, NGO and private sectors around the world.

http://www.iucn.org

Selective Fishing and Balanced Harvest in Relation to Fisheries and Ecosystem Sustainability

Report of a scientific workshop organized by the IUCN-CEM Fisheries Expert Group (FEG) and the European Bureau for Conservation and Development (EBCD) in Nagoya (Japan), 14–16 October 2010

Selective Fishing and Balanced Harvest in Relation to Fisheries and Ecosystem Sustainability

Report of a scientific workshop organized by the IUCN-CEM Fisheries Expert Group (FEG) and the European Bureau for Conservation and Development (EBCD) in Nagoya (Japan), 14–16 October 2010

Serge M. Garcia (Ed.), Jeppe Kolding, Jake Rice, Marie-Joëlle Rochet, Shijie Zhou, Takafumi Arimoto, Jan Beyer, Lisa Borges, Alida Bundy, Daniel Dunn, Norman Graham, Martin Hall, Mikko Heino, Richard Law, Mitsutaku Makino, Adriaan D. Rijnsdorp, François Simard, Anthony D.M. Smith and Despina Symons

Published by: IUCN, Gland, Switzerland

Citation: Garcia, S.M. (Ed.), Kolding, J., Rice, J., Rochet, M.-J., Zhou, S., Arimoto, T., Beyer, J., Borges, L., Bundy, A., Dunn, D., Graham, N., Hall, M., Heino, M., Law, R., Makino, M., Rijnsdorp, A.D., Simard, F., Smith, A.D.M. and Symons, D. (2011). *Selective Fishing and Balanced Harvest in Relation to Fisheries and Ecosystem Sustainability*. Report of a scientific workshop organized by the IUCN-CEM Fisheries Expert Group (FEG) and the European Bureau for Conservation and Development (EBCD) in Nagoya (Japan), 14–16 October 2010. Gland, Switzerland and Brussels, Belgium: IUCN and EBCD. iv + 33pp.

ISBN: 978-2-8317-1336-6

Cover photo: CSIRO

Available from: IUCN (International Union
for Conservation of Nature)
Publications Services
Rue Mauverney 28
1196 Gland
Switzerland
Tel +41 22 999 0000
Fax +41 22 999 0020
books@iucn.org
www.iucn.org/publications

A catalogue of IUCN publications is also available.

Contents

Acknowledgements

The workshop was organized by the Fisheries Expert Group (FEG) of the IUCN Commission on Ecosystem Management (IUCN-CEM) and coordinated by the European Bureau for Conservation and Development (EBCD). It was convened jointly by Serge M. Garcia (FEG Chair), Jake Rice (FEG Vice Chair, Fisheries and Oceans, Canada,), Jeppe Kolding (FEG member, University of Bergen, Norway), Marie-Joëlle Rochet (Institut français de recherche pour l'exploitation de la mer (Ifremer), France) and Shijie Zhou (CSIRO, Australia). It was coordinated by Despina Symons Pirovolidou (FEG member, EBCD, Belgium) assisted by Kathleen Laissy (EBCD). All local arrangements and contacts with the different Japanese institutions were very effectively undertaken by Dr Mitsutaku Makino (FEG member, Fisheries Research Agency, Japan).

The meeting was held in Nagoya 14–16 October 2010, just before the 10th Convention of the Parties of the Convention on Biological Diversity (CBD COP 10, 18–29 October 2010) and attended by 21 participants (see Annex 1). The meeting agenda is available in Annex 2. Its conclusions were presented at a side-event organized during COP 10 on 20 October.

The meeting was sponsored by the International Union for Conservation of Nature (IUCN), the CBD Secretariat, and the Census of Marine Life (CoML). It received financial support from the IUCN-CEM, the Ministry of Fisheries and Coastal Affairs and the Ministry of Foreign Affairs of Norway, the Global Guardian Trust (GGT, Japan), the Ocean Alliance of the University of Tokyo, the National Association for the Conservation of Fishing Grounds (Zenkoku Gyojou Kankyou Hozen Kyoukai), the Japan Fisheries Association, Ifremer and DTU Aqua (Denmark).

Abstract

The conventional selectivity paradigm is briefly reviewed and its performance examined from an ecosystem perspective. It is stressed that the overall (cumulative) selectivity of the harvest process in an ecosystem is the result of nested selection by fishers and fisheries of: (i) habitats; (ii) species assemblages; (iii) populations; and (iv) individuals. A range of ecosystem models predict the strong impact of concentrated fishing (selective fishing) on ecosystem structure stability, resilience and productivity. There seem to be advantages (in both yield and maintenance of ecosystem structure and functioning) to distributing fishing pressure broadly across available species and ecosystem compartments. Balanced harvesting was therefore defined by the workshop as a strategy that distributes fishing pressure across the widest possible range of trophic levels, sizes and species, in proportion to their natural productivity, reducing fishing pressure where it is excessive. The few attempts to verify the impacts predicted by models in real ecosystems with empirical data had limited success, indicating that such a demonstration might be a significant challenge. Data from African small-scale fisheries were presented as a possible example of the capacity of multiple fisheries targeting an extremely broad range of species and sizes to extract high yield with limited impact on ecosystem structure. There are also a number of examples of surprising consequences of selectivity regulations resulting in either operational changes in the fishery or to unexpected shifts in the ecosystem. Emerging research priorities and management implications are reviewed.

1. The Issues

Fishing is by nature a selective process. Fishers traditionally use selective gears and target particular species and specific components of populations during some seasons in selected areas. The question of which gears and mesh sizes to use in a particular fishery in order to fish sustainably dates back at least 600 years in fisheries lore, much longer than the quantitative question of how much to fish. There is a long-standing culture in fishery science and management, to protect the juveniles with the expectation of increased yield and greater sustainability. Only recently has attention been drawn to the need for old mature spawners to escape being caught too. Similarly, with growing criticism about by-catch, discards and endangered species, selectively targeting certain species or sizes has taken on a sacred status in fisheries research and management. The selective protection of endangered and emblematic species adds selectivity constraints on the set of resources that can be exploited or impacted. Any kind of selective removal, however, will unavoidably change the demographic composition of a population and the species composition of a community. These changes alter ecosystem structure and can result in changes to ecosystem functioning including energy flow, element recycling, species interactions, productivity, and resilience. Consequently, separate species- or size-based selectivity regulations, altering important ecosystem properties in unknown directions, may actually diminish rather than enhance ecosystem and fisheries sustainability. Furthermore, the adoption of the ecosystem approach to fisheries and the increasing concern that size-selective fishing might induce evolutionary change in the exploited species imply that the concept of fishery and gear selectivity needs to be reassessed from an ecosystem perspective. The issue of fishery selectivity and the practice of its regulation are perhaps not so simple as previously thought, whether in terms of productivity and resilience or conservation. There is a need to review the likely impact of such practices at the ecosystem level and to reflect on the best way to use our understanding and experience in selective fishing to ensure an overall harvesting strategy that is sustainable in an ecosystem context.

2. Purpose of the Workshop

The purposes of the workshop were to:

1. bring together the available science (theory, models and empirical evidence), synthesize established results and identify gaps in the understanding;
2. derive the practical consequences of the emerging science, to raise decision makers' and scientists' awareness of the issue and, eventually, deliver relevant general management advice, based on this knowledge; and to
3. identify research avenues and develop scientific collaboration to better address the issue and deliver more relevant practical advice.

The workshop examined the extent to which selective fishing as currently and traditionally practiced is able to contribute effectively to both ecosystem and fisheries sustainability. Participants touched upon the concepts of biodiversity, stability and resilience in relation to continuous or discrete perturbations in order to evaluate whether the present selectivity management paradigm is adequate to accommodate different life history strategies and a food-web perspective. In so doing, the workshop contributed to the debates on by-catch, discards and species conservation in an ecosystem approach to fisheries.

The workshop also discussed what a shift from the conventional paradigm of gear/fishery selectivity to that of a more "balanced harvest" (defined further below) would imply for the ecological and management dimensions of sustainability. It is acknowledged that balanced harvesting would have economic and social consequences as well, but these were not considered in depth at the workshop. Questions that were addressed included: 1) Would exploitation and protection strategies based on ecological principles and considering resource communities (as opposed to single species) better buffer natural variation and human-induced changes than conventional harvest strategies? 2) How does selectivity interact with fishing intensity? 3) How do the combined selectivity profiles of multiple metiers interact at system level?

3. Theory and Models

A number of presentations addressed the available theory and some of the relevant models when dealing with the issue of populations and ecosystem impacts of selective harvesting. Their content is briefly summarized below. While these notes have been reviewed by all participants, they reflect the views and conclusions of their authors.

3.1 Ecological and evolutionary impacts of size-selective fishing (J.E. Beyer and K.H. Andersen)

The presentation gave an overview of the current state-of-the-art of size-based fish community modelling and discussed the pros and cons of this approach. The community modelling used in the presentation is based on first principles derived from two central assumptions: 1) big fish eat smaller fish, and 2) mass conservation provides a strong link between growth and natural mortality. Size-spectrum models are well suited to assess the general impact of size-based selective fishing at the species, but more importantly, the at ecosystem level.

The size-spectrum models (Andersen and Beyer, 2006) are: 1) based on few assumptions (Figure 1); 2) come in different forms with different data-requirements, from the data-poor models (one parameter for a species, a few for an ecosystem) to complex size-spectrum food-web models; and 3) even though the models are mathematically complex, they can be solved numerically (see http://www.spectrum.stockassessment.org).

On the single-species level, size-spectrum models can demonstrate how different size-selective fisheries are expected to influence the spawning-stock biomass, stock structure, yield, recruitment, as well as the evolutionary rates of change in size at maturation, growth and investment into gonads of the species. At the community level, the models provide assessments on how size-selective (or asymptotic size-selective) fisheries influence, not only the target size- and asymptotic size-range, but the whole community.

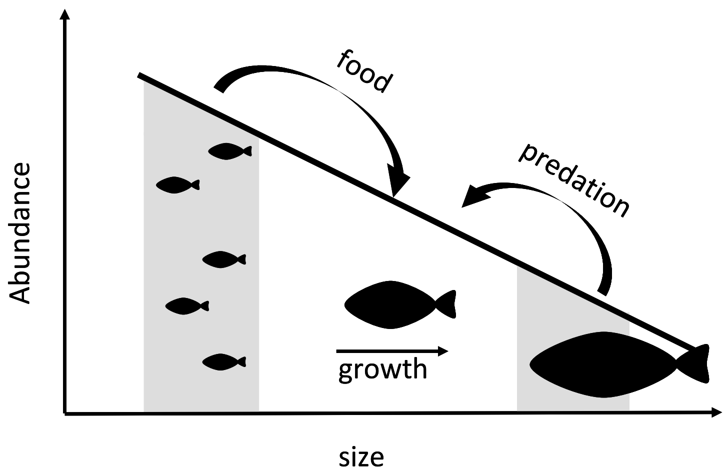

Figure 1. Simple assumptions: small fish grow and large fish eat small ones

These models make it possible to quantify the effects of trophic cascades (Andersen and Pedersen, 2010). They demonstrate five important aspects of size-selective fishing on the community:

1. Perturbation on a size-range (or asymptotic size-range) generates a trophic cascade. The trophic cascade propagates from the localized disturbance (e.g., by fishing) in the target size-range to the rest of the community;
2. The trophic cascade can propagate both up and down trophic levels;
3. The trophic cascade is damped, which means that the indirect effect on the neighbouring trophic levels is expected to be much smaller than the direct impact on the targeted range;

4. The direct effects of a given amount of fishing on a specific size range are stronger when applied to higher trophic levels than on lower ones (see also Section 4.5);
5. The indirect effects of fishing, i.e., the changes in the ecosystem that do not result directly from the fishing activity but emerge through the ecosystem processes (i.e., through the trophic chain) are smaller than the direct effects of fishing on the target species. Further, these indirect effects are larger when small species are targeted than when large species are targeted (Andersen and Rice, 2010).

Finally, it is noted that size-based community models are particularly useful for addressing functional diversity. *Functional diversity describes how many functional groups are represented in an ecosystem.* In the example considered, the functional groups are characterized by the trait "asymptotic size", and the functional diversity is how evenly biomass is distributed over species with different asymptotic size. Looking at the functional diversity of the system brings us much closer to the internal dynamics of the ecosystem which is responsible for maintaining the stability and resilience of the system.

This model was used to predict fishing impacts on the fish community on the Zambian side of Lake Kariba (see Section 4.3), and the resulting predictions were corroborated by the empirical observations available, indicating that a broadly targeted complex of fisheries with high levels of effort, using small mesh sizes, would sustain highest overall yields with minimal alteration of the size spectrum.

3.2 Ecological drivers of stability and instability in marine ecosystems (R. Law, M.J. Plank, G.W. Delius and J.L. Blanchard)

This presentation was motivated by the purpose of the workshop to examine the effects of exploitation on the structure, function and, especially, resilience of marine ecosystems. Adopting the widely used interpretation of resilience in ecology as the tendency to return to a reference state, the dynamic-systems methodology of local asymptotic stability of steady states can be used to learn about resilience.[1]

To investigate asymptotic stability requires a dynamic model of marine ecosystems. In the talk, a model was described which builds on two basic widely observed properties: 1) the approximate invariance of biomass in logarithmic size intervals; and 2) the body-size dependent feeding, in organisms that grow over several orders of magnitude in the course of their lives. Such organisms change their trophic level as they grow, so a standard notion of food webs with species located at a single trophic level for their entire life span is not appropriate.

The steady state of the dynamic model is consistent with the observed approximate invariance of biomass in logarithmic body mass intervals. We give an analysis of the asymptotic stability of this steady state, as shown in Figure 2. Local asymptotic stability is measured by the real part of the dominant eigenvalue, $\mathrm{Re}(\lambda^*)$, of the linearized operator describing the dynamics of these perturbations. If $\mathrm{Re}(\lambda^*)$ is positive, the steady state is unstable; if it is negative, the steady state is stable. The more negative it is, the faster the return to steady state. Some background is given in Datta *et al*. (2010). The results show that there is a bifurcation point between stability and instability of the steady state in a region of parameter space in which real ecosystems would be expected to occur. The message is that the power-law steady state is not necessarily stable. Moreover, even if the steady state is stable (i.e., $\mathrm{Re}(\lambda^*) < 0$), ecosystems with $\mathrm{Re}(\lambda^*)$ close to zero return to steady state more slowly than ones in which $\mathrm{Re}(\lambda^*)$ is more negative, which means that these ecosystems are less resilient to external shocks, and are likely to show more variation over time.

[1] This entails making small perturbations from the steady state and examining whether these decay with time (the steady state is stable), or grow (the steady state is unstable). As a metaphor, consider a ball at the bottom of a valley or the top of a hill. The ball is at rest (in a steady state) at both locations but these rest points are entirely different. Moving the ball a small distance from them, the displacement decays in the case of the valley bottom (as the ball returns at the bottom), and grows in the case of the hilltop (as the ball falls towards the next valley).

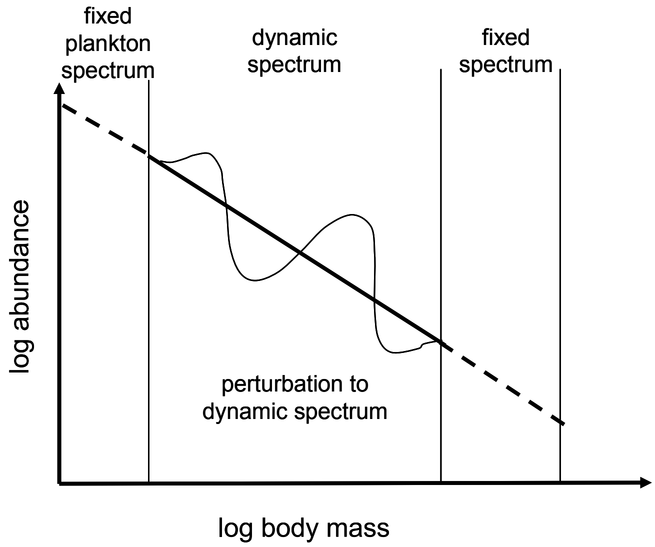

Figure 2. A stability analysis entails making small perturbations from the steady state of the size spectrum and examining whether these decay (steady state stable) or grow (steady state unstable)

Truncation of size spectra *per se*, as might be expected from selective exploitation of large-sized organisms, makes Re(λ^*) more negative and in this sense increases stability. Feeding behaviour, measured as the logarithm of the Predator-Prey Mass Ratio (log(PPMR)), and diet breadth, affects stability; Re(λ^*) increases as log(PPMR) increases, and decreases as diet breadth increases. Thus the stability of marine ecosystems is expected to change as the relative abundance of species in the ecosystem with different feeding behaviours is altered by exploitation. There is empirical evidence that fish species with large log(PPMR) fluctuate more over time that those with small log(PPMR); again this suggests that the stability of the steady state is not neutral with respect to changing the relative abundance of species by exploitation. Preliminary results suggest that exploitation of large organisms from size spectra can shift the steady state from stability to instability.[2] This is in keeping with the observation, made elsewhere, that it can be deleterious to remove the Big, Old, Fat, Fecund, Female Fish (BOFFFF). General considerations of exploitation of large body sizes from size spectra suggest that indirect effects may propagate back down to smaller sizes with deleterious effects.

On the basis of these results, the authors suggest that ecosystem-based models, by internalizing[3] fish growth and mortality, give and understanding of dynamics in marine ecosystems, different from that of the single-species yield per recruit (Y/R) approaches traditionally used. Exploitation patterns affect resilience of marine ecosystems in a number of different ways, depending on the effects they have on the relative abundance of species and the size classes removed.

There is yet much to understand about this formalization, and the predictions it makes about marine ecosystems. The ecosystem model aggregates organisms ignoring species identity, and does not address the important practical problem of how coexistence of species is achieved when the size-based ecosystem model is disaggregated to its constituent species.

[2] See converging conclusions in Sections 3.1, 4.1 and 4.5.

[3] "Internalizing" here means replacing the parameters for growth and mortality, which are given as inputs in many models, with the dynamical process in which fish feed on smaller organisms, growing as they eat them and causing the death of their prey.

3.3 Selective versus unselective fishing in modelled ecosystems (E.A. Fulton and A.D.M. Smith)

In a study using 37 published ecosystem models from 31 ecosystems from around the world, the authors examined the shape of the Multispecies Maximum Sustainable Yield (MMSY) versus exploitation rate curves for different assumptions about selectivity of fishing. The authors found that the form of fishing used (i.e., the fishing pattern across sizes and species) was far more important in determining the shape of the curve than the type of ecosystem that was fished. Where very selective fishing on larger-bodied animals (current target species) was simulated, the classical dome-shaped relation between yield and exploitation rate was produced. However, if fishing was broadly distributed across many species and animals of all sizes, the yield curve increased linearly with exploitation rates to high levels, at which point yields collapsed suddenly. However, the models also showed that conservation trade-offs do require lower exploitation rates. The task is therefore finding combinations of gear and other management levers that result in spreading the fishing pressure while protecting more vulnerable groups and not just "spreading the present excessive burden".

These are preliminary results and need further exploration and analysis before too much inference should be drawn from them. However, initial results support the view that a more "balanced" exploitation pattern may be able to maintain (or even increase) yields from marine systems without having such adverse impacts on species and community structure.

4. Symptoms of the Problem: The Effect of Fishing

4.1 The effects of fishing selectivity on marine communities: how do we get from intuition through theory to evidence? (M.-J. Rochet)

The objective of reducing by-catch and discards by improving fisheries selectivity (i.e., concentrating fishing on a few target species or size classes) potentially conflicts with the goal of maintaining ecosystem structure and function. To investigate this intuition, the presentation showed theoretical results from two models:

1. A size spectrum model that led to the conclusion that fishing-generated oscillations in the biomass flow appear at lower fishing intensity and have wider amplitude when fishing is selective and/or when large fish are targeted, than when the fishing mortality is more broadly distributed ("balanced harvesting") or when small fish are targeted.
2. A more detailed model involving species-specific life histories (LeMANS, Hall *et al*., 2006) with which, by contrast, no general conclusion on the impact of fishing selectivity on biodiversity could be obtained. With these results, neither selective nor balanced fishing can be said to be generally preferable for conserving biodiversity. The outcome depends on both the particular species composition and size structure of the community, and the shape of the selectivity function, which to this point has been little studied at the community level (Figure 3). The difference with the size-spectrum results can be ascribed to: i) the overlap between the fishing selection curve and the size spectrum, that does not have a regular shape in LeMANS; and ii) the assumption that growth is not food-dependent in LeMANS, which prevents effects from propagating bottom-up in the food web. This prevents the amplification of perturbations due to trophic cascades propagating both top-down and bottom-up, destabilizing the size-spectrum models.

The LeMANS model was used to predict the effect of fishing selectivity on the fish community, that is, trends in a series of biodiversity metrics (e.g., evenness should be lower when fishing is more size-selective on Georges Bank, but unaffected in the North Sea). Preliminary results of an empirical analysis of survey data from the North Sea and Georges Bank suggest that most of these trends cannot be detected in the data. No evidence of an effect of fishing selectivity pattern on community structure and trends could be found, probably because variations in fishing intensity and selectivity were confounded and interact with multiple other drivers during the period of observation. Providing empirical evidence of the effects of fishing selectivity at the community level might be a formidable challenge.

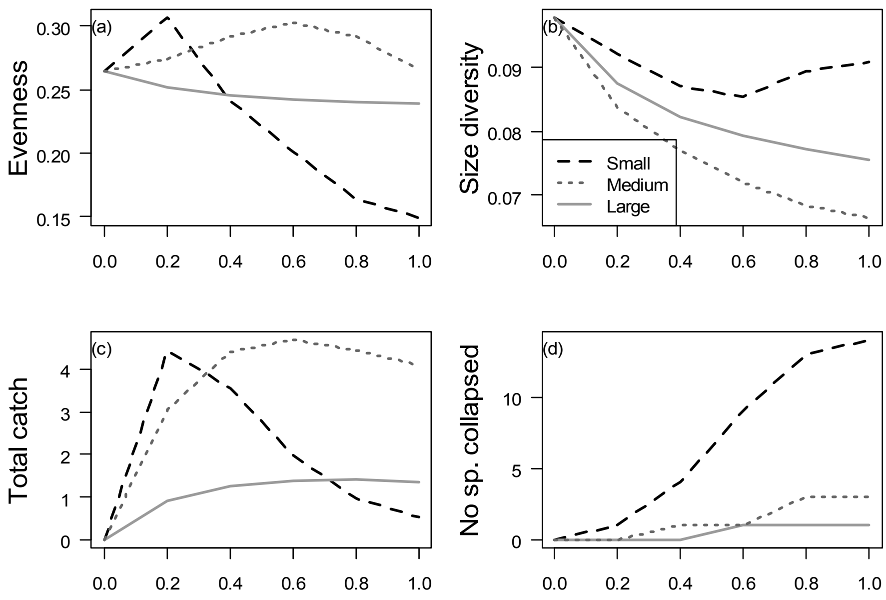

Figure 3. Effects of increasing fishing mortality on species evenness (a), size diversity (b), catch in million tonnes (c) and number of species collapsed (d) for the North Sea. Collapse is defined by decrease below 10 percent of unexploited biomass. Size selection is modelled for all individuals of the 14 fished species as a logistic function with parameters regarding steepness and size-at-50%-selection as follows; small species (0.25; 15); medium species (0.10; 40); large species (0.25; 65) (Rochet *et al.*, in press)

4.2 Is a diversified harvest of an ecosystem a better way to maintain its integrity? (M. Hall)

Is selective fishing good from the point of view of maintaining the structure and function of an ecosystem, or in more precise terms, its resilience and stability? In an Appendix to Hall (1996), the author posed the question to a group of ecologists and fisheries scientists in a small meeting to address some ecological questions that could improve fisheries management. It appears that the dogma that selective fisheries (i.e., fisheries concentrating on few target species) are an objective of “good” fisheries management has become enshrined in the legislation of most countries. Coming from an ecosystem perspective, it is clear that heavy non-selective harvesting of a mixture of r and K species will result in losses of some species, and ecosystem changes. But a similar consequence can be expected from harvesting some species to the maximum level, while granting full protection to others. The wisdom of a heavy concentration of single fisheries on the smaller number of components possible without consideration of the cumulative effect on the ecosystem can be questioned. If the harvest of protein and other raw materials was seen from an ecosystem point of view, trying also to maintain ecosystem resilience and stability, then the allocation of the extractive effort on species would likely follow patterns very different from the present concentration on a few high-value targets that results from economic profit seeking. There are several examples of unwise approaches to fisheries management on the subject of by-catches, where the focus on a single object for protection has resulted in negative consequences for the ecosystem. The protection of dolphins in the tuna purse seine fishery of the eastern Pacific, beyond what many consider cautious sustainability has pushed the fishery into a significant change with many potentially negative consequences on the target and non-target species (Hall, 1998; Hall and Donovan, 2001; see also Table 1).

Testing the hypothesis that a balanced or diversified harvest is “better” from the ecosystem point of view is a necessary step. Examples of exploration with models are available, but perhaps microcosm or whole lake experiments could be performed.

The practical implementation of a system based on new principles would require creativity and caution, but the current situation of many fisheries may increase the acceptance of new concepts. Trading quotas of over-harvested species for others unutilized, together with policies of full retention, and the creation of a system of economic incentives including educated consumer choices, and intelligent State policies could gradually shift the harvest system.

4.3 The fishing pattern of open access, non-regulated African freshwater fisheries: the paradoxical gap between theory and practice (J. Kolding and P.A.M. van Zwieten)

Selectivity is deeply rooted in contemporary fisheries theory, and fisheries acts and management regulations, aimed at controlling selectivity and hence concentrating fishing on some species and sizes, are almost ubiquitous. Small-scale fisheries, due to their general lack of data for quota-based management, are in particular regulated by gear and mesh size regulations as these are the cheapest to implement and easiest to monitor.

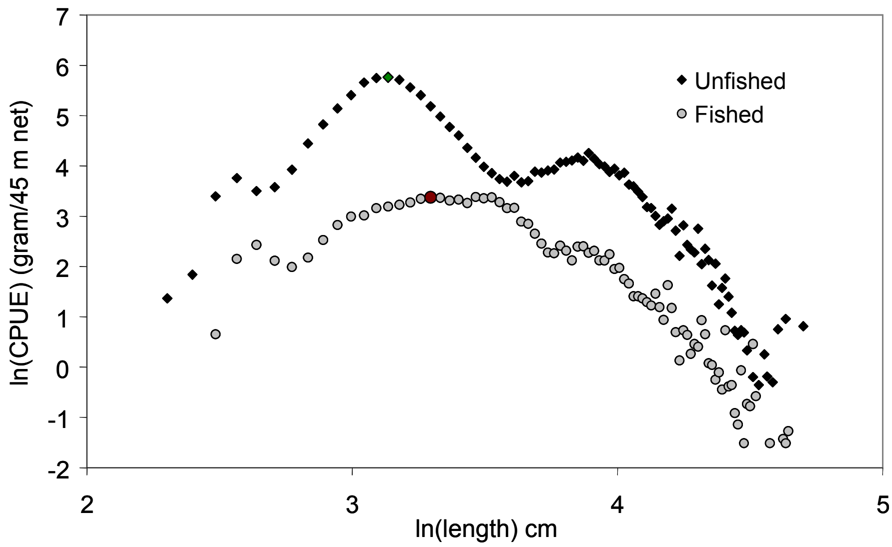

Figure 4. Ecosystem structures (log of relative abundance by size group) in Lake Kariba under heavy fishing with predominantly small mesh sizes (grey circles) and with no fishing (black squares) (modified from Kolding *et al.*, 2003a)

Enforcement of fishery regulations in African freshwater fisheries, however, is usually weak or absent. This, combined with open access policies, generates a competitive and evolving fishing pattern that employs a large range of fishing strategies, gears and mesh sizes, some of which are technically considered illegal because of their poor selectivity. It results in the often negative image of destructive indiscriminate fisheries. This presentation showed that on closer inspection of the facts, in specific artisanal and rather unmanaged fisheries of Africa, the use of a wide range of versatile fishing methods and mesh sizes, each of which selects specific sections of a fish community, resulting in a very broad distribution of the fishing pressure on the ecosystem components, leads to high yields while maintaining the ecosystem structure, i.e., the proportions between the abundance of the different size groups (Figure 4). Such "unregulated", broadly targeted adaptive fishing patterns appear to be far more effective in conserving the ecosystem than single-species management theory predicts. This pattern of development appears to be the result of strong competition between fishers and low individual catch rates, and could be considered analogous to natural predator niche specialization and co-evolution. This requires, obviously, that fishing pressure (using "low tech" gears) remains at levels compatible with the ecosystem productivity. The immense pressure from outside to adopt for small-scale fisheries the conventional management thinking based on gear restrictions, size limits, and classical economic theory is likely to have, under present conditions, negative ecological effects.

4.4 Fisheries and ecosystem sustainability: a mixed fisheries case study (A.D. Rijnsdorp, J.J. Poos, D. Beare and G.J. Piet)

North Sea flatfish fisheries, targeting a variety of flatfish species with small-meshed bottom trawls, are characterized by high levels of discarding and substantial impacts on benthic invertebrates and habitats. Discards comprise both undersized fish of the target fish, in particular plaice and dab, as well as over-quota fish and marketable fish of low market value (high-grading) (Poos *et al.*, 2010).

In 1989, a closed area (Plaice Box) was established to reduce the discarding of undersized plaice, based on historical data on size distributions. The measure has not resulted in a decrease in discarding, however, because the fish behaviour changed unexpectedly and the juvenile plaice moved offshore, leaving the Plaice Box when still undersized. The offshore movement of plaice is likely related to the higher temperatures and lower benthic productivity observed since the mid 1990s (van Keeken *et al.*, 2007) although it can not be excluded that the reduced trawling disturbance in the box negatively affected the production of the benthic food as suggested by a trawling impact ecosystem model (Hiddink *et al.*, 2008). Despite increased discarding, however, the plaice stock has increased due to a coincidental decrease in fishing effort since the box was established due to effort reduction measures coinciding with increased fuel costs.

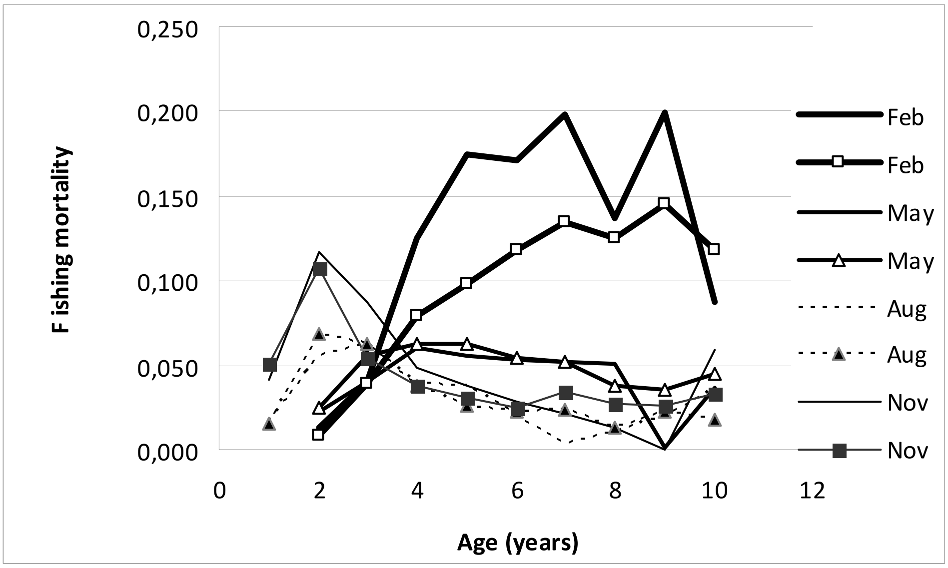

Figure 5. Fishing patterns for plaice male (lines) and female (lines and symbols □ and Δ) in different months

In the longer term, historical information indicates that the size and age at maturation and the maximum body size of the plaice have decreased since the early 1900s, while there are indications that the reproductive investment has increased (van Walraven *et al.*, 2010). These changes are consistent with the assumption of a fisheries-induced evolution eroding the productivity of the stocks. Eco-genetic modelling (i.e., with models that integrate both ecological and evolutionary dynamics) shows that targeting the intermediate size classes (i.e., reducing fishing pressure on juveniles and large spawners) may reduce the evolutionary response. Because of the seasonal differences in the overlap of the fishery and different-sized fish (Figure 5), it is also concluded that space-based management may offer an avenue to reduce the ecosystem impacts of the fishery as well as its evolutionary effects.

4.5 Sustainable fisheries: balancing exploitation with production across species and trophic levels (A. Bundy)

The presentation explores the hypothesis that balanced exploitation of marine ecosystems minimizes the impacts of fishing, leading to more sustainable fisheries. The ecosystem impacts of different fishing strategies are tested using a tropho-dynamic simulation model (Ecopath with Ecosim). Ecosystem response is measured using a 4-dimensional ecosystem exploitation index (4D EEI) measuring: 1) the trophic balance of exploitation (TBI), 2) the intensity of exploitation (E), 3) species richness (SRI), and 4) disturbance of the trophic structure (DI). Results indicate that the fishing strategy that results in minimal disturbance to the ecosystem is one that balances moderate exploitation rates with production at different trophic levels (Figure 6). Greatest disturbance occurs, for a given yield, when it is removed from the top trophic levels.

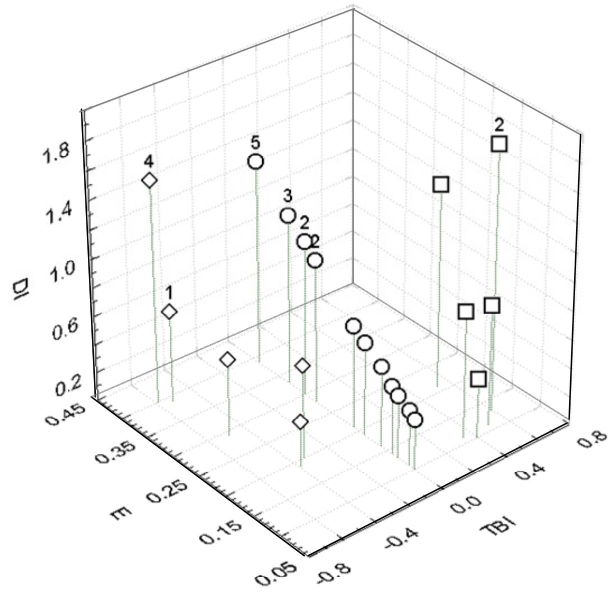

Figure 6. 4D EEI phase plot showing modelling results of different exploitation patterns on the same ecosystem, fishing heavier on the bottom of the food chain (diamonds), on the top of the food chain (squares) or balancing exploitation across all trophic levels (circles). Numbers represent the number of species declining below threshold level in SRI (modified from Bundy *et al.*, 2005)

The 4D EEI has been tested on an empirical case study from the Eastern Scotian Shelf, Canada. Results indicate that since 1970: 1) the trophic balance index has been high; 2) the exploitation index has been high; 3) there has been a decrease in species richness; and 4) there has been an increase in the disturbance index since the mid-1980s (the reference year). These results indicate that the ecosystem has never been exploited in balance and that exploitation has been very high, resulting in high disturbance of the trophic structure.

The model supports the hypotheses that balanced exploitation results in minimal change to trophic structure and species loss, and that fishing pressure that is not in balance with ecosystem production results in high disturbance of ecosystem structure. This suggests that fisheries and ecosystem management aiming at sustainable fishing and the maintenance of ecosystem structure and functioning should aim to harvest the ecosystem components in proportion to their production, by trophic level, species or size group. However, in ecosystems where species structure has already been negatively altered, recovery strategies should first be implemented to recover productivity and resilience before implementing a balanced harvest strategy. This will entail reducing or stopping fishing at trophic levels (species or size groups) most severely impacted; and exploiting the remaining species at conservative/low levels.

In heavily harvested ecosystems, where species structure has changed, the relevant questions are: 1) what are the objectives; 2) what ecosystem structure would most assist in reaching these objectives; and 3) what management measures would be needed?

The ultimate objective is to develop reference exploitation patterns for sustainable and non-sustainable zones (as defined, for example, by the 4D index), then to identify appropriate management responses.

5. Implications for Research, Policy and Management

5.1 Managing marine biological assets through diversification (S. Zhou, A.D.M. Smith and G. Marteinsdottir)

The concept that is emerging is that conserving biodiversity and using a wide range of the resources may better contribute to ecosystem and fisheries' sustainability (Zhou *et al*., 2010). This can be achieved through well designed selectivity patterns. At species assemblage level, it implies that management should aim at a wide distribution of the fishing pressure to balance direct and indirect impacts across species. From that perspective, by-catch, if maintained within limits imposed by sustainability, may not be an impediment to maintenance of community structure and ecosystem stability (Zhou, 2008). Using multispecies simulations with the Baranov catch equation, the presentation demonstrated that less selective removal of particular ecological groups has less immediate impact on biodiversity (measured by the Shannon Diversity index) or less long-term impact on biodiversity under continuous fishing than a highly selective fishing pattern. At population level, analysis based on the yield-per-recruit model demonstrates that impact on age diversity indices (i.e., natural demographic structure) can be reduced when fishing selectively removes individuals at middle age while maintaining sustainable yields. This is consistent with the idea of protecting small and old fish.

The presentation also proposed various diversity indicators and reference points that could measure fishing-induced changes in biodiversity (Figure 7) and provided a framework integrating the classical biological reference points used in fisheries with new inter- and intra-species diversity reference points with the view to maintaining ecosystems and sustainable fisheries. It is hoped that the new ideas could stimulate discussions between fishery and conservation scientists on future fisheries and ecosystem management.

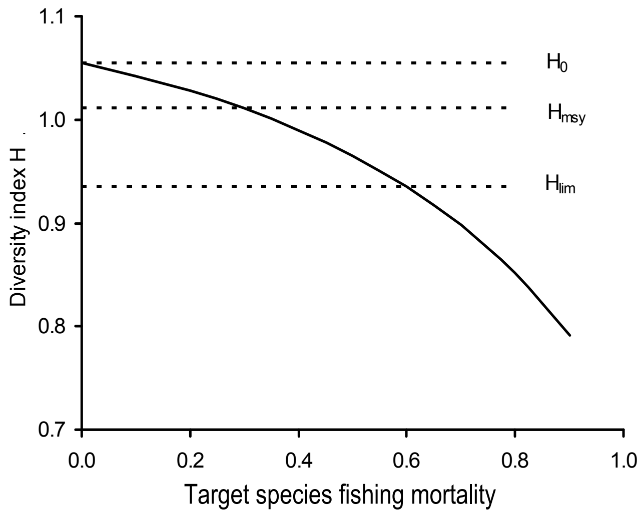

Figure 7. General relationship between diversity and fishing intensity when fishing is selective. H_0, H_{msy}, and H_{lim} are diversity reference points corresponding to target species biomass at B_0, B_{msy}, and B_{lim} when no fishing mortality occurs in other species (Zhou *et al.*, unpublished data)

5.2 An evolutionary perspective to selective fisheries (M. Heino)

All fishing, whether highly selective or balanced, is evolutionarily selective, i.e., induces phenotypical and possibly genetic adaptation. Fishing causes very "unnatural" mortality patterns (Figure 10), and therefore fisheries-induced selection can be very strong.

Selective breeding in aquaculture and harvest experiments have shown that selected traits are heritable. Analyses of field data indeed suggest that capture fisheries-induced evolution is also common. Furthermore, models and experiments suggest that stocks adapting to fishing can sustain higher fishing pressures.

However, in most cases (with the exception of fisheries exploiting exclusively the spawners), this occurs at the cost of two changes undesirable for fisheries: a decrease in both fisheries productivity and adult body size (Law and Grey, 1989; Heino, 1998; Ernande *et al*., 2004). It would therefore be logical to want to minimize such disadvantageous evolution.

Solutions exist in two directions: fishing less intensively, or fishing differently. Fishing less intensively is a simple and foolproof solution but it implies lower catches at least in the short term. Might fishing differently (compared to the current focus of saving juvenile fish) be preferable? Doing exactly the opposite could sometimes help: a pure spawner fishery can allow for evolution of increased yield and body size; alas, this is only exceptionally a practical option. There is indeed some theoretical promise that targeting middle-sized fish (reducing pressure on juveniles and old fish) might offer a good balance to reduce evolution while maintaining reasonable catches. However, as always in a multispecies and multigear environment, implementing this strategy requires stock-specific information and can be difficult to implement.

Another option is to fish less selectively, harvesting also more of the young, small-sized individuals as natural predators do. This will often reduce selection but also catches. In conclusion, fisheries-induced evolution is another good reason to harvest fish populations at conservative levels, and changes in selection pattern can have unforeseen evolutionary consequences that should be considered when implementing an ecosystem approach.

5.3 Sustainable fisheries in a new European Common Fisheries Policy (L. Borges)

In the upcoming reform of the European Common Fisheries Policy, one of the options is to set a general goal of ecological sustainability of fisheries. Within this global objective, specific targets relating to, for example, discards may be specified. In this context, selectivity would contribute towards that global objective but may not necessarily need to be prescribed. In other words, by establishing an ecosystem-related management objective, selective fishing (at fishery level) and balanced exploitation (at ecosystem level) are necessary elements of the strategy needed to reach that goal. However, the details of such strategies may not necessarily need to be regulated. On a European context, where “over-legislation” is the rule, this would require a change of policy to a results-based management, with a simplification of the different technical measures legislation. It will also have implications on the nature of the scientific advice to fisheries management. In practical terms, the usual scientific advice regarding gear technology (e.g., mesh size and gear configuration) would be changed to advice on minimum selectivity standards (e.g., by fishery or species assemblage) and other technical measures (e.g., closed areas and seasons) producing the appropriate selectivity pattern at the ecosystem level, i.e., maintaining ecosystem structure while ensuring sustainable harvesting.

5.4 Ecosystem-based approach to fishing technology development for sustainable fisheries (T. Arimoto)

The improvement of gear selectivity has been a traditional goal for fishing technology, for minimizing the capture of unwanted species and sizes. Selective fishing is achieved by means of mesh size enlargement, the use of a variety of by-catch reduction devices, as well as closed seasons and areas. This concept can be applied in an ecosystem-based approach for fisheries management, by identifying different zones (e.g., coastal and off-shore) with different biodiversity aspects, for different users of small-scale and large-scale fisheries, which require different management systems. Historically, in the management system in the coastal waters in Japan, the Fishermen’s Cooperative Association created the concept of “*own garden*” with fishing access limited to the cooperative members. *Sato-umi* is another concept for sustainable and harmonious establishment of areas allocated to nature conservation and for human activities in the coastal area. In order to enhance the self management concept, it is essential to provide technical support to identify the best or smarter usage of fishing gear in accordance with the specific type of capture and with the required selectivity performance for species and sizes in each gear type. It is also essential, within an ecosystem approach to fisheries, to define the desired outcomes of the “balanced harvest” measures at scales larger than the single fishing communities, e.g., at the ecosystem scale.

5.5 Gear-based technical measures and the ecosystem approach to fisheries management (N. Graham)

The presentation illustrated current problems in several EU fisheries, including cod stock collapse and excessively high discarding of commercial and non-commercial species. Focus towards results-based management has begun to facilitate the use of more conservation-oriented fishing gears i.e., for reducing catches of severely depleted species. Historically, gear selectivity research has tended to focus on regulatory issues for regulating the size of first capture and the underlying factors that influence selectivity and more recently, a move towards conservation-based engineering based around species selectivity for limiting the capture of mega-fauna for example. Research has also begun to focus on mitigating the physical habitat impacts of fishing gear through technical modification. The presentation gave a summary of the wide range of gears used based on the FAO gear classification and demonstrated that gears have a wide range of selectivities both in terms of the biodiversity of species retained and the age spectrum within species (Figure 8).

Using the example of the North Sea, it was noted that there are a wide range of gears used acting on different components of the ecosystem from lower trophic levels e.g., sand eel fisheries for fish meal production using very small mesh sizes (16mm) up to large mesh static gear fisheries targeting large gadoids e.g., cod, using mesh sizes >250mm. A wide range of gears are operated between these extremes and in many cases there will be some degree of overlap in the catch profile.

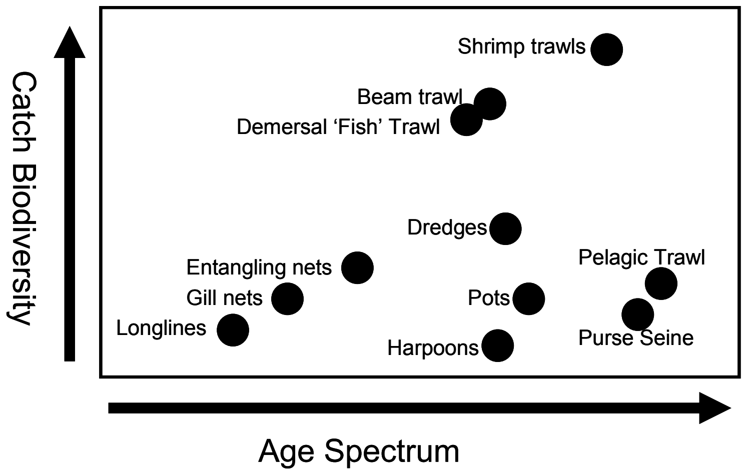

Figure 8. Age spectrum and biodiversity of the catch of various fishing gears

Practical examples were given of what could be done with mobile and static gears to achieve a balanced exploitation that takes account of all the species implicated in the capture process. It was demonstrated that selectivity can be adjusted through gear technology measures to manage single species exploitation with a technological approach to fishing that minimizes the ecosystem impact of fishing while retaining the economic, social, and food security benefits of that fishing. For example, protecting BOFFFFs can be achieved by changing fishing technique (from trawling to gill netting) or by modifying the trawl design to include a size-selective grid, where the conventional cod-end meshes can control the retention of smaller length classes and the bar spacing of the grid can be modified to exclude larger individuals (Figure 9).

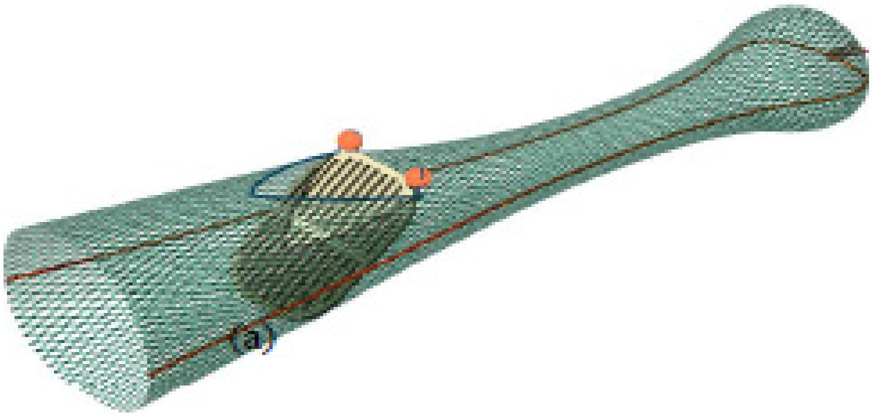

Figure 9. Example of size-selective grid (Crown Copyright, reproduced with the permission of Marine Scotland)

5.6 Managing for balanced exploitation: data availability and needs (D.C. Dunn, P.N. Halpin and E. Vanden Berghe)

Traditional fisheries have largely been managed through single-species stock assessment models based on data from fisheries-dependent sampling and to a lesser extent scientific surveys of the resources being exploited. However, to understand the effects of selective fishing and to balance exploitation across a community or an ecosystem, biodiversity indices and measures of ecosystem health and services are required. Due to the predominance of single-stock management, the requisite data are not widely available and often are not even collected. Management agencies have recently expanded data collection regimes to more systematically include by-catch, discards, and finer spatial and temporal resolution metrics of fishing effort. Fisheries-independent data are still generally scarce, though efforts such as the Census of Marine Life have brought a wealth of new information to the table. In order to meet the needs of ecosystem-based management, the scope of fisheries-dependent data collected must be broadened and more resources must be dedicated to fisheries-independent surveys and monitoring. The presentation integrated some of the implicit and explicit data requirements in the preceding presentations. This summary offered participants the opportunity to discuss the types of data required to assess the ecosystem impacts of selective fishing and to monitor the results of a balanced exploitation strategy, and the degree to which those data needs are currently being met by observer programmes and data repositories such as the Ocean Biogeographic Information System (OBIS). Among the major data gaps listed by participants, the lack of time series data was repeatedly cited as a significant obstacle to understanding the effect of selective fishing on ecosystem structure and function.

6. Synthesis of Discussions

The presentations summarized above were followed by numerous discussions and the workshop came progressively to a set of conclusions presented below that can be taken as reflecting the workshop views on the issue of selective fishing and balanced harvesting.

6.1 Premises

The discussions were grounded on a common understanding about fisheries, conservation and sustainability that could be briefly summarized as follows:

1. Exploited aquatic ecosystems are complex social-ecological systems (*sensu* Folke *et al*., 2000). They are only partially understood and weakly predictable or controllable.
2. Responsible and sustainable use of ecosystems aims to extract goods and services without reducing the options available to future generations.
3. Conservation of biodiversity aims to protect ecosystem stability and productivity. It also promotes the delivery of ecosystem goods and services, including food security and ecosystem health.
4. All uses alter the ecosystem structure (and possibly functioning) to some variable extent.
5. Harvest needs to be selective with the usual goals to: a) select the most favourable area/habitat in which to operate (based on its physical and ecological characteristics); b) target the adequate mix of species and sizes requested by a selective market; c) be economically efficient (e.g., catching the more valuable sizes and species at the lowest possible cost); d) comply with conservation constraints (e.g., avoiding protected species) and e) avoid growth overfishing (avoiding the capture of juveniles in order to let them grow). The latter, however, is an expectation under the single species yield-per-recruit (Y/R) maximization paradigm and it is questionable as soon as species interactions through the food chain are considered.
6. For a number of reasons, fisheries' performance in meeting these goals has been mixed. For example: a) selectivity is often insufficient, resulting in significant discards; b) juveniles are often massively captured and marketed or discarded depending on local circumstances; c) many fisheries operate at the edge of economic failure; d) the number of threatened species has increased during the last five decades.
7. Fishing capacity and selectivity interact strongly and the expected benefits of selectivity based on conventional Y/R theory (e.g., higher yields through improved survival of juveniles) are often confounded by progressive changes in fishing pressure and ecological (e.g., trophic chain) relationships.
8. There is a concern that selectivity may increase the evolutionary pressure that fishing places on populations, resulting in overall changes that are not favourable to fisheries and may be unfavourable to ecosystem maintenance.
9. Conservation is also selective when protecting particular species, sizes or habitats. Some conservation instruments are more selective than others.
10. The objective of changing selectivity may conflict with that of maintaining ecosystem structure and functioning.
11. The total net impact of all interventions, extractive or protective, voluntary or accidental, is what matters for ecosystem maintenance and what should be the concern of both fisheries management and conservation.
12. There are reasons to question whether the present piecemeal approach to selective fishing and protection is optimal in this respect, particularly considering the inadequacy of the single species-based theory to deal with complex ecosystems.
13. The selectivity of fishing and conservation measures interact, affecting ecosystem functioning in a manner that is neither intuitive nor easy to forecast.
14. New elements of science shed some light on the issue and these were the focus of this workshop.

6.2 Why do selectivity and its consequences matter?

It is important to clarify, for the various target audiences of this report, why the questions of selective fishing and selective protection practices and their combined consequences are relevant in the context of an ecosystem approach to fisheries and to conservation of biodiversity and of ecosystem structure and properties. Three key elements must be considered. First, several aspects of the conventional selectivity paradigm are based on single-species technical and economic considerations without considering ecosystem effects (e.g., trophic flows) and evolution. Second, the ecosystem approach was adopted by policy makers because of the growing recognition of the need for a holistic view of resources use including biodiversity and ecosystem structure, properties and processes. Third, the selective removal of a narrow range of species (or sizes of these species) may not be the best way to harvest the whole community in a sustainable manner, i.e., preserving the structure and function of the ecosystem.

As a consequence, a number of questions come to mind, such as:

1. *Regarding the ecosystem components that are voluntarily impacted (i.e., targeted by harvesting)*: Is the ecosystem impact buffered anyway because: 1) the targeted elements have functional equivalents in the ecosystem; or 2) the targeted elements are highly connected to the other ecosystem components? If the answer were negative, the impacts could radiate further through the system and through space, resonate longer, and be amplified rather than buffered by system processes.
2. *Regarding those components that are being protected*: Are they so especially fragile or vulnerable that, if they received the same perturbation as targeted species, the impact would result in greater *direct* harm (than on the voluntarily impacted components)? Are they so vital to ecosystem functioning that such equal perturbation would result in greater *indirect* consequences?
3. *Are there threshold levels* above which conventional selectivity strategies may cause regime shifts or would significantly alter ecosystem structure and function?

6.3 Definitions

6.3.1 Selectivity

The meeting discussed the meaning of the term "selectivity" in detail to reach a comprehensive definition. It was stressed that the usual meaning of the term was connected to a single-species management paradigm and that the shift to an ecosystem approach called for definitions covering the species, the assemblage and the ecosystem perspective. Selectivity was tentatively defined at ecosystem level as:

> *The process through which fishing obtains a catch the composition of which differs from that of the ecosystem being harvested. The relative probability of a species, sex, size or any relevant biological or ecological group to be caught.*

Selectivity results in a characteristic fishing pattern. It was stressed that selectivity and final catch composition depended on several interacting factors:

- *Economy*: selecting the targets that can be economically caught and placed on viable markets, or limiting the type of technology a fisher can afford;
- *Technology*: selecting the sizes/species that may be catchable with available gear;
- *Ecology*: the accessible habitats and the species they contain;
- *Fish behaviour*: such as migration, aggregation, attraction or avoidance reactions that condition catchability;
- *Legislation*: through the various regulations fixing what catch is allowed and with what means;
- *Culture*: as local ethics and religion or culinary habits do not recognize certain species as resources to be utilized, or as species to be used only in certain ritual circumstances.

Selectivity results from the distribution of fishing in space (selecting the area/habitat and depth of operation) and/or time (selecting the hour, day, fishing season) as well as through the type and characteristics of the gear used (including mesh size) and the way it is used. It impacts the individual fish (e.g., its risk of death in relation to its shape, size, age or sex), the population (e.g., its reproductive potential, gene pool), the species assemblage and ultimately the ecosystem (e.g., by modifying the species composition, resilience and productivity). Selectivity ought to be defined, therefore at the level of the gear (e.g., mesh or hook size; gear structure), the vessel, the fleet, the fishery and across fisheries in a given ecosystem. The last two matter particularly under the ecosystem approach.

It was indicated (in Section 5.4) that individuals of some species of fish going through the process of escaping through a net were heavily stressed and most often died. Thorough reviews of the subject (e.g., Suuronen, 2005) indicate however that this is usually the case of pelagic fish (and this is one reason why mesh selectivity is rarely used in these species and that demersal species such as haddock, whiting, saithe and cod had shown up to 90 percent survival. There is also research showing high survival after release from hooks, traps or other sort of gear and this suggests that improvements in gear or operational modes (e.g., making shorter sets) may succeed in increasing survival rates and returning unwanted captures alive to the ecosystem.[4]

Species-based protection measures induce additional selectivity in the fishing process and, under an ecosystem approach, their impact needs to be assessed at the assemblage and ecosystem level.

Finally, new science is pointing to the collateral effects of selective fishing (and indeed of all fishing) on phenotypes and possibly genotypes and strategies are needed to minimize these effects. Figure 10 shows the difference between the distribution of predation mortality (M) and fishing mortality (F) by age group. It shows that fishing inverts the risks for the individuals, inducing a strong pressure towards smaller size and earlier reproduction.

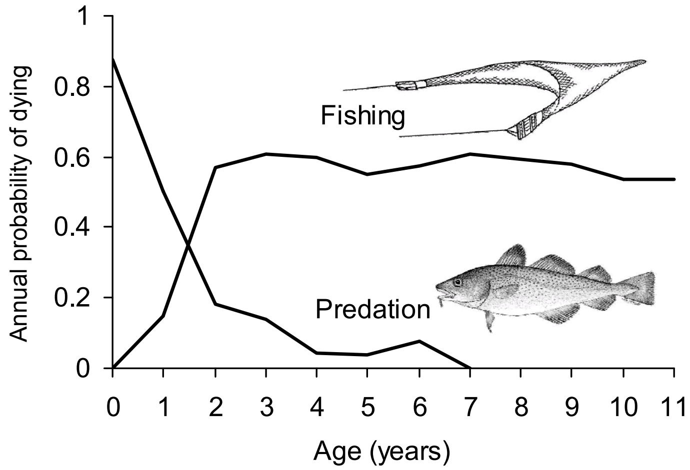

Figure 10. Annual probability of dying from predation or fishing for the different age groups of North Sea cod (*Gadus morhua*), average 1987–1994 (from Kolding and van Zwieten, in press)

6.3.2 Balanced harvesting

Balanced harvesting aims at the implementation of fishing and protection patterns (in relation to size and species composition) that are coordinated at ecosystem level, and lead to better balancing of fisheries harvest with biological productivity and ecosystem resilience. It intends to provide a better balance between

[4] There is also an active ICES working group (WGQAFM) dealing with this whole area of unaccounted mortality including things like escape mortality.

ecosystem and human well-being as well as between the rates of use of the different ecosystem components. Balanced harvesting was defined by the workshop as:

> *A strategy that distributes fishing pressure across the wider possible range of trophic levels, sizes and species of an ecosystem, in proportion to their natural productivity, reducing fishing pressure where it is excessive.*

What constitutes acceptable balance is a matter for society to decide, informed by science about the options available and the expected impacts. From knowledge of species' productivities (recruitment and growth rate) and trophic and other interactions in the ecosystem, it may be possible to estimate how best harvesting should be distributed among species and sizes to produce high sustainable yields while maintaining ecosystem properties. However, this task might be complicated by the complexity of, and uncertainty about, interactions. Some modelling results presented at the workshop strongly suggest that diversifying the composition of the harvest taken from an ecosystem, among sizes and functional groups, in proportion to their natural production, would lead to a smaller total impact on the ecosystem (e.g., on its stability and productivity) for a given level of removals or to a higher level of removals for the same level of ecosystem impact.

Balanced harvesting does not mean unselective fishing or indiscriminate, chaotic exploitation. It doesn't entail simply adding new species, sizes or functional groups to the current harvested range.

The specific idea of *balanced harvesting* is not new. It emerged progressively through the multispecies and ecosystem science (see Caddy and Sharp, 1986: 133; Hall, 1996; Hall *et al*., 2000; and Bundy *et al*., 2005). Caddy and Sharp for example state that "[i]n theory a food web could be maintained 'in balance' by fishing each component in proportion to the rate of natural predation it is subjected to". This is equivalent to exploiting each food web level proportionally to its natural production. Caddy (1990) raised doubts regarding the simplistic assumptions behind mesh size regulations, particularly in the context of multispecies fisheries, and suggested the use of refuges to protect old spawners.

In the Eastern Pacific, for example, the action taken towards zero-dolphin mortality had significant collateral effects on other components of the ecosystem (see Section 6.6). It was stressed that high levels of protection for some components of an otherwise significantly used ecosystem was very likely to lead to unexpected ecosystem changes affecting both protected and unprotected species.

The workshop looked into the concepts of selectivity and balanced harvest only from an ecological perspective. It is recognized that adding socio-economical dimensions to the issue might shift the solution in directions that are not easily foreseen.

6.4 Theory

The theory behind conventional selectivity management derives from the original work by Beverton and Holt (1957). It is based on the concept of maximum sustainable yield in relation to the age at first capture and the distribution of fishing mortality on age groups. It applies to single populations and, in simple implementations, does not take trophic interactions between fisheries and species into account except through the use of natural (predation) mortality. The latter has usually been taken as constant with time and age, after the age at first capture, so that natural resource dynamics are not captured.

The development of the multispecies multigear fisheries theory in the 1970s (Andersen and Ursin, 1977; Laevastu and Larkins, 1981) raised the understanding at the level of co-occurring species assemblages, accounting for cross-predation effects as well as technical interaction between fleets catching the same species. Much progress in that direction was made in the following years, particularly through the ICES Multispecies Working Group and the use of the Multispecies Virtual Population Analysis (MSVPA). However, the main uses of that work were simply re-setting the natural mortality parameter of single species assessments once or twice a decade – as shown in the reports of the ICES Advisory Committee on Fisheries Management (ACFM) from the 1990s – and some estimates of multispecies consequences of changes in mesh size e.g., ICES, 1989. In practice, most of population-based mesh size regulations continued to be based on single-species theory (to reduce the take of juveniles), modified as needed to reduce the take of unwanted species and not the results of the multispecies consequences of mesh changes.

The development of more and more ecosystem models since the 1980s has shifted attention to food chain and predator-prey relationships, opening the avenue for a more ecosystemic concept of selectivity. Here, the aim is not to optimize yield from a population reducing collateral effects, but optimizing the long-term production of an assemblage or an ecosystem, preserving its biodiversity, structure and resilience. A number of selectivity issues emerged which are not always intuitive. An example is the concern that adopting a larger mesh will release larger fish that may have a negative impact on recruitment of the target species (including through cannibalism) or on associated species (through higher predation) with unknown overall effect. While the focus of conventional selectivity has been on releasing juveniles, attention has started to be paid more recently to the need to protect also a sufficient biomass of old mature spawners (Caddy, 1990).

6.5 Modelling results

Several modelling approaches have been used to investigate the impact of fishing selectivity on populations, communities and ecosystems. Models used included steady-state and dynamic size-based models, dynamic body mass-based models, length-based multispecies models (e.g., LeMANS), mass balanced models (e.g., Ecopath, Ecopath with Ecosim, EwE) and more complex nutrient-driven ecosystem simulation models (e.g., Atlantis).

The theory of fishing-induced evolution at the population level is now well developed. Fisheries-induced selection is often predicted to drive evolution towards stocks that can sustain higher fishing pressures by decreasing age at maturity and adult body size (Section 5.2). A notable exception is a pure spawner fishery. As Law and Grey (1989) showed for NE Arctic cod, with selective fishing of spawning cod only, the equilibrium yield after evolution could be substantially increased.

At the community level, multispecies model results have suggested that increasing mesh size in a multispecies context, accounting for predator-prey relationships, might not have the expected benefits and might indeed have the very opposite effects (Pope, 1991;[5] Figure 11). It has been shown for example that, for North Sea cod, the estimated impact of using a larger mesh size (from 85 to 120 mm) is positive for the target and all associated species when species interactions are not taken into account but systematically negative for all species when these interactions (particularly predation) are accounted for (ICES, 1989). A recent study dedicated to the selectivity question predicted, in addition, that narrowly targeted harvests, focusing on a limited range of species or size, are generally not optimal for biodiversity conservation (Section 4.1).

[5] Pope (1991) stressed that, in the case of an increase in mesh size to 120 mm (in the roundfish and saithe fleets), "the calculations suggested that increasing mesh size would tend to decrease the yield and the value of the majority of species, a result contrary to the advice given by single species assessments".

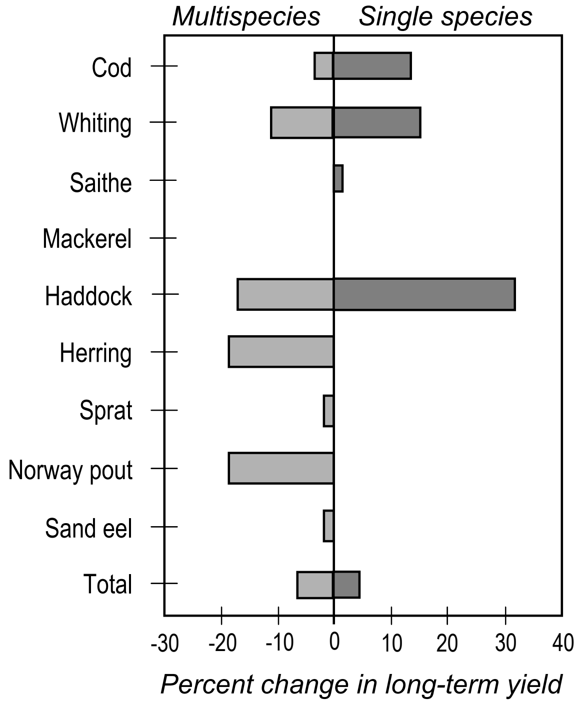

Figure 11. Percent changes in the long-term fishery yields for the North Sea multispecies system resulting from an increase in trawl mesh size from 85 to 120 mm for the directed fishery for cod. Results are presented for single species (but multi-fleet) Y/R assessment (dark bars) and multispecies virtual population analyses (MSVPA) including interspecies predation (light bars). Lower yields in the multispecies analysis are due to greater predation rates from large predatory fish (cod, whiting, haddock, saithe) released by the larger mesh sizes (redrawn from ICES, 1989)

At the ecosystem level, species-based, size-based, or mixed approaches have been developed. The advantage of the size-based approach lies in its relative simplicity, and the fact that the underlying theory is well developed. For example, the conditions of ecosystem stability have been examined in detail (Section 3.2). Fishing tends to destabilize the trophic flow in size spectra, more so when targeting a narrow range and/or larger sizes (Section 4.1). When life-history diversity is introduced in the model, trophic cascades are damped, but again targeting large sizes generates more disturbance than targeting small sizes (Section 3.1). Species-based and mixed approaches have been less developed and need further analyses, but their results lead to conclusions consistent with the other model results (Sections 3.3 and 4.5).

Model results typically concur that the exploitation strategies predicted to maximize multispecies yield while best maintaining ecosystem structure and processes are not those that target narrow ranges of species or sizes. Rather, harvesting an intermediate to wide range of species or sizes, preferably not too high in the food chain, seems to be a better strategy to maximize yield under ecosystem conservation constraint.

However, this result is sensitive to some model assumptions, such as the diversity of life histories. It is also dependent on the way selectivity at the community level is represented in the model; as there is limited knowledge of the actual shape of selectivity in real communities, this needs to be assumed, so that model predictions are dependent on unverified assumptions.

Model results also concur that fishing selectivity and intensity closely interact in determining the impact of fishing on the ecosystem – a given fishing intensity may be sustainable with one given selectivity pattern, but not with another.

6.6 Empirical evidence

Many of the elements considered by the workshop in favour of balanced harvesting came from modelling results. It has been difficult however to find empirical evidence of the effects of balanced harvesting. For example, in the only presentation that looked for empirical evidence to test models' conclusions (see Section 4.1) it was not possible to detect, in trawl survey data, the ecosystem impacts predicted by a model in the North Sea and Georges Bank.

Increasing mesh sizes in fisheries to allow smaller fish to escape is generally considered positively by most managers and by society (if not by the fishers, Misund *et al*., 2002) but it has been shown above that, in North Sea fisheries, taking predation into account may very significantly modify the expected outcome of such measures. Moreover, a recent review of the changes actually observed in these fisheries following the introduction of the 120 mm mesh size in 2001, shows the effects on species yields bore no resemblance to any of the single species or multispecies forecasts illustrated in Figure 11 (Norman Graham, pers. comm.). This indicates that single-species forecasts of selectivity patterns may be too simplistic to be correct and that multispecies and ecosystem–based forecasts are difficult to obtain and test in practice.

In several small-scale inland fisheries in Africa, the slope of the size spectrum has been maintained despite the rarefaction of all size groups, in situations of heavy and overall non-selective fishing leading to widespread fishing pressure on the species and size spectra (Misund *et al*., 2002; Kolding *et al*., 2003a and 2003b; van Zwieten *et al*., 2003; and Section 4.3 of this report). This was considered by some participants as a possible example of unplanned balanced harvest. On the contrary, on the Eastern Scotian Shelf, high and selective exploitation resulted in high disturbance of the trophic structure and species richness.

The apparent coherence of the model-based conclusions must therefore be qualified by the difficulty encountered in trying to verify the model forecasts with historical observations. The reasons for this divergence may relate to a variety of problems with *inter alia* : 1) measuring fishing pressure and selectivity at community level, including a clear distinction between size- and species-selectivity; 2) interaction between multiple pressures including the simultaneous changes in fishing intensity, selectivity and environmental drivers; 3) the positive and negative consequences of fishing on benthic productivity; and 4) the length of the time-series of data available. Data quality may also be an issue in many places. Considering the dynamism and susceptibility of ecosystems to external drivers this is not so surprising and separating the impacts of selectivity from those resulting from environmental variability might be a real challenge in the future.

A number of examples exist showing the emergence of unexpected results (surprises) of selectivity regulations. The very positive effect of the dolphin protection in the Eastern Pacific tuna fisheries, for example, obtained by increasing species selectivity relative to dolphins, was accompanied by profound changes in the fishery leading in the medium term to extremely high, new and negative ecological impacts on many more species (Table 1).

	Before	After
Yellowfin mean size	18-22 Kg	3-6 Kg
Discard weight/set	0.1 t (1%)	4.6 t (10%)
By-catch rate/set	1 dolphin 0.3 sailfish 0.2 manta ray	26 sharks 1.8 marlins 800 large bony fishes 1250 small fishes 0.04 turtles

Table 1. Unexpected effect of introducing selectivity measures in the Yellowfin tuna purse seine fishery in the Central Eastern Pacific (Hall, 1998)

As a result of this, the development of the tuna fishery on fish aggregating devices (FADs) led to declines in the condition of Yellowfin and Bigeye tuna stocks, increased by-catch of declining stocks of sharks (Oceanic whitetip and Silky shark) and other species that have not been assessed yet. It has also been shown that the use of the circle hook to reduce turtle by-catch has led to an increase in the by-catch and accidental mortality of blue sharks. These examples underline the difficulty in forecasting the effects of selectivity measures and the trade-offs involved at assemblage, ecosystem and fishery sector levels.

There is also ample evidence of phenotypic changes under increased selective fishing pressure, e.g., in plaice and cod (Rijnsdorp, this meeting; Heino, this meeting, reviewed in Law, 2000; Jørgensen *et al*., 2007; Heino and Dieckmann, 2008) but no definite proof yet that this effect is a genetic response to the pressure. The use of dome-shaped fishing pressure (sparing juveniles and old spawners) seems theoretically promising albeit hard to implement in multispecies fisheries. It appears that the direction of the phenotypic – or perhaps genetic – adaptations of the fishes to fishing (e.g., reproducing earlier, reducing maximum size) helps the population to resist/withstand the increasing fishing pressure (successful adaptation). However, the adaptations also tend to reduce yields in most circumstances (except in spawner fisheries)[6] and sizes, an unfavourable development for fisheries, and the limits of that adaptation as well as the extent to which resilience to other pressures such as climate change are also affected have yet to be explored.

6.7 Research questions

The workshop identified a number of scientific matters requiring priority attention in order to resolve the issues identified above. The list has not been ranked and does not pretend to be exhaustive.

Selectivity needs to be defined, described and investigated at the community level. What is its pattern? How could it be estimated? How is it determined by the gears deployed? This is very much related to the issue of data needs and sampling: how can we estimate what is available? How to pull together different sources of information, such as fishery-dependent and independent data? Fuzzy or qualitative approaches may be useful here.

On the other hand, a novel issue is to define and describe what a balanced exploitation is, what exactly it should be aimed at and how this could be achieved. Should mortality be proportional, or increase more than proportionally, with components' mortality, biomass, production, productivity, or with a combination of these? The magnitude of these processes would also have to be estimated to make it possible to estimate the "balanced harvesting pattern". It is therefore important to review the information available on the productivities of the species and sizes that balanced harvesting of the ecosystem would be likely to exploit.

Although the theory and modelling of the impact of selective fishing on communities and ecosystems is already well developed, it has been little corroborated in nature and there is a need for more empirical evidence that highly selective fishing indeed affects real communities and ecosystems as expected. Even the available empirical evidence of fishing-induced evolution is indirect. Experimental evidence could be sought by conducting contrasted exploitation experiments in microcosms or lakes; the limit to this approach is cost, and the requirement to wait long enough to see the community effects, that may propagate slowly through complex feedbacks in the food webs. Another approach would be a retrospective comparison of exploited ecosystems, either in lakes (North America or Africa could provide good examples) or in the marine environment (e.g., by comparing sufficiently "insulated" no-take areas with adjacent exploited areas). The foreseeable difficulties of such studies will lie in: 1) finding ecosystems that are ecologically comparable although exploited in a different way (similar ecological settings might foster similar exploitation patterns); 2) disentangling the changes in fishing intensity and selectivity, which might generally be closely linked; 3) controlling for the effects of multiple pressures co-occurring and potentially interacting; and 4) detecting signals in noisy data.

Much progress is expected from comparisons of ecosystems in which more or less balanced harvesting is carried out, and with contrasted management policies. Similarly, a diversity of ecosystem or community

[6] In the NE Arctic cod fishery, harvesting just the spawners on the Norwegian coast generated selection for delayed maturation and greater growth on the feeding grounds in the Barents Sea. Assuming an appropriate genetic component to maturation, the calculations suggested that the stock was undergoing genetic change towards a state that would give a greater yield at equilibrium. Usually, however, there is no such neat separation between immature and mature individuals, allowing fishing mortality to be focused on the mature ones.

models relying on diverse assumptions will be required to examine the robustness of predictions and provide a full picture of the expected effects of fishing.

Most fisheries have performed poorly at catching their target when it was narrow, and therefore have generated discards. What might happen if the paradigm were to change and if the target became wider, aiming at “a balanced exploitation”? At first sight it would seem easier, but it may not be so easy to catch an appropriately “balanced” catch, even if balance was well defined. Research on the difficulties and solutions to achieve this is required.

A related question is how to implement the shift in paradigm in already overexploited systems. When a system has been strongly exploited in an unbalanced way so that some ecosystem components are depleted, shifting to balanced exploitation may not be sufficient to restore ecosystem structure and biodiversity. The appropriate exploitation strategies in that context need to be developed.

The ecosystem efficiency of conventional technical measures such as mesh-size regulations or deployment of selective devices has not yet been much examined. There is an urgent need to thoroughly analyze how these and other regulations affect mortality-at-size when they are implemented.

Over the last decades, community ecology has developed many models for explaining community composition and the coexistence of species. However, most of these models do not apply in a fisheries context, as they rely on assumptions on resource partitioning which are not the limiting factor in exploited communities. Models to that effect need to be developed, potentially taking account of size structure. So far the effects of fishing have been primarily examined on functional diversity, but management objectives might be framed as species diversity; the effects of fishing on species diversity and the consequences of species diversity losses need to be examined as well.

There is a strong need to include the spatial dimension to tackle biodiversity and address questions such as the co-occurrence of species or the spatial aspects of the fishing selection process.

While the theory of fishing-induced evolution is well developed and some indirect evidence is available, the consequences on the community level have been little examined. There is a need to incorporate fishing-induced changes in life history in community models to obtain a more complete picture of the potential effects of fishing.

The potential economic and social consequences of adopting a balanced harvesting strategy are likely to be large: these consequences, and the implications of these consequences from the socio-economic perspective on an ecosystem approach to fisheries need to be investigated.

6.8 Management implications

The predictions obtained from models and the little empirical evidence available led the workshop to make some suggestions in terms of management objectives and strategies.

6.8.1 Management objectives and indicators

One of the key premises to management is the existence of a set of agreed objectives. Clear principles and conceptual objectives already exist in national and international agreements and legislation, such as the need to maintain ecosystem structure (biodiversity) in order to maintain ecosystem functioning, ensure food security as well as economic and social wellbeing, and satisfy other requirements such as carbon footprint, protection of habitats and non-target species, emblematic species, etc. These are embedded in the UN Convention on the Law of the Sea, the FAO Code of Conduct for Responsible Fisheries, the CBD etc. Conceptual objectives need to be translated into more operational ones, tailored to specific ecological and socio-economic situations. There is, however, no general agreement on the “operational objectives” that are to be derived from the conceptual ones.

Nonetheless, indicators and reference points are clearly required as management benchmarks, to inform decision making on the state of the system components and the direction in which they are heading. Issues in that respect relate to the cultural context (important and diversified) and practical issues (regarding data availability, agreement on a small set of indicators, problems of monitoring). Because of uncertainty, the use of indicators will need to be complemented by systematic risk assessments.

It is stressed that reserves might play an important role as areas providing the reference states without which changes in the ecosystems, driven by fishing or not, will not be understandable. However, how much can be effectively learned about system functioning and trends from reference areas depends on their location, size, environment, history, fish behaviour (migrations in and out of the area), degree of protection and indeed effective isolation from the surrounding system.

6.8.2 Management strategies

The key questions behind the balanced harvest concept are: 1) *at ecosystem level*: How to slice the ecosystem pyramid[7] of trophic levels? And 2) *at population level*: How to harvest the age/size structure? In other words, how to decide what is an acceptable harvest pattern (i.e., the level of fishing pressure and its distribution on population and ecosystem components) and how can we determine at any time how far away we are from a balanced harvest? The question has no easy answer yet, even though it is strongly suggested that the harvest must be made in proportion to natural production, connected to natural mortality which itself can change over time and with changes to system structure. It is clear that strategies to achieve that proportionality (or balance) need to be built around the concept of cumulative selectivity and exploitation, i.e., the total resulting selectivity pattern and total harvest at the ecosystem level, rather than solely at the individual fishery or gear level. It is suggested that a useful first step would be to undertake a thorough evaluation of the overall cumulative performance of the selectivity-based strategies already in place (usually species-based), by ecosystem.

Thought is also needed regarding the criteria to be used to qualify the "balance": Would the policy try to balance harvest across sizes? Species? Trophic levels? What are the indicators of "balance"? What is the scale and what are the value judgements related to that scale? Or, in other words, what is an acceptable impact to the balance?

Depending on the ecosystems and the systems of harvest, what tools can be used to balance harvest? Gear selectivity? Time and space allocations and controls? Market controls? Capacity controls? Economic incentives? In practice, it would most likely be a combination of all or many of these. What are the implications for the quotas policies and the progressive generalization of Individual Transferable Quotas (ITQs)? Can this hyper-fractioning of the resources be compatible with a real ecosystem approach to fisheries? In what way? How can ecolabelling criteria be adapted to better account for fisheries properties at ecosystem level? Is this feasible? Is it desirable? Should new food technologies be developed and promoted to allow for a better use of a wider range of species, satisfying food security requirements while reducing pressure on single ecosystem components? As some ecosystem components will always have higher prices than others, could economic measures provide incentives towards a better utilization of catch in order to re-establish an economic "balance" to facilitate a balanced harvest? A practical problem is that of creating markets for small low-value fish in the developed world as fish since reduction to oil and meal fetches a price that is perhaps one tenth of food fish prices.

It emerged clearly from the preliminary discussions that management strategies will have to depend on local conditions, whether ecological (e.g., in what state is the system and how is it evolving?); economic (e.g., what are the costs of change and the alternatives?); technological (e.g., are fisheries small or large-scale? Is the ecosystem inshore or offshore?); or social (e.g., how important is the fishery to the dependent community and what are the social costs of making changes now versus maintaining the status quo?).

In small-scale fisheries for example, gear regulations (including for selectivity) are the only ones systematically applied, particularly in data-poor situations, and it has been argued (see Section 4.3) that their application has often been nonsensical (Kolding and van Zwieten, in press).

It was also stressed that, in any case, the problems raised by selective harvesting and selective protection (the other side of the same coin) need to be discussed **together**, calling for a collaboration between the two streams of governance (and science). In this context, it is clear that the question of balanced harvest offers an important opportunity to discuss the role of marine protected areas and reserves in balancing harvesting strategies.

---

[7] The question refers to Elton's pyramid of abundance by size groups, as well as the trophic chain of abundance by trophic level.

Finally, while recognizing that the model-based conclusions need to be further confirmed and backed up by more empirical evidence, the group underlined that the management strategies would need to:

- Reduce overall impact by eliminating overfishing as a prerequisite for implementing and benefiting from balanced harvest;
- Recognize that the modern conventional management strategies tend to increase segmentation and the concentration of fishing on some pieces of the biodiversity spectra and that this is not in line with important aspects of an ecosystem approach;
- Broaden the narrow consideration of single-species regulations to include assessment and forecasts of impacts on assemblages and ecosystem regulations;
- Increase focus on diversity and diversification of catch and of fisheries to better distribute the impact; and
- Target intermediate sizes, reducing pressure on juveniles and old spawners.

6.9 CBD COP side-event

A lunch-time side-event was organized on 20 October during the CBD COP 10 meeting in order to present the results of the workshop to a broader audience. The event was moderately attended due to competition with important programmatic events of the CBD. It was nonetheless very useful and allowed for the presentation and clarification of the main themes and conclusion of the workshop, in a constructive manner.

References

Andersen, K.H. and Beyer, J.E. (2006). "Asymptotic size determines species abundance in the marine size spectrum". *The American Naturalist* 168: 54–61.

Andersen, K.H. and Pedersen, M. (2010). "Damped trophic cascades driven by fishing in marine ecosystems". *Proc. Roy. Soc. London B* 277: 795–802.

Andersen, K.H. and Rice, J.C. (2010). "Direct and indirect community effects of rebuilding plans". *ICES Journal of Marine Science* 67(9): 1980–1988.

Andersen, K.P. and Ursin, E. (1977). "A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorus circulation and primary production". *Meddeelser fra Danmarks Fiskeri- og Havundersogelser NS* 7: 319–435.

Beverton, R.J. and Holt, S.J. (1957). *On the dynamics of exploited fish populations*. Fishery Investigations Series II, Volume XIX. London: HMSO.

Bundy, A., Fanning, P. and Zwanenburg, K.C.T. (2005). "Balancing exploitation and conservation of the eastern Scotian Shelf ecosystem: application of a 4D Ecosystem exploitation index". *ICES Journal of Marine Science* 65: 503–510.

Caddy, J.F. (1990). "Options for the regulation of Mediterranean demersal fisheries". *Natural Resources Modelling* 4(4): 427–475.

Caddy, J.F. and Sharp, G.D. (1986). *An ecological framework for marine fishery investigations*. FAO Fisheries Technical Paper 283.

Collie, J.S. and Rochet, M.-J. (2010). "Temporal Changes in the Diversity of Shelf-sea Fish Communities". Presentation at ICES Annual Science Conference, 20–24 September 2010, Nantes, France. ICES CM 2010/Q:03.

Datta, S., Delius, G.W., Law, R. and Plank, M.J. (2010). "A stability analysis of the power-law steady state of marine size spectra". *Journal of Mathematical Biology.* [In press]

Ernande, B., Dieckmann, U. and Heino, M. (2004). „Adaptive changes in harvested populations: plasticity and evolution of age and size at maturation". *Proceedings of the Royal Society B: Biological Sciences* 271: 415–423.

Folke, C., Berkes, F. and Colding, J. (2000). "Ecological practices and social mechanisms for building resilience and sustainability". In: Berkes, F., Folke, C. and Colding, J. *Linking social and ecological systems. Management practices and social mechanisms for building resilience*. Cambridge: Cambridge University Press.

Hall, M.A. (1996). "On bycatches". *Rev. Fish Biol. and Fisheries* 6: 319–352.

Hall, M.A. (1998). "An ecological view of the tuna-dolphin problem". *Rev. Fish Biol. and Fisheries* 8: 1–34.

Hall, M.A. and Donovan, G.P. (2001). "Environmentalists, fishers, cetaceans and fish: is there a balance and can science help to find it?" In: Evans, P. and Raga, A. (Eds) *Marine Mammals: Biology and Conservation*. New York: Plenum Press.

Hall, M.A., Alverson, D.L. and Metuzals, K. (2000). "Bycatch: Problems and solutions". In: Sheppard, C.R.C. (Ed.) *Seas at the Millennium: An environmental evaluation. Vol. III: Global Issues and Processes*. Amsterdam and Oxford: Pergamon Press and Elsevier Science. Reprinted in *Marine Pollution Bulletin* 41(1-6): 204–219.

Hall, S.J., Collie, J.S., Duplisea, D.E., Jennings, S., Bravington, M. and Link, J. (2006). "A length-based multispecies model for evaluating community responses to fishing". *Canadian Journal of Fisheries and Aquatic Sciences* 63: 1344–1359.

Heino, M. (1998). "Management of evolving fish stocks". *Canadian Journal of Fisheries and Aquatic Sciences* 55: 1971–1982.

Heino, M. and Dieckmann, U. (2008). "Detecting fisheries-induced life-history evolution: an overview of the reaction norm approach". *Bulletin of Marine Science* 83: 69–93.

Hiddink, J.G., Rijnsdorp, A.D. and Piet, G. (2008). "Can bottom trawling disturbance increase food production for a commercial fish species?" *Canadian Journal of Fisheries and Aquatic Sciences* 65: 1393–1401.

ICES. (1989). "Report of the multispecies assessment working group". ICES CM 1989/Assess: 20. Copenhagen: International Council for the Exploration of the Sea.

ICES. (1997). "Report of the multispecies assessment working group". ICES CM 1997/Assess: 16. Copenhagen: International Council for the Exploration of the Sea.

Jørgensen, C., Enberg, K., Dunlop, E.S., Arlinghaus, R., Boukal, D.S., Brander, K., Ernande, B., Gårdmark, A., Johnston, F., Matsumura, S., Pardoe, H., Raab, K., Silva, A., Vainikka, A., Dieckmann, U., Heino, M. and Rijnsdorp, A.D. (2007). "Managing evolving fish stocks". *Science* 318: 1247–1248.

Jul-Larsen, E., Kolding, J., Overå, R., Nielsen, J.R. and van Zwieten, P.A.M. (2003). *Management, co-management or no-management? Major dilemmas in Southern African freshwater fisheries*. FAO Fisheries Technical Papers 426/1 (Synthesis) and 426/2 (Case Studies). Rome: FAO.

Kolding, J. and van Zwieten, P.A.M. The tragedy of our legacy: how do global management discourses affect small-scale fisheries in the South? Forum for development studies. Submitted, http://www.tandf.co.uk/journals/sfds [In press]

Kolding, J., Musando, B. and Songore, N. (2003a). "Inshore fisheries and fish population changes in Lake Kariba". In: Jul-Larsen *et al.*, FAO Fisheries Technical Paper 426/2.

Kolding, J., Ticheler, H. and Chanda, B. (2003b). "The Bangweulu Swamps – a balanced small-scale multispecies fishery". In: Jul-Larsen *et al.*, FAO Fisheries Technical Paper 426/2.

Laevastu, T. and Larkins, H.A. (1981). *Marine fisheries ecosystem: its quantitative evaluation and management*. Farnham: Fishing News (Books) Ltd.

Law, R. (2000). "Fishing, selection, and phenotypic evolution". *ICES Journal of Marine Science* 57: 659–668.

Law, R. and Grey, D.R. (1989). "Evolution of yields from populations with age-specific cropping". *Evolutionary Ecology* 3: 343–359.

Misund, O.A., Kolding, J. and Fréon, P. (2002). "Fish capture devices in industrial and artisanal fisheries and their influence on management". In: Hart, P.J.B. and Reynolds, J.D. (Eds) *Handbook of Fish Biology and Fisheries, vol. II*. London: Blackwell Science.

Norris, S. with Hall, M., Melvin, E. and Parrish, J. (2002). "Thinking like an ocean: Ecological lessons from marine bycatch". *Conservation in Practice* 3(4): 10–17.

Poos, J.J., Bogaards, J.A., Quirijns, F.J., Gillis, D.M. and Rijnsdorp, A.D. (2010). "Individual quotas, fishing effort allocation and over-quota discarding in mixed fisheries". *ICES Journal of Marine Science* 67: 323–333.

Pope, J.G. (1991). "The ICES Multispecies Assessment Working Group: evolution, insights, and future problems". *ICES Mar. Sci. Symp*. 193: 22–33.

Rochet, M.-J., Collie, J.S., Jennings, S. and Hall, S.J. Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model. *Canadian Journal of Fisheries and Aquatic Sciences*. [In press]

Rochet, M.-J., Benoît, E. and Collie, J.S. (2009). "Is selective fishing more harmful to marine communities than even exploitation? Theoretical investigations". ICES CM 2009/M: 07.

Suuronen, P. (2005). *Mortality of fish escaping trawl gears*. FAO Fisheries Technical Paper 478.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M. and Siemann, E. (1997). "The Influence of Functional Diversity and Composition on Ecosystem Processes". *Science* 277: 1300–1302.

van Keeken, O.A., van Hoppe, M., Grift, R.E. and Rijnsdorp, A.D. (2007). "The implications of changes in the spatial distribution of juveniles for the management of North Sea plaice (*Pleuronectes platessa*)". *Journal of Sea Research* 57: 187–197.

van Walraven, L.Y., Mollet, F.M., van Damme, C.J.G. and Rijnsdorp, A.D. (2010). "Fisheries-induced evolution in growth, maturation and reproductive investment of the sexually dimorphic North Sea plaice (*Pleuronectes platessa* L)". *Journal of Sea Research* 64: 85–93.

van Zwieten, P.A.M., Goudswaard, P.C. and Kapasa, C. (2003). "Mweru-Luapula is an open exit fishery where a highly dynamic population of fishermen makes use of a resillient resource base". In: Jul-Larsen *et al*., FAO Fisheries Technical Paper 426/2.

van Zwieten, P.A.M., Béné, C., Kolding, J. and Brummett, R. (Eds) Review of tropical reservoirs and their fisheries in developing countries: The cases of Lake Nasser, Lake Volta and Indo-Gangetic Basin reservoirs. FAO Fisheries Technical paper. [In press]

Zhou, S. (2008). "Fishery by-catch and discards: a positive perspective from ecosystem-based fishery management". *Fish and Fisheries* 9: 308–315.

Zhou, S., Smith, A.D.M., Punt, A.E., Richardson, A.J., Gibbs, M., Fulton, E.A., Pascoe, S., Bulman, C., Bayliss, P. and Sainsbury, K. (2010). "Ecosystem-based fisheries management requires a change to the selective fishing philosophy". *Proceedings of the National Academy of Sciences (PNAS)* 107: 9485–9489.

ANNEX 1. List of Participants

Arimoto, T.	Tokyo University of Marine Science and Technology, 4-5-7, Konan, Minato-ku, Tokyo 108-8477, Japan. Tel/Fax: +81354630470. Email: tarimoto@kaiyodai.ac.jp
Beyer, J.	DTU Aqua, National Institute of Aquatic Resources, Technical University of Denmark (DTU), Charlottenlund Castle, Jægersborg Allé 1, DK-2920 Charlottenlund, Denmark. Mobile: +4521706558. Email: jeb@aqua.dtu.dk
Borges, L.	Formerly: European Commission, Rue Joseph II 79, 1000 Brussels, Belgium. Presently at Sustainable Fisheries Partnership. Tel: +32476974451; Mobile: +32476974451. Web: www.sustainablefish.org; www.fishsource.org Email: lisa.borges@sustainablefish.org
Bundy, A.	Population Ecology Division, Bedford Institute of Oceanography, PO Box 1006, Dartmouth, NS B2Y 4A2, Canada. Tel: + 9024268353; Fax: +9024261506. Email: alida.bundy@dfo-mpo.gc.ca
Dunn, D.	Duke University Marine Geospatial Ecology Lab & Census of Marine Life, 135 Marine Lab Rd, Beaufort, NC 28516, USA. Tel: +12525047605; Fax: +12526488369. Web: mgel.env.duke.edu Email: daniel.dunn@duke.edu
Garcia, S.M.	Meeting Chair. IUCN-CEM Fisheries Expert Group (Chair). 14 Via Perdasdefogu, 00050 Aranova (Rome), Italy. Tel/Fax: +390661705228. Email: garcia.sergemichel@gmail.com
Graham, N.	Marine Institute, Rinville, Co Galway, Ireland. Tel: +353(0)91387200; Fax: +353(0)91387201. Email: norman.graham@marine.ie
Hall, M.	Inter-American Tropical Tuna Commission. 8604 La Jolla Shores Dr., La Jolla, CA 92037, USA. Tel: +18585467044. Web: http://www.iattc.org Email: mhall@iattc.org
Heino, M.	Department of Biology, University of Bergen. Box 7803, 5020 Bergen, Norway. Inst. of Marine Research, Bergen, Norway. Evolution and Ecology Program, Int. Inst. for Applied Systems Analysis, 2361 Laxenburg, Austria. Tel: +4755584544; Fax: +4755584450. Web: http://www.bio.uib.no/evofish/mh/ Email: mikko.heino@imr.no
Kolding, J.	IUCN-CEM Fisheries Expert Group. Department of Biology, University of Bergen, N-5020 Bergen, Norway. Tel: + 4755584407. Web: http://www.uib.no/bio/en Email: jeppe.kolding@bio.uib.no
Laissy, K.	Meeting assistant. European Bureau for Conservation and Development (EBCD), 10 Rue de la Science, 1000 Brussels, Belgium. Tel: +3222309070; Fax: +3222308272. Email: kathleen.laissy@ebcd.org
Law, R.	Biology Department, University of York, Heslington, York, YO10 5DD, UK. Tel: +441904328586; Fax:+441904328505. Email: RL1@york.ac.uk
Makino, M.	Fisheries Research Agency, 2-12-4, Fukuura, Kanazawa, Yokohama-city 236-8648, Japan. Tel/Fax: +81457887655. Web: http://www.k4.dion.ne.jp/~mitsutak/Index.htm Email: mmakino@affrc.go.jp
Rice, J.	IUCN-CEM Fisheries Expert Group (Vice Chair). Senior National Advisor – Ecosystem Sciences. Fisheries and Oceans Canada, 200 Kent Street, Stn. 12S015, Ottawa, Ontario K1A OE6, Canada. Tel: +16139900288. Fax: +16139540807. Email: jake.Rice@dfo-mpo.gc.ca

Rijnsdorp, A.D. Wageningen Inst. for Marine Resources & Ecosystem Studies (IMARES), P.O.Box 68, 1970 AB Ijmuiden, Netherlands. Tel: +31317487191; Fax: +31317487326. Email: adriaan.rijnsdorp@wur.nl

Rochet, M.-J. Département Ecologie et Modèles pour l'Halieutique, Ifremer, B.P. 21105. 44311 Nantes Cedex 03, France. Tel: +33240374121; Fax: +33240374075. Email: Marie.Joelle.Rochet@ifremer.fr

Simard, F. Global Marine Programme, IUCN, 28 Rue Mauverney, CH-1196 Gland, Switzerland. Tel: +41229990298; Mobile: +41797511161. Web: www.iucn.org Email: francois.simard@iucn.org

Symons, D. IUCN-CEM Fisheries Expert Group (Coordinator). Director, European Bureau for Conservation and Development (EBCD), 10 Rue de la Science, 1000 Brussels, Belgium. Tel: +3222309070; Fax: +3222308272. Email: despina.symons@ebcd.org

Smith, A.D.M. CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, Tasmania 7001, Australia. Tel: +61362325372; Fax: +61362325000. Email: tony.d.smith@csiro.au

Yagi, N. Graduate School of Agricultural and Life Sciences, University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan. Tel/Fax: +81358415599. Email: yagi@fs.a.u-tokyo.ac.jp

Zhou, S. CSIRO EcoSciences Precinct, 41 Boggo Road, Dutton Park, QLD 4102, Australia. Tel: +61738335968. Email: shijie.Zhou@csiro.au

Annex 2. Programme

OPENING

<u>Thursday 14 October</u>

09:00-09:15 Welcoming address. General introduction to the issues addressed by the meeting and the meeting process: Serge. M. Garcia (Chair IUCM-CEM-FEG)

09:15-09:45 Overview: Jake Rice (DFO Canada, Vice Chair IUCN-CEM-FEG)

09:45-10:00 Questions & Answers about the meeting process and its outcomes.

THEME 1: THEORY AND MODELS

10:30-11:15 Ecological and evolutionary impacts of size-selective fishing. J.E. Beyer and K.H. Andersen

11:15–12:00 Ecological drivers of stability and instability in marine ecosystems. Richard Law, Michael J. Plank, Gustav W. Delius and Julia L. Blanchard

12:00-12:45 Selective versus unselective fishing in modelled ecosystems. Beth Fulton and Tony Smith

14:30-15:30 Discussions on Theme 1: Summary of theory available; identifying gaps and needs for further modelling work.

THEME 2: THE SYMPTOMS OF THE PROBLEM: EFFECT OF FISHING

15:30-16:15 The effects of fishing selectivity on marine communities: how do we get from intuition through theory to evidence? Marie-Joëlle Rochet

16:15-17:00 Is a diversified harvest of an ecosystem a better way to maintain its integrity? Martin Hall

17:00 Session closure

<u>Friday 15th October</u>

09:00-09:45 The fishing pattern of open access, non-regulated African freshwater fisheries: The paradox between theory and practice. Jeppe Kolding

09:45-10:30 Fisheries and ecosystem sustainability: a mixed fisheries case study. A.D. Rijnsdorp, J.J. Poos, D. Beare and G.J. Piet

11:00-11:45 Sustainable fisheries: balancing exploitation with production across species and trophic level. Alida Bundy

11:45-13:00 Discussions on Theme 2: Summary of evidence available; how to address the challenge of providing convincing evidence of the impact of selectivity in the context of communities subject to the influence of many factors?

THEME 3: IMPLICATIONS FOR RESEARCH, POLICY AND MANAGEMENT

14:30-15:15 Managing marine biological assets through diversification. Shijie Zhou, Gudrun Marteinsdottir and Tony Smith

15:15-16:00 An evolutionary perspective to selective fisheries. Mikko Heino

16:00-16-45 Sustainable fisheries in a new European Common Fisheries Policy. Lisa Borges

17:00 Session closure

Saturday 16 October

09:00-09:45 Ecosystem-based approach to fishing technology development for sustainable fisheries. T. Arimoto

09:45-10:30 Gear-based technical measures and the ecosystem approach to fisheries management. Norman Graham

11:00-11-45 Managing for balanced exploitation: data availability and needs. D.C. Dunn, P. N. Halpin and E. Vanden Berghe

11:45-13:00 Discussions on Theme 3: Summary of practical implications of potential impacts of selective fishing; summary of practical tools available. Which advice can already be delivered? Which gaps remained to be filled? Data and research issues.

14:30-17-00 Wrap-up session. This session will intend to derive research priorities and practical advice from the available knowledge, identifying knowledge gaps and potential collaborative work. Questions to be addressed will be decided at the meeting but may include:

- What message can be delivered regarding the issue of balanced harvesting?
- Potential suggestions for fisheries and conservation management: potential directions? Specific actions?
- Potential suggestions for research (including data collection and management, analyses, modelling and field experiments) needed before the case for balanced exploitation can be made with enough evidence?
- Discussion and consideration of: (i) a report, (ii) elements for a joint publication.

17:00 Closure of the meeting

SIDE-EVENT

Wednesday 20 October

A side-event will be organized during the CBD COP 10 meeting in order to present the results of the workshop to a broader audience. Workshop participants wishing to attend are welcome. The FEG's Chair, Vice-Chair and Coordinator will take care of the presentation at the event and report back to all participants.

INTERNATIONAL UNION
FOR CONSERVATION OF NATURE

WORLD HEADQUARTERS
Rue Mauverney 28
1196 Gland, Switzerland
mail@iucn.org
Tel +41 22 999 0000
Fax +41 22 999 0002
www.iucn.org