



# Balanced Harvest in the Real World. Scientific, Policy and Operational Issues in an Ecosystem Approach to Fisheries



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# Balanced Harvest in the Real World. Scientific, Policy and Operational Issues in an Ecosystem Approach to Fisheries

Report of an international scientific workshop of the IUCN Fisheries Expert Group (IUCN/CEM/FEG) organized in close cooperation with the Food and Agriculture Organization of the United Nations (FAO), Rome, 29/09-02/10/2014

Garcia, S.M. (Ed.); Bianchi, G.; Charles, A.; Kolding, J.; Rice, J.; Rochet, M-J.; Zhou, S.; Delius, G.; Reid, D.; van Zwieten, P. A. M; Atcheson, M.; Bartley, D.; Borges, L.; Bundy, A.; Dagorn, L.; Dunn, D.; Hall, M.; Heino, M.; Jacobsen B.; Jacobsen, N. S.; Law, R.; Makino, M.; Martin, F.; Skern-Mauritzen, M.; Suuronen, P. and Symons, D.



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The Scientific Steering Committee consisted of: Serge M. Garcia, Gabriella Bianchi; Anthony Charles; Jeppe Kolding; Marie-Joelle Rochet; Jake Rice; Shijie Zhou and Despina Symons.

The meeting was co-chaired by Gabriella Bianchi (FAO) and Serge M. Garcia (IUCN-CEM-FEG). Presentation summaries were provided by the authors of the presentations made at the meeting. Discussion reports on the different sessions were provided by Anthony Charles; Gustav Delius; Serge, M. Garcia; David Reid; Marie-Joelle Rochet and Paul, A.M. van Zwieten under the Editorial responsibility of Serge, M. Garcia.

## EXECUTIVE SUMMARY

The concept of the Ecosystem Approach has entered the fishery harvesting discussions both from fishery perspectives (Reykjavik Declaration; FAO 2003 Annex to the Code of Conduct and from the principles of the Ecosystem Approach adopted by the CBD in 1995. Both perspectives establish the need to maintain ecosystem structure and functioning, whether for sustainable use of biodiversity (CBD) or simply to keep exploited ecosystems healthy and productive (fisheries). In response, the “Balanced Harvest” (BH) concept was suggested by a group of scientists brought together by the IUCN Fisheries Experts Group during the CBD CoP 10 in 2010. The meeting and the BH concept as consolidated there highlighted some of the collateral ecological effects of current fishing patterns and unbalanced removals of particular components of the food web, stimulating a critical rethinking of current approaches to fisheries management.

The meeting on “Balanced Harvest in the real world - Scientific, policy and operational issues in an ecosystem approach to fisheries” (Rome, September 29-October 2, 2014) examined the progress made since 2010 on a number of fronts. It considered questions related to the scientific underpinning of the BH concept, including theory, modelling, and empirical observations. It began to explore the economic, policy and management implications of harvesting in a more balanced way.

### **The scientific underpinnings of Balanced Harvesting**

Four presentations explored the implications of BH for ecosystem structure and function, using a variety of modelling approaches. All found that BH did result in biological communities with greater diversities in species and size compositions than did harvesting with similar intensity within conventional fisheries management. Furthermore, coexistence of species was facilitated under BH. All models that addressed density dependence explicitly, found such feedback to be important for the ecosystem consequences of BH to be realized (Law et al, Andersen et al, Zhou and Smith), and concluded that this is consistent with the results of models where density dependence was less explicitly structured in the dynamics, but still present in the model structure.

When harvesting was targeted at specific size groups or trophic levels, size yields depended on how life history parameters interacted with harvesting. Higher yields and persistent community composition were possible from focusing fishing on lower trophic levels rather than higher levels (Zhou and Smith) and BH provided higher yields when density dependence was stronger on adults (top down ecosystem control) whereas conventional management produced higher yields when density dependence was strongest prior to maturation (stronger bottom-up influences on ecosystem dynamics; Andersen et al.). The effects of totally non-selective fishing were variable among models, with community size structure persisting in size-based models of African lake communities (Plank et al), but many species being lost under high fishing intensity in species-based models (Zhou and Smith).

The message emerging from these studies -regarding the effects of different balanced harvesting strategies on aquatic ecosystems- is more nuanced than the one that came out of the previous meeting in Nagoya in October 2010. The results have shown that different models do not always provide similar or coherent results, depending *inter alia* on the

definition of productivity and on assumptions made on the relation between growth, mortality and feeding. It was agreed that using a large range of models was needed to get deeper understanding of complex ecosystem processes and that, in these preliminary stages of concept development, communication of modelling results to the public had to be careful to avoid creating confusion.

The difficulty of comparing results from different models was discussed, and two particularly important conclusions were made. First, different balanced harvesting strategies are possible that could result in different outcomes, particularly when moving between species- and size-based models. Second, a common set of metrics should be identified to facilitate the cross-evaluation of balanced harvesting strategies. In addition, issues such as selection of appropriate scales of the ecosystems to be modelled and migration of species and sizes across several trophic chains require more attention.

Overall, the discussion led to the conclusion that models have already contributed much to deepening our understanding of balanced harvesting strategies but that many interesting questions still remain to be explored.

### **Empirical evidence**

Six presentations analysed empirical data which was drawn from either (i) areas with long histories of exploitation with varying degrees of selectivity, or (ii) experimental tank populations where distribution and levels of exploitation could be directly manipulated. Many of the analyses compared empirical results to model predictions, or contrasted model results fit to multiple sets of empirical data. All results were in at least general consistency with the predictions of BH, but many qualifiers and nuances emerged from the presentations. More closed systems – such as experimental tanks (Pauli et al.) or lakes (Kolding, Jacobsen et al.) – were able to achieve conditions closest to BH exploitation; in these systems, the expectations of community responses to balanced and unbalanced harvesting were most strongly supported.

Comparative analyses of larger scale and more open fisheries systems provided more nuanced results. Results confirmed that conventional fisheries management is skewed towards larger sizes and higher trophic levels (Kolding, Bundy et al.), but as the distribution of fishing mortality broadens among species and sizes, higher yields can be taken with less disruption of various measures of community structure (Rochet et al.; Kolding, Bundy et al.). However, detailed patterns in space and time of catches and of community structure metrics were difficult to attribute to any specific harvesting pattern, since the reality of many covariates in the real world implies that empirical data sets reflect the consequences of multiple interacting factors, and not solely the pattern of fishing mortality on species and sizes. Other factors were also argued to contribute to the challenges of both implementing BH, and measuring the effects of its implementation. Particularly in larger scale, well-managed fisheries, objectives guide harvesting; where the objectives of conventional management are closely aligned with both economic incentives and the patterns of natural variability of the exploited systems, such conditions may hold less well under BH (Skern-Mauritzen et al.). In addition, as has been stressed many times, BH is not unselective fishing, but rather selective fishing that is based on productivity rather than value and catch rates. To achieve true BH, gear configurations and mixes of fishing methods may actually

have to be much more selective than at present, with engineering challenges that are significant (Suuronen et al.).

In the ensuing discussions, it was recognized that more empirical evidence would be useful but information on the evolution of species and size compositions at ecosystem level are very scarce and generally noisy, because of poor quality or uncertainty in the data, and difficult to interpret unambiguously because of the confounding effects of changes in external drivers including climate, management strategies, technological progress, in the fisheries, market conditions, trade constraints and many more. Empirical evidence also requires a set of metrics to assess change in relation to the BH hypothesis. Based on the discussions, these should focus on ecosystem status and on yield. Ecosystem status would have to be in terms of a small number of concrete and discrete metrics that could be used as indicators for important characteristics of the ecosystem (e.g. biodiversity indicators, community structure, and food web status or ecosystem functioning indicators) while yield improvements through BH could be in terms of biomass (fish protein), economic yield (revenue, profit, and rent return), social objectives (e.g. employment, work safety) or societal objectives (e.g. food security; ecosystem health). In seeking empirical evidence, African lakes have proven to represent good case studies, but controlled experimental situations could also be useful, including both in natural environments (including coastal systems and lakes) and artificial ones. Finally, the workshop identified the need to consider the long term implications of BH – i.e. the goal of maintaining ecosystem structure and functioning for long term sustainability rather than over short periods.

### **Economic, policy and management implications for both fisheries and biodiversity conservation.**

The final set of eight presentations covered a wide range of practical implementation issues with BH, including social, economic policy, and practical challenges. Economic challenges include (i) the necessary trade-offs between BH and other ecological, economic and social principles and objectives; (ii) economic aspects of BH performance targets (e.g. biomass, extirpation risk, yield); (iii) economic consequences of the need to broaden the size and species ranges and to lower exploitation rates for target and non-target species; and (iv) distribution of costs and benefits among fisheries, fishers, and between the present and the future (Charles et al., with various aspects of those challenges also highlighted in other talks e.g. Makino and Okazaki, Borges). Presentations on the policy challenges presented multiple perspectives, with some highlighting the possible compatibility of BH with objectives of eco-certification (Acheson and Agnew) and strong compatibility with the FAO interpretation of the Ecosystem Approach to Fisheries (Bianchi), and the more general Ecosystem Approach Principles of the CBD (Garcia et al.). Other presentations, however, highlighted potential incompatibilities with current fishing policies, such as the discard ban (Borges), and concerns about expanding large scale fisheries on pelagic stocks generally (Hall) and large pelagic tunas specifically (Dagorn et al.). Presentations of the practical challenges also were mixed. Van Zwieten and Kolding proposed a potential practical framework for tracking consequences of implementation of BH with a suite of ecosystem indicators, and Garcia et al. presented a framework that included practical ways to determine the nature of fishery adjustments needed to improve the balance of harvesting. However, Graham and Reid highlighted the major challenges to be faced in micro-managing fleets to have an aggregate (across fleets in an ecosystem) outcome of BH. This

concern is already present in the presentation of Hall, and Dunn et al. presented some of the real time challenges in tracking and adjusting the operations of fleets.

The following paragraphs summarize the meeting's progress on resolving these issues, and on resolving a number of misconceptions about BH, as summarized in Garcia. These include (i) the degree of selectivity implied by BH; (ii) implications for gear design; (iii) interactions with spatial management tools; (iv) the boundaries of the norm; (v) the relevance of discard bans; (vi) the vision of BH as "a licence to kill"; (vii) the expected simplification of management tasks including performance assessment; (viii) reduction of conflicts; (ix) connections with stock rebuilding; (x) delegation of responsibilities to the actors; (xi) compatibility with the CFP; and (xii) the role of conventional management instruments.

The following points emerged in the discussion. BH should be understood as broadening the selectivity perspective from the individual operation (gear and vessel scales) to the community-level selection of the overall fishing pattern (at trophic chain and ecosystem scale). The meeting highlighted, therefore the need for clarification on a number of questions before large-scale practical implementation can be considered. For example: (i) How should fishing patterns be scaled to each component's productivity to exert a fishing pressure proportional to it? (ii) What is the appropriate "ecosystem" scale at which the "balance" should be assessed? (iii) How will the individual selectivity of a fishing operation (or the fishing pattern of a specialized fleet) be nested within the overall selectivity and fishing pattern necessary to obtain a balanced harvesting across the ecosystem?

In relation to how BH could be considered as a strategy for implementation of the Ecosystem Approach to Fisheries, it was recognized that BH only addresses the objective of food production and maintaining ecosystem structure and functioning. Other ecological objectives (e.g. those related to minimizing impacts on habitats) as well as social and economic objectives, are not explicitly covered by BH although its sustainability will depend on its performance in relation to them.

An operationalized BH assessment of fish or marine communities and overall exploitation patterns would have to be strategic, ecosystem-based, with long-term (5-10 years) cycles of evaluation within which the current shorter-term fisheries management-related assessments (e.g. MSY-based, one-year cycles) will be implemented.

In order to be practical, the implementation of BH needs to steer away from fleet micromanagement. If the performance criteria and monitoring at ecosystem (and EEZ) and sector level can only be undertaken by the State or a competent agency, the lower level management should rather be devolved to the actors themselves, unleashing their capacity to innovate and optimize costs and benefits. Furthermore, there is also the issue as to what extent excluding taxonomic groups (e.g. charismatic species) and sizes (e.g. juveniles, adults) from the BH equation would lead to desirable outcomes.

Overall, more work is required on the scientific and practical underpinnings of BH before implementation can be tested, which also depends on the specific objectives of each fishery (e.g. food or value). Experiments would be useful to test some assumptions. On the other hand, a piecemeal (partial approach to BH) may perhaps be undertaken under the present fisheries management paradigm by reducing fishing mortality overall or, as appropriate, on some specific components of the resources system while increase fishing mortality on other

components of the same system. In fact, rebuilding overfished stocks and reducing fishing mortality on heavily exploited stocks are well in line with the BH concept. In any case the social and economic effects (both costs and benefits) of BH strategies and their distribution in space, time and actors, need to be assessed.

### **Final discussion**

Balanced harvesting provides a mechanism for meeting Principle 5 of the CBD Ecosystem Approach, transformed into a strategic goal (maintain structure and functioning), materialized as a sort of control rule established at ecosystem level, and resulting in a fishing regime producing the desired ecosystem outcomes. However, BH was originally discussed in the context of only one of the 12 CBD Principles of the Ecosystem Approach. When considered relative the other Principles there are possible synergies, potential conflicts and trade-off, which this workshop began to explore.

BH, as a strategic mechanism, does not fully replace conventional management but provides a means to help reconfigure it into a fuller ecosystem-based framework. In some fisheries, particularly some types of small-scale fisheries, adapting regulations and practices to move to BH may be a natural evolution, compatible with fisher goals and fishing behavior. In other fisheries, implementation challenges will be significant, and in some cases overwhelming. The key will be to find the way to nest the operational (single fishery) and the strategic (ecosystem) scales of assessment, management and outcomes. Partial implementation is a possibility to ease the transition but its feasibility needs to be studied. In any case, while the issues are numerous, the proposal has only appeared recently and progress is already being made, with a range of potential instruments identified.

Finally, future research efforts should: (i) improve theoretical and empirical evidence; (ii) connect with other environmental initiatives; (iii) connect with other planned fisheries reforms to ensure coherence between the UNCLOS and CBD standards and between environmental, social and economic performance; (iv) increase assessments of social and economic aspects of BH; and (v) harness the capacity of existing management tools and processes to move toward BH.

## **1. INTRODUCTION**

Fisheries have obvious impacts on ocean biodiversity and these are expected to increase as a result of a growing demand for fish. Because of the concerns over these impacts, the international community committed, during the 2001 FAO-Iceland Conference in Reykjavik (Iceland), to aim at responsible fisheries in a healthy marine ecosystem and, consequently, the Ecosystem Approach to Fisheries (EAF) was adopted by the FAO Committee on Fisheries (COFI) in 2003. The EAF implies, among others, a commitment to sustainable use of aquatic biodiversity. Key to this commitment is the adoption of management strategies that ensure maintaining ecosystem properties, including ecosystem structure and function, consistent with the central requirement of the CBD for sustainable use (Malawi Principles).

Worldwide, fishery policies and harvest strategies are evolving rapidly from a conventional stock- or fishery-based management to a more ecosystem-conscious management. The aim is to reduce and account for collateral impact on the food web and species assemblages,

giving effect to the Law of the Sea Convention (LOSC) requirement to manage sustainably target species as well as dependent and associated species. Although some progress has been made towards implementation (e.g. through an Ecosystem Approach to Fisheries), it has proven difficult to put into practice the high level objectives and intentions contained in these instruments.

Moving from single species to ecosystem level management has been a major challenge both for science and management and most management strategies remain based on single species considerations. As a consequence, fisheries policies and strategies are still often based on regulations grounded in single species, conventional fisheries management and do not fully take into account the ecosystems interactions and cascading impacts across the food web. A key difficulty is in obtaining accurate representations of food webs that are necessary for taking trophic links into account in practical fishery management. Another challenge relates to identifying fishery management regulations that would minimize the impact on the ecosystem structure and functioning while being also socially and economically acceptable. Such regulations will necessarily address both the amount of fishing (through regulation of fishing capacity and allowable catches) and the pattern of fishing (i.e. the distribution of fishing pressure on sizes and species) with the view to ensure a more ecologically balanced harvest.

Fishing practice requires generally the selection of specific targets and sizes to satisfy market demand. At the level of the fishing vessel, the difference between the biodiversity available on the fishing ground and what is brought on board is the result of seasonal availability and composition of the resources; skippers' decisions regarding the depth and habitat in which to operate, and the gear capacity to retain/avoid a range of species and sizes. Some fisheries, like purse-seining for anchovy are more selective than others such as shrimp trawling. At the ecosystem and fishery sector levels, the selection is the total outcome of the selection operated in the various specialized fleets/fisheries. As a whole, mature fishery sectors, with their large and small-scale components, capture a very wide range of species and sizes.

The catching selection process is imperfect, though, and a further "selection" may occur either at sea, or at the landing site, sometimes discarding what cannot be sold with sufficient profit. Discards vary with fisheries, are higher in fisheries using trawls than purse-seines and tend to be reduced or practically non-existent in most small-scale fisheries. Similarly, markets and consumers tend to be more "selective" in developed than developing countries, influencing catch selection and discarding practices. In all of these aspects, though, generalizations are potentially misleading.

During their historical development, fisheries have progressively extended the range of target species as markets developed and/or stocks declined. In that evolving context, the fundamental tenets of conventional fisheries management have been to ensure, on each target species population a highly selective fishing pattern that tends to protect juveniles and immature individuals, concentrating fishing on adults. In addition, conventional management has tended to organize the fisheries (and the licensing system) according to a limited range of target species (or groups of species), particularly in fisheries regulated through species-based quotas. Such selective fishing management strategies have been implemented through a range of management instruments including mesh size and gear

regulations as well as closed seasons and areas, also aimed at safeguarding the spawner's biomass. Coupled with a level of fishing effort most frequently beyond recommended limits, these strategies have led to profound changes in the species and size composition of fish populations and communities. It is understandable that any kind of selective removal of certain ecological components of the ecosystem (and more specifically of the food web) will change the natural composition of a living resources community and its biodiversity, possibly resulting in changes in ecosystem structure, functioning and resilience, and affecting the sustainability and stability of fisheries yields. In addition, the phenotypic and, possibly, genetic evolution resulting from selective fishing adds impact on the long-term productivity of marine ecosystems, changing the growth and reproduction patterns (e.g. in Heino and Dieckmann, 2008). Hence, regulations aimed at optimizing single-species fisheries need to take into consideration and be complemented by ecosystem considerations. Indeed, increasing evidences with inclusive ecological reasoning and deliberate ecosystem modelling indicate that many current management policies have a range of unintended negative impacts on the ecosystem as a whole and on the fisheries' future.

In the last few years, a “Balanced Harvest”<sup>1</sup> (BH) concept has been suggested by a group of scientists to reemphasize the need for a critical rethinking of current approaches to fisheries management. This concept aims to give attention to the many collateral ecological effects of fishing by avoiding unbalanced removals of particular components of the ecosystem, while supporting more sustainable fisheries (Jul-Larsen et al. 2003; Bundy et al., 2005; Zhou et al., 2010; Rochet et al., 2011; Garcia et al., 2011; 2012).

The meeting on “Balanced Harvest in the real world - Scientific, policy and operational issues in an ecosystem approach to fisheries” (Rome, September 29-October 2, 2014) examined a number of questions related to Balanced Harvest, e.g.:

- What does biodiversity really mean in relation to fisheries? What properties of biodiversity do fisheries affect and how could they be protected?
- What are practical ecosystem indicators and reference points that can assist managers to track whether ecosystem objectives are being achieved?
- What “ecosystem” or “trophosystem” are we referring to or trying to keep “balanced” (boundaries, scales and composition)?
- How can we determine the fishing pattern and intensity to maximize food production while minimize environmental impacts at ecosystem level, also taking into consideration different properties and dynamics of different ecosystems? How could BH be practically implemented in the real world?
- What are the technological and economic implications of BH, including market implications?
- What are its implications for the modern theories of fishing rights, TACs and quotas?

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<sup>1</sup> It has been suggested that this strategy might also be called “**Ecologically-Balanced Harvest**” as the objective is to maintain ecosystem structure and function, or “**Physiologically-Balanced Harvest**” (Ken Andersen) as the implementation principle is that each component is harvested in proportion of its natural productivity.

- How can the situation of fisheries be globally assessed in relation BH objectives and criteria?
- How can industries add value to currently low-valued components to facilitate their integration in the market?
- Can cultural exchange and development of seafood processing techniques influence people's dining habits?
- How can environmental NGOs, food industry professionals, media, educators, and retailers play a role in better understanding and implementing balanced harvest?

The presentations and ensuing discussions are reported below, following the meeting structure. First, the scientific underpinnings of BH in the light of the new results obtained through modelling and empirical observations. Second, the available empirical evidence of BH. Third, the economic, policy and management implications of a practical implementation of the concept for both fisheries performance and biodiversity conservation. Each section includes at the end a short report on discussions that followed the presentations. The report ends with summary conclusions of the final wrap-up session.

## 2. THEORY AND MODELS

### 2.1 Balanced harvesting promotes coexistence of interacting species.

**Law, R.; Plank, M.J. and Kolding, J.**

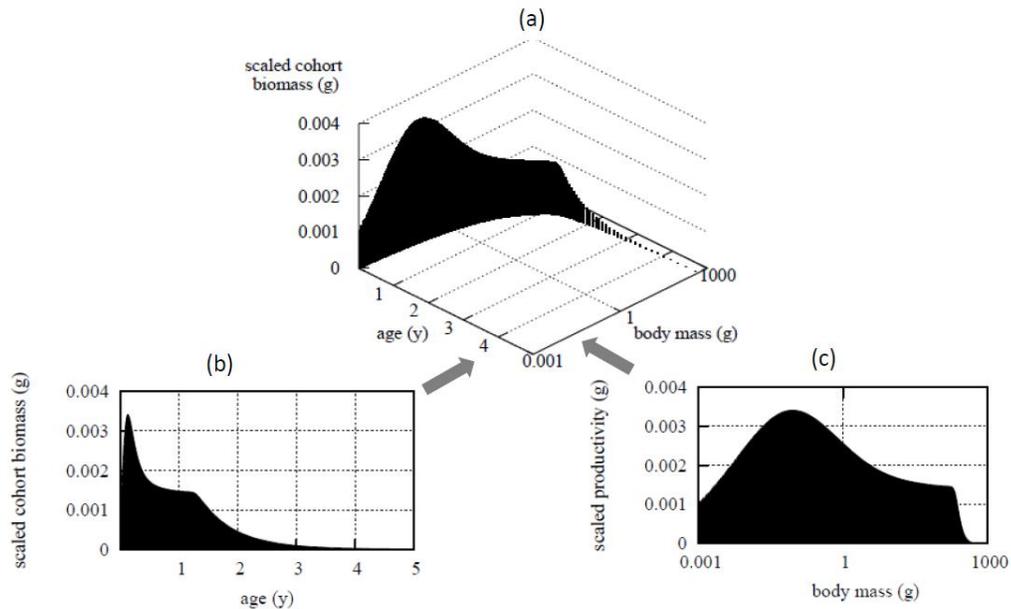
We used a dynamic, size-spectrum model to examine balanced harvesting in a simple ecosystem containing two interacting fish species (with life histories similar to Atlantic mackerel and cod), supported by a fixed plankton spectrum. Such models internalize body growth and mortality from predation, allowing bookkeeping of biomass at a detailed level of individual predation and growth, and enabling scaling up to the mass balance of the ecosystem. The model is described in detail in Law, Plank and Kolding (2014).

Our results were based on the standard measure of productivity from ecosystem ecology, which has dimensions  $\text{mass area}^{-1}$  (or  $\text{volume}^{-1}$ )  $\text{time}^{-1}$ . This is different from the mass-specific measure of productivity often used in fisheries which has dimensions  $\text{time}^{-1}$ . The measure of productivity is important, because different measures give different results in the context of balanced harvesting. We examined numerical solutions of the size-spectrum model at equilibrium, and demonstrated three kinds of mass balance: (1) input and output of each fish species, (2) input into and loss from the fish assemblage as a whole, and (3) recycling of mass within the fish assemblage.

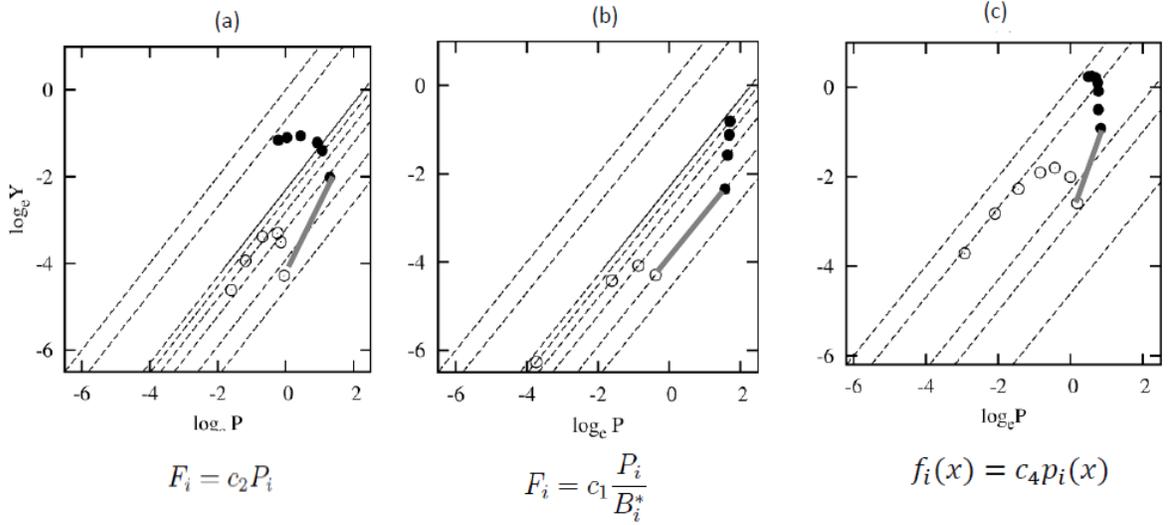
Mathematical analysis of the equilibrium (Law, Plank and Kolding 2014, Appendix E) showed an equivalence between the body size at which productivity is maximized and the age at which cohort biomass is maximized. Productivity reached its peak at body sizes less than 1 g and, correspondingly, cohort biomass was maximized much earlier in life than in other fishery models (**Figure 1**). This was caused in part by a high natural mortality rate for small fish, needed so that growth of larger mackerel and cod would be similar to that observed in reality. The early peak in cohort biomass contrasts with other analyses of fisheries. However the size-spectrum model has the feature of strict coupling of mortality to

continuous body growth, absent in other models. More work will be needed resolve this discrepancy.

We balanced harvesting to productivity in two ways. The first entailed a modest change to bring fishing mortality in line with the total productivity of each species, using current patterns of exploitation (**Figure 2a**). This is a partial step to balance harvesting, that promotes coexistence of mackerel and cod, unlike single-species management (Law, Plank, Kolding 2014).



**Figure 1.** Equilibrium cohort biomass and productivity of mackerel by age and body mass in the mackerel-cod assemblage. (a) Cohort biomass on the age-size trajectory of a cohort. (b) Image of cohort biomass in the direction of age. (c) Image of scaled productivity in the direction of body mass. Peaks of cohort biomass and productivity in (b) and (c) correspond to the same single peak on the age-size trajectory of (a).



**Figure 2.** Total yields ( $Y$ ) and productivities ( $P$ ) of mackerel (filled circles) and cod (open circles) at equilibrium computed under three patterns of harvesting. Points come in pairs for each pattern of harvesting; the first pair are joined by a grey line. Increasing the constant  $c_i$  increases the intensity of fishing. Contours of constant  $Y/P$  are shown as dashed lines. (a) The species coexist under heavy fishing,  $F_i$ , regulated by minimum size at capture (mackerel: 100 g, cod: 1000 g), when fishing is in proportion to productivity of each species. (b) Cod collapses under heavy fishing, when fishing is in proportion to the ratio of productivity to biomass. (c) The species coexist and generate greater biomass yield under heavy fishing, when fishing is in proportion to productivity of each species and each body size,  $f_i(x)$  within species (minimum size of capture 1 g).

Note that a mass-specific measure of productivity based on the ratio  $P/B$  does not prevent the collapse of cod (**Figure 2b**). The second entailed a more radical change, to bring fishing mortality fully in line with productivity by body size, as well as by species. This also promoted coexistence of the species. It also brought further benefits: (1) greater resilience of the assemblage; (2) better replacement of natural mortality by fishing mortality, making the effect of fishing on the assemblage more benign; (3) substantially increased biomass yield, from matching fishing better to components of productivity (Law, Plank, Kolding 2014).

## 2.2 A reappraisal of fisheries selectivity in light of density-dependent regulation.

**Andersen, K.H.; Jacobsen, N.S, and Beyer, J.E.**

All fish stocks are regulated by some density dependence. Historically, fisheries science has focused on density dependence in the early life stages, modeled as a Beverton-Holt or Ricker stock recruitment function (Ricker, 1954; Beverton and Holt, 1957). The result of this density dependence is that when fishing a single stock, the yield is maximized when fishing starts around maturation. Recent results show that density dependence may also be

regulated later in life through growth, and thus changing the optimal size selectivity pattern (Lorenzen, 2008; Svedang and Hornborg, 2014).

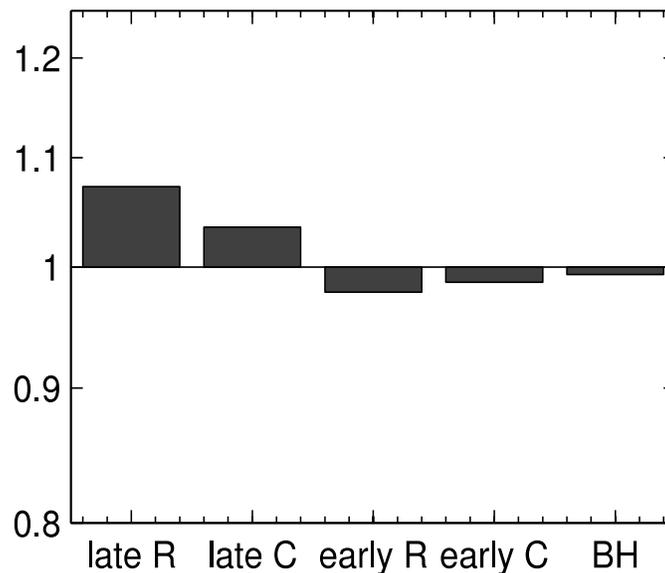
In this presentation we showed that different density dependence regimes may cause differences in optimal fishing patterns, when considering a single stock. The presentation covered four emerging density dependent regimes in a size-structured model:

1. Late in life density dependence regulated by the resource (late R);
2. Late in life density dependence regulated by cannibalism (late C);
3. Early in life density dependence regulated by the resource (early R); and
4. Early in life regulated by cannibalism (early C).

Furthermore, the simulations were compared with a hardwired Beverton-Holt stock-recruitment function. The results showed that balanced harvesting can provide the highest yield when density dependence is late in life, whereas fishing around size at maturation provides the highest yield, when density dependence is early in life (**Figure 1**) – a result coherent with traditional fisheries theory.

The conclusion is that from a single species perspective harvesting smaller individuals, with higher intensity than larger ones, may only be a good strategy when the population density dependence is regulated late in life. In this context, we emphasize the need to explore how different parameterizations can cause differences in model output.

In a marine community density dependence will to a large degree be regulated by predation and food availability, so results may differ in a multispecies context (Jacobsen et al., 2014).



**Figure 1.** Ratio between the maximum yield from a balanced selection and a trawl selectivity for the five different types of density dependence (see text). Late density-

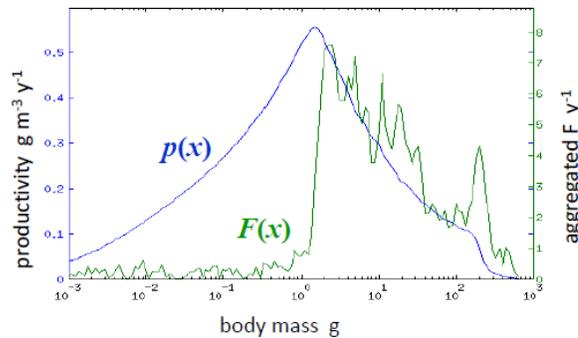
dependence makes balanced selection slightly better, while for early density-dependence the difference is negligible.

### 2.3 Do unregulated, artisanal fisheries tend towards balanced harvesting?

Plank, M.J.; Law, R. and Kolding, J.

We gave preliminary results from a study of self-organising fishing, using a minimal model of individual fishers' behaviour, to see what pattern of exploitation would emerge in a fishery without size-based regulations. The fishers operated with the same efforts, taking fish of different body sizes. Efforts were low enough for the fish stock not to be endangered; in other words, we addressed the 'how', not the 'how-much', question. From time to time, fishers changed their net meshes to take a new randomly chosen range of fish sizes, and were more likely to do so if their current yield was small relative to the maximum yield obtained by any person. The fish stock was modelled as a dynamic size spectrum supported by a constant plankton spectrum; the fishers had no direct knowledge about these dynamics.

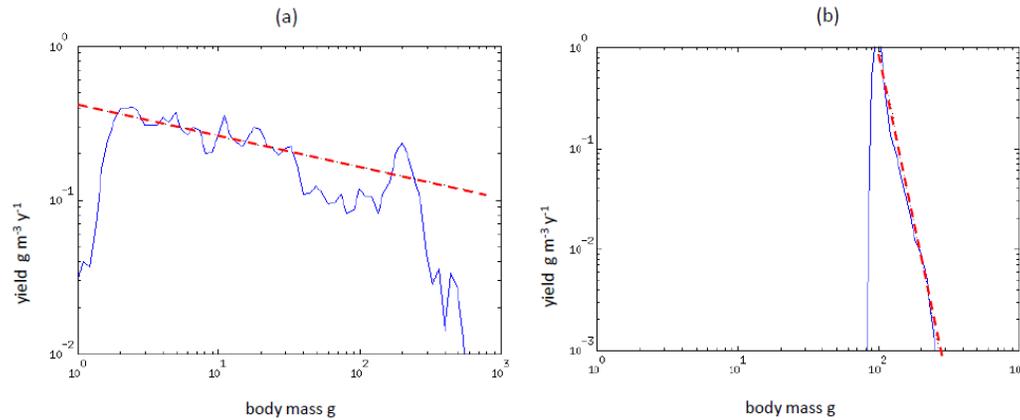
We found that fishers self-organised to generate an aggregated fishing mortality rate approximately in line with the productivity of the fish stock over body size (productivity measured as mass volume<sup>-1</sup> time<sup>-1</sup>) (**Figure 1**). This solution gave all fishers about the same yield. Put another way, the fishers distributed themselves over the range of fish body sizes close to an ideal-free distribution (IDF). An IDF is a Nash equilibrium at which any person changing their pattern of harvesting would experience a reduction in yield. This matching of fishing mortality to productivity is close to balanced harvesting (Garcia et al., 2012), except that fishing was confined to the right-hand side of the body size at which productivity peaked.



**Figure 1:** Stock productivity  $p(x)$  and aggregate fishing mortality rate  $F(x)$  as a Function of log body mass  $x$ , when fishing was close to a stationary state.

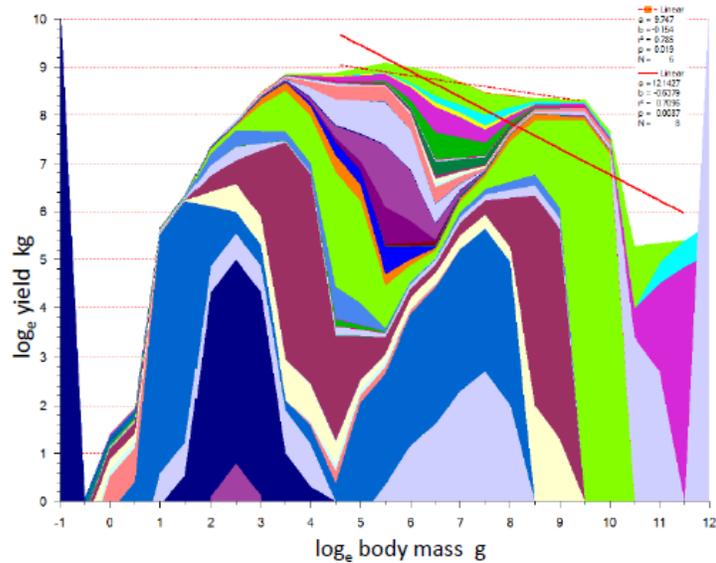
At the solution, theory predicts that the yield should scale with the logarithm of fish body mass with an exponent of  $1-\gamma+\alpha$ , where  $\gamma$  is the exponent with respect to population density ( $\sim 2.0$ ), and  $\alpha$  is the exponent with respect to volume searched per unit time ( $\sim 0.8$ ). This prediction is possible because the biomass of the fish stock became approximately constant

when expressed as a function of log fish body mass, as in Sheldon's rule (Sheldon et al. 1972). Consistent with the prediction, we found the scaling of yield with log body mass to be about -0.2 (**Figure 2a**). In contrast, an external regulation, limiting fishing to body masses greater than 100 g, gave a slope of about -7, and a yield substantially reduced from 1.3 to 0.4  $\text{g m}^{-3} \text{y}^{-1}$  (**Figure 2b**).



**Figure 2:** Yield as a function of log body mass, (a) when fishers were free to choose nets to cover the full range of body masses, and (b) when fishers were restricted to nets catching fish of approximately 100 g and larger.

A scaling near to -0.2 could be envisaged as a signature of balanced harvesting. We examined the scaling on the catch from the fish assemblage in the Bangweulu swamps of Zambia, where there is a fishery experiencing relatively little external regulation (Ticheler et al. 1998, Kolding et al. 2003). The exponent was estimated to be in the range -0.1 to -0.5 (**Figure 3**). We anticipate that the exponent from well-developed fishery with size-at-entry regulations would give a much more negative value, but have still to check this.



**Figure 3:** Yield estimated from Bangweulu Swamps catch data as a function of log body mass; colours refer to different species. Lines were fitted to the total catch over log<sub>e</sub> body mass ranges 4.5 to 9.5, and 4.5 to 11.5.

## 2.4 Effect of fishing intensity and selectivity on community structure and fishery production at trophic and species levels

Shijie Zhou, S. and Tony Smith

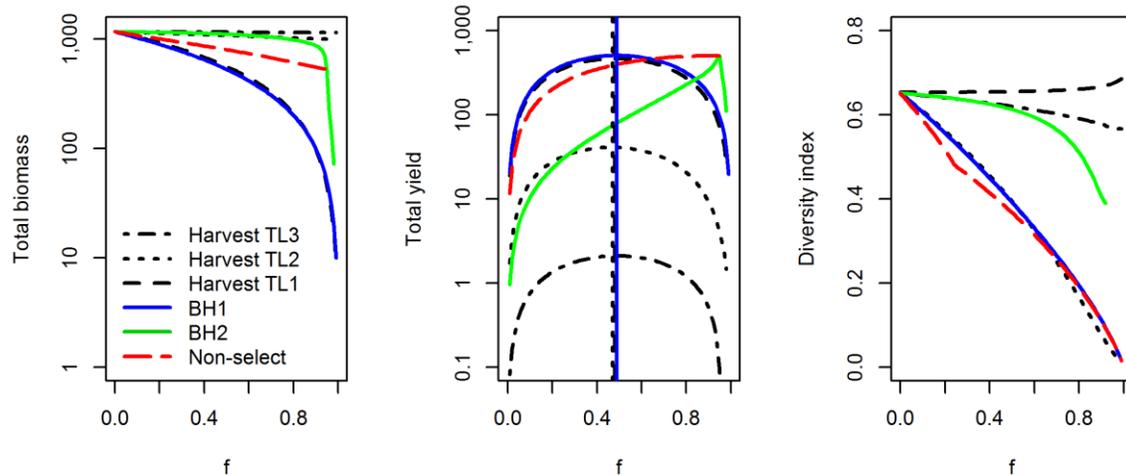
Species and trophic levels are the building blocks of ecosystem services and environmental sustainability. We used a simple multispecies predation and competition model to explore how alternative fishing pattern and intensity affect species composition, community structure, and fisheries yield.

We use modified Lotka-Volterra competition, predator and prey dynamics models (Beddington and Cooke, 1982) to study community dynamics under fishing. This approach is similar to the method for investigating whale-krill interaction (May et al., 1979) but we use a nonlinear response function instead of a linear one; it considers species competition similar to more recent studies (e.g., Gamble and Link, 2009, 2012), but our models couple carrying capacity of predators with available preys rather than assuming independent carrying capacity among species. A hypothetical community with three trophic levels and four fish species was constructed. We studied the following fishing strategies on such a community:

- Case 1 assumed no interaction among species;
- Cases 2 to 4 selectively harvested species at a single trophic level;
- Case 5 harvested competitors at a different rate;
- Case 6 represented non-selective fishing that harvested all species at a fishing mortality rate proportional to their abundance;

- Case 7 (balanced harvest BH1) harvested all species at a rate proportional to their intrinsic population growth rate; and
- Case 8 (balanced harvest BH2) harvested all species proportional to their production.

We evaluated three properties of the community: biomass, yield, and biodiversity. By simultaneously solving the multiple differential equations for these cases, we showed that selectively harvesting species at higher trophic levels produced very low yields, caused severe biodiversity loss and altered community structure (**Figure 1**).



**Figure 1.** Total biomass and yield across all species at equilibrium for alternative fishing scenarios. Harvest TL3: selectively harvest apex predator at trophic level 3 only; Harvest TL2: selectively harvest predator at trophic level 2 only; Harvest TL1: selectively harvest herbivore (primary consumer) at trophic level only; BH1: fishing mortality rate proportional to intrinsic population growth rate; BH2: catch proportional to production; Non-select: catch proportional to biomass. The vertical lines on the yield panel are the maximum yields corresponding to each fishing scenarios except BH2 and Non-select where yield continue to increase. On the diversity index panel, under non-selective fishing a species that was fished harder than its competitor becomes extinct at the inflection point.

Selectively harvesting fish species at the lowest trophic level produced high yield and it was the only strategy that could maintain community structure. Harvesting competitors at a different rate (Case 5) drove the species that was fished harder to extinction. Non-selective fishing (Case 6) could result in relatively high biomass and high yield, but severely impacted biodiversity and community structure. Case 7 resulted in the highest total yield, but caused biodiversity loss and altered community structure. Case 8 maintained high total biomass and had a low impact on biodiversity at a wide range of fishing intensities. However, the yield was lower than Cases 6 and 7. The general conclusions from this study are comparable with other studies using different modeling approaches (Bundy et al. 2005; Law et al. 2011). This study contributes to current debate on the concept of balanced harvest

and provides an insight into fishing strategies at species and trophic levels that balance yield and ecological impact.

## **2.5 Discussion summary**

### **Delius, G. (Rapporteur)**

Participants commented on the fact that the papers presented at this meeting make more differentiated statements about the effects of balanced harvesting than was the case at the previous workshop in Nagoya (Garcia et al., 2011). Rather than just answering the question whether balanced harvesting is beneficial or not, they presented a nuanced message regarding the different effects of different balanced harvesting strategies. While initially some in the audience felt unease about this more complicated picture, during the discussion it became clear that this increased understanding of the details constitutes an important advance that has been achieved over the last few years.

A nice summary of the kinds of models that have been used to examine balanced harvesting has been compiled by the ICES Working Group on the Ecosystem Effects of Fishing Activities (ICES, 2013) and this was projected on the screen during the discussion. The discussion focussed on the types of models that were most suitable. For example it was suggested that, to properly capture the consequences of balanced harvesting for the size spectrum, a model needs to resolve the size structure of populations and that an appropriate coupling between growth, mortality and predation is essential. The general opinion was that: (i) modellers should work with a large range of models, (ii) none of the models on the list should be discarded, and others, for example OSMOSE, should be added. It was however also pointed out that it was necessary to be careful (and very explicit) when communicating the results of these models to the public, to avoid creating confusion.

The difficulty in comparing the results from different models was discussed, and two particularly important factors were identified

1. There are many different balanced harvesting strategies. There is agreement that balanced harvesting involves spreading fishing pressure over a broad range of sizes and species, but there are many choices for how exactly the fishing pressure should depend on size and species, and different papers have investigated different scenarios. The effects of balanced harvesting were shown to depend strongly on these choices and this issue deserves further exploration.
2. There are many different ways of assessing the benefits of balanced harvesting strategies. One can look at the impact on the yield, on biodiversity, on resilience, on evolution, etc. It was suggested in the discussion that it would be good to develop a common set of metrics to facilitate the cross-evaluation of balanced harvesting strategies.

With the exception of the models presented by Shijie Zhou, the models presented at the meeting are extremely high-dimensional because they include a large number (in the hundreds) of size classes. They shift the emphasis from resolving a large number of species to resolving a much larger number of size classes because: (1) size is a dominant factor in

determining the predation interactions between fish and (2) fish grow over many orders of magnitude during their lifetime.

It was pointed out, in the discussion, that in balanced harvesting we are dealing with two difficult questions at once, namely balancing across species and balancing across size classes and trophic levels. Models with few species detail can help to increase our understanding of the general mechanism by concentrating on the effect of balancing across sizes separately from the effect of balancing across species. However, alternate approaches focussing on a larger number of species are also required to fully investigate the effects of balanced harvesting.

There are many factors that could be taken into account in future modelling investigations. As an example, the choice of scale for the ecosystem being modelled was mentioned (in a set of nested ecosystems and trophic chains) and the way in which migration of some of the top predators (e.g. mammals) across many smaller trophic chains can couple together several smaller-scale ecosystems into a larger whole. In the discussion, modellers stressed that they are very interested in listening to exactly what kind of questions empiricists would like to see investigated by future models.

Overall, the discussion led to the conclusion that models have already contributed much to deepening our understanding of balanced harvesting strategies but that many interesting questions remain to be explored.

### 3. EMPIRICAL EVIDENCE

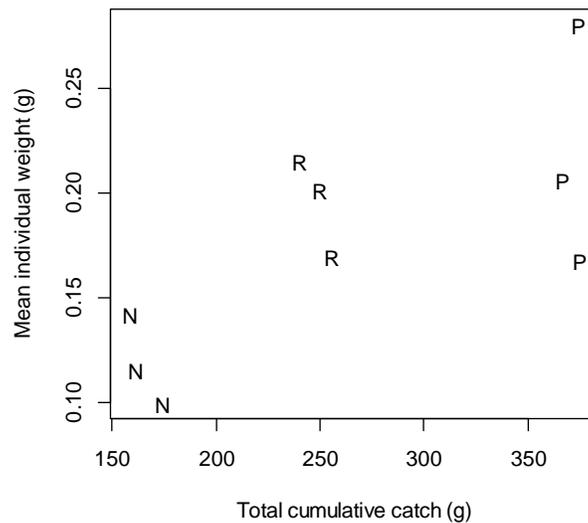
#### 3.1 Changes in productivity and life-history traits in experimentally harvest guppy populations.

**Díaz Pauli, B.; Savolainen, H.; Utne-Palm, A.C.; Ellertsen, D.M.; Reznick, D and Heino, M.**

We have carried out a three-year harvesting experiment designed to better understand the rate and nature of fisheries-induced evolution in populations of iteroparous species consisting of multiple age classes. The experiment is based on Trinidadian guppies (*Poecilia reticulata*). All tanks received the same daily amount of food. Harvest was conducted every 6 weeks for a total of 28 harvest cycles, corresponding to 4–6 guppy generations, depending of the harvest regime. Replicate tanks were harvested following one of the three size selection regimes: (1) “positive”, where fraction  $P$  of guppies larger than 16 mm (approximate male maturation length) was harvested, (2) “random”, where fraction  $P/2$  of guppies were harvested irrespective of their size, and (3) “negative”, where fraction  $P$  of guppies smaller than 16 mm was harvested (this regime was augmented with harvest of fraction  $P/2$  of guppies above 16 mm at the ninth harvest to avoid overcrowding above the limit).  $P$  was adjusted such that populations would neither grow too big nor crash and varied from 25% to 50%; the same  $P$  was used for all tanks at a given harvest event but varied over time. The positive size selection regime resembles the traditional way of targeting large

fish, whereas the random and negative size selection regimes are closer to natural mortality and probably also more “balanced”.

Total biomass yield was the highest for positive size selection, followed by random and negative size selection. Also the mean weight of caught individuals was highest for positive harvest, although the size for random harvest was not much less. Schaefer production model suggests that the MSY for random size selection was about 75% of the MSY positive harvest, and the MSY for negative harvest about 40% of the MSY positive harvest. (**Figure 1**)



**Figure 1:** Cumulative catch and mean individual catch weight over the whole experiment for negative (N), random (R), and positive (P) fishery size selection regimes.

There were large fluctuations in growth and maturation, which are partly related to density-dependent feedbacks (per capita food availability). However, ongoing work to characterize life histories under standardized conditions suggests that changes are partly genetic. Specifically, female maturation advanced more under positive size selection than random size selection and negative size selection. Maturation under negative size selection did not change.

The experiment supports the prediction that more “natural” mortality regimes drive less unwanted evolution than the prevailing positively selective regimes. However, regarding biomass yield, the positive regime performed best, in line with the classical single-species theory of fishing where food is not accounted for. Nevertheless, the yields from differences between regimes were getting smaller over time (probably because of changes in life histories) but not vanishing. The results for yield are the opposite of what were reported by Conover and Munch (2002) for a simpler experimental setting, and different for life-history change (neutral regime was evolutionarily neutral in the Conover and Munch experiment, but not in ours).

### **3.2 The Barents Sea ecosystem - balanced harvest?**

**Skern-Mauritzen, M.; Hansen, C.; Howell, D.; Huse, G. and Bjordal A.**

The Barents Sea is a large (1.6 million km<sup>2</sup>) shelf system bordering the Arctic Ocean. The northern and eastern areas are covered by cold Arctic water masses, while the southern and western areas by warm Atlantic water masses, mixing along the Polar Front. The strong climatic gradients in the system result in strong geographic patterns in distributions of species and communities, as well as in life history strategies, productivity and thus vulnerability to fishing. However, the communities and ecosystem structure is reorganized seasonally, through extensive spawning and feeding migrations, and over years, through a current 'borealization' of the system; boreal species from the warmer areas immigrating to the Arctic areas, likely a result of the recent warming of the system. The strong connectivity between the different communities is a challenge in the balanced harvest perspective, as the different geographic regions cannot be managed in isolation; the whole dynamic system needs to be considered.

The abundance of the different commercial stocks in the Barents Sea has varied quite dramatically over the last decades, due to both fishing and to recruitment variability. Typically, periods of poor recruitment are irregularly interspersed by years with good recruitment. Thus, the productivity within stocks varies substantially over time. Traditional fisheries meet this variability by tracking the good year classes, and by reducing harvest rates at low abundances. A balanced fishery should track the changing productivity in stocks and in different size groups within stocks. More modeling effort using more biological realistic models including this variability is required to assess stock and ecosystem responses to balanced harvest.

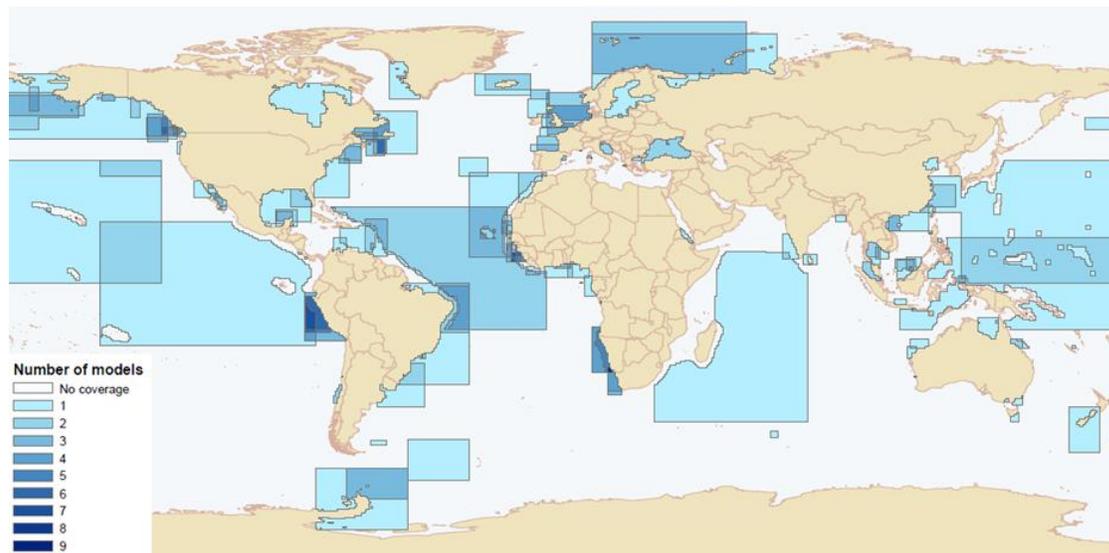
The current, traditional management framework combined with selective fisheries works well in the Barents Sea. Most stocks are above safe limits, harvest control rules are established and enforced, and the warm climate increases the production of the commercially important stocks. Nevertheless, there is a harvest on strongly interacting stocks across multiple trophic levels, including zooplankton, small pelagic fish, large demersal fish, shrimps, crabs and marine mammals. We expect that the demand for marine production will increase, and combined with development of new technologies and new markets the total catches from this system are likely to increase. We therefore need a scientifically sound ecosystem based management framework to meet this development, and to balance harvest among stocks. It is, however, our opinion that a strict balanced harvest is not realistic in the Barents Sea, due to the vast areas with interconnected species and communities, and due to the high spatio-temporal variation (seasons, years) in species productivity and distributions. For management of the Barents Sea, the most relevant questions relative to a balanced harvest are

- How balanced should we harvest?
- How balanced can we harvest, how well can we track variation in productivity over time?
- How do we preserve dynamic ecosystems with no steady states?

### 3.3 Exploitation patterns in fisheries, a global meta-analysis from 151 Ecopath models

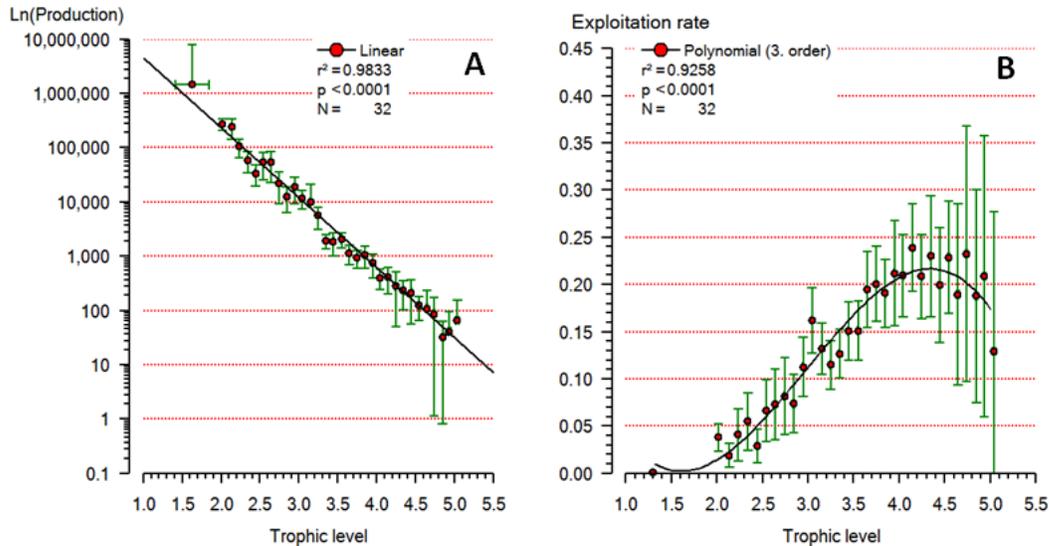
**Kolding, J.; Bundy, A.; Christensen, V.; Steenbeek, J.; Law, R.; Plank, M.; and van Zwieten, P.A.M.**

151 published Ecopath models from all over the world, covering around 40% of the world's ocean surface (Christensen et al. 2014, **Figure 1**), were used for a meta-analysis of the global fishing pattern by trophic levels. The models were categorised into 6 main ecosystem types: Temperate (N = 51); Tropical (N = 47), Tropical upwelling (N = 25); High latitude (N = 16); Temperate upwelling (N= 10) and Inland Seas (N = 2). Balanced harvest is defined as distributing the fishing mortality in proportion to production (Garcia et al 2012), and as both total annual production,  $P = Z*B$  and Catch,  $C = F*B$  (where  $P$  = production;  $F$  = Fishing mortality;  $Z$  = Total mortality and  $B$  = Biomass) are readily available in Ecopath, it is easy to compare the two over the whole exploited community, and their ratio,  $C/P = F/Z$ , is the so-called exploitation rate  $\epsilon$ . As a general rule of thumb, the exploitation rate shall not exceed 0.4, particularly on forage fish, for it to be sustainable (Pikitch et al. 2012)



**Figure 1:** Distribution of the 151 Ecopath models used in the analysis. After Christensen et al. 2014.

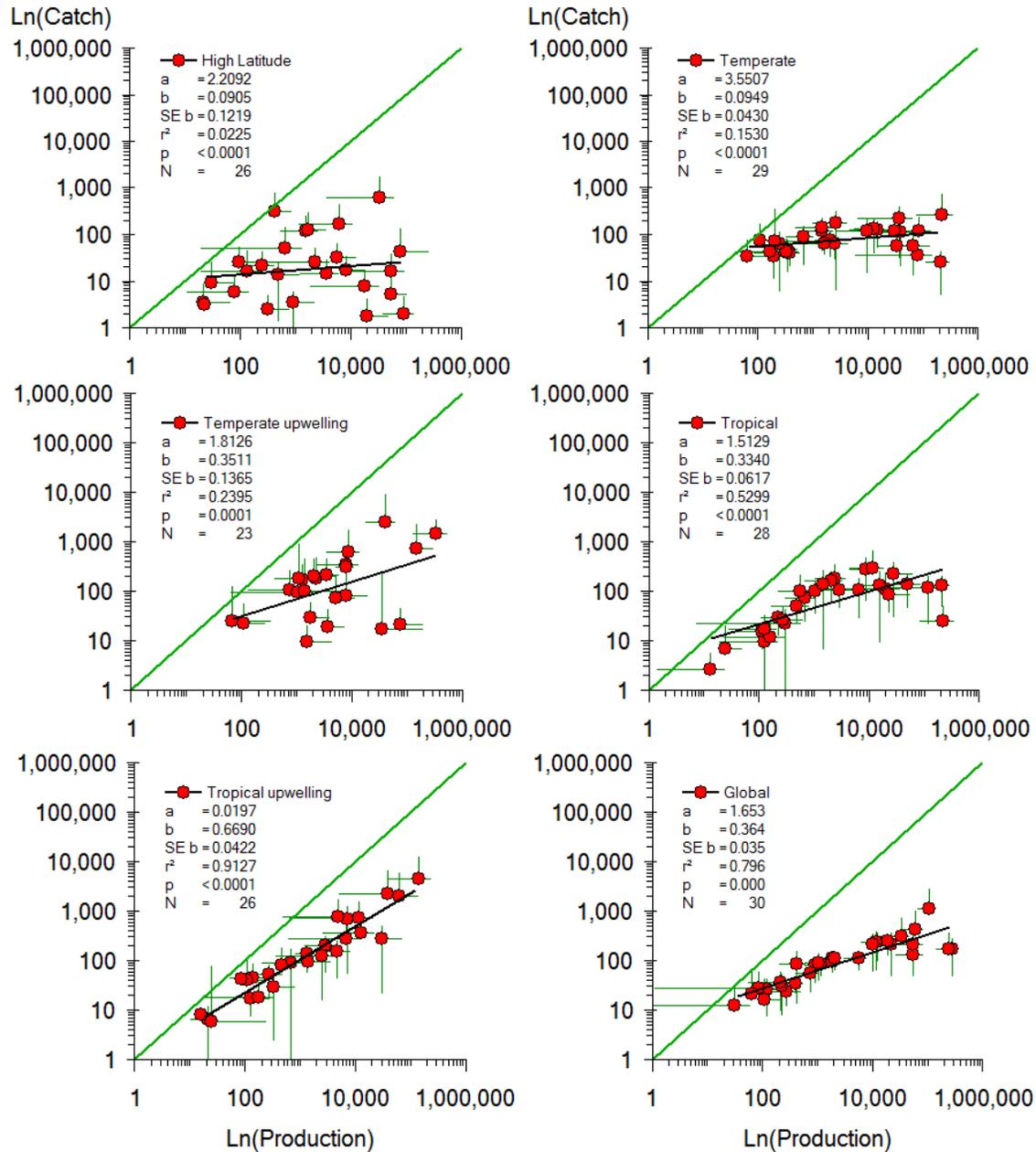
Ecopath models are constructed by species and trophic levels, therefore, the trophic level (TL) of each functional group was used to describe the structure of the communities since there is a positive correlation between TL and size in fishes (Romanuk et al. 2011). Overall, there is a strong decrease in total production with increasing TL (**Figure 2A**), with about 90% loss between each level as expected from general trophic transfer efficiency.



**Figure 2:** **A:** Total (average) production per unit area ( $\text{kg}/\text{km}^2/\text{year}$ ) against trophic level (TL) in 151 Ecopath models across the world. **B:** The global fishing pattern expressed as average exploitation rate ( $E = C/P = F/Z$ ) against TL. Error bars represent the 95% confidence limits.

The global fishing pattern (**Figure 2B**) shows a marked peak at trophic levels 4-5, and very light exploitation ( $< 10\%$ ) at TL 2-3, indicating that humans seafood is taken mainly from the high trophic level ocean species. This contrasts sharply with human feeding behaviour from land-based sources, where 80% of the diet is from plants (TL=1). (Duarte et al. 2009). Overall, only 2% of the human food is taken from the oceans (FAO 2006) and since the average TL for humans is around 2.21 (Bonhommeau et al. 2013) we are about 80% terrestrial vegetarians. In contrast, we are feeding about two TLs higher from the oceans, resulting in around 99% of the corresponding energy being lost in transfer inefficiency. At the overall global ecosystem level, overfishing seems not to be a problem as the average exploitation rate is well under 0.4, even for the highest trophic levels (although there is a wide range of exploitation rates as shown by the error bars in **Figure 2B**). The general concern that we are fishing too many small fish to secure the sustenance of higher trophic levels (Pikitch et al. 2012) seems not supported at the global ecosystem level, but these data include species that are caught as bycatch with extremely low  $F$  (**Figure 2B**). Under Balanced harvest the exploitation should be proportional to the production, and the exploitation rate  $E$  should thus be approximately constant across species, sizes or trophic levels. **Figure 2B** show the highly skewed global fishing pattern towards high TLs (with low productivity), and if the objective of fishing was to maximize sustainable yield (MSY), then we would need to relieve pressure on high TL and increase pressure on low TL.

The overall global fishing pattern shows the world's market preference for large fish at high TLs. As this preference, to a large extent, is dominated by consumers in Western industrial countries, a hypothesis was formed that the general fishing pattern would become increasingly balanced when moving from North to South. The trend in overall fishing patterns by five main ecosystems and their degree of balance is shown in **Figure 3**.



**Figure 3.** Average fishing pattern in 5 main ecosystems across the world, and the global average, expressed as  $\ln$  catch ( $\text{kg}/\text{km}^2/\text{year}$ ) versus  $\ln$  production (same units). Each point is the average functional group in binned TLs with one decimal (Fig 2). The more the slope deviates from the 1:1 line (green) between yield and production, the more “unbalanced” (*sensu* Garcia et al., 2012) the fishery is. Fishing pressure or exploitation rate ( $E$ ) is inversely correlated with orthogonal distance from the 1:1 line. P-values give the test of slopes  $\neq 1$ . All slopes are significantly different from 1, but only Tropical, Tropical upwelling and Global are significantly different from zero.

As expected the high latitude and temperate fisheries are the least balanced, while the balance improves when moving into tropical fisheries. Upwelling fisheries, both temperate

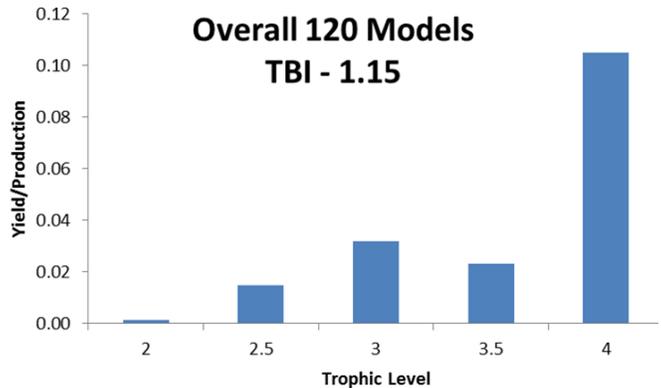
and tropical, are the most balanced and this makes sense as they are traditionally focused on high productive, low trophic level, species.

In a separate analysis we explored these results at the ecosystem level using the trophic balance index (Bundy et al 2005). The trophic balance index (TBI) measures the evenness (pattern) of exploitation across TL by comparing their exploitation rates, which are estimated as the sum of yield (Y) divided by the sum of production (P) at each TL (i). The evenness of exploitation is then given by the coefficient of variation of all Y/P:

$$TBI = \frac{sd(Y_{TL2}/P_{TL2}.....Y_{max}/P_{max})}{average(Y_{TL2}/P_{TL2}.....Y_{max}/P_{max})} \quad [1]$$

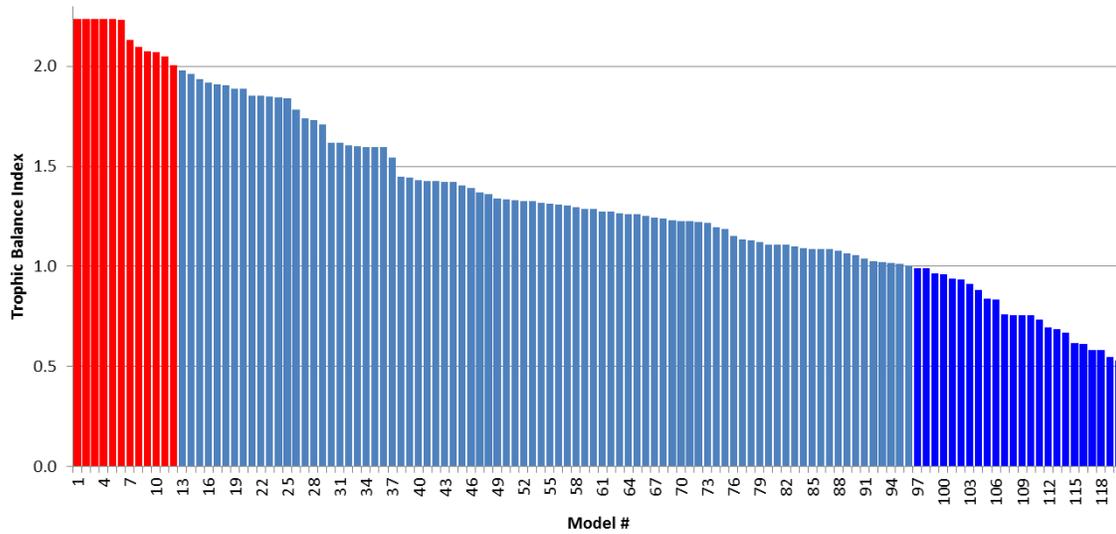
When exploitation rate is the same across all TLs, TBI=0. Functional groups may be grouped into integer or fractional TL classes. In this case, the functional groups in the Ecopath models were grouped in 0.5 TL classes. Because the maximum value of TBI depends on the number of TL classes over which it is estimated, the number of trophic levels must be standardized for making comparisons across ecosystems. In this case, the models were standardised to 5 TL groupings, 2.0-2.49, 2.5-2.99, 3.0 – 3.49, 3.5-3.99, 4.0+. Models that did not contain groups at trophic level 4 or higher were excluded from the analysis. This reduced the total number of models to 120.

The average pattern of exploitation across all models is highly skewed to trophic level 4+ (**Figure 4**), with very low exploitation at trophic levels 2 and 2.5, confirming the results above. This pattern was repeated across many of the 120 modelled exploited ecosystems and no ecosystem was exploited in balance: values of TBI ranged from a minimum of 0.53 to a maximum of 2.24 (**Figure 5**).



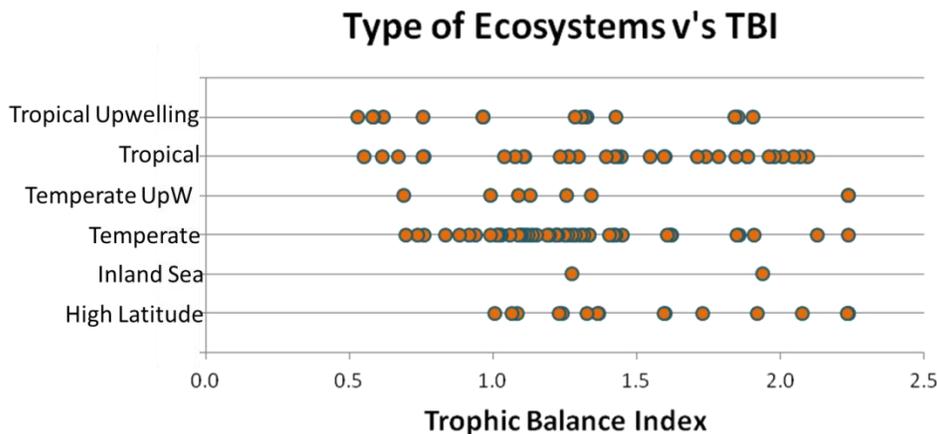
**Figure. 4.** Average distribution of exploitation patterns across the subset of 120 Ecopath models.

In the ecosystems to the far left of **Figure 5** (in red), only one trophic level was exploited, trophic level 4+. They were either in high latitude systems, oceanic systems or models from an early time period. Models to the right hand of **Figure 5** were more evenly balanced.



**Figure 5.** Trophic Balance Index for the subset of 120 modelled, exploited marine ecosystems.

The six systems with the lowest TBI were tropical ecosystems, consistent with the results of the global analysis above. However, there was no consistent pattern of TBI with latitude, or ecosystem type, when examined over all 120 models (**Fig. 6**). There was also no relationship between TBI and time, Large Marine Ecosystem (LME) or LME stock status (Kleisner and Pauly 2011). There was a noisy relationship between TBI and exploitation rate ( $r^2 = 0.17$ ,  $p < 0.001$ ) and between TBI and total catch per  $\text{km}^2$  ( $r^2 = 0.19$ ,  $p < 0.001$ ).



**Figure 6.** Trophic Balance Index (TBI) plotted against ecosystem type for the subset of 120 models.

This preliminary analysis indicates that all ecosystems examined exhibit a wide range of TBI values, mostly at the higher end of the possible range. Therefore exploitation patterns are very uneven and skewed towards the higher trophic levels, with no systematic pattern across time or space. Few systems are close to balance, but the closest are tropical systems, which typically harvest a wide range of species and size classes using a large variety of

fishing gear (Kolding and Van Zwieten 2011). Ecosystems with lower TBI had higher exploitation rates and higher total catches. Further investigation is required to determine whether exploitation increased because TBI decreased, or whether TBI decreased because of increased exploitation across lower trophic levels, thus increasing catch, as predicted by our hypothesis.

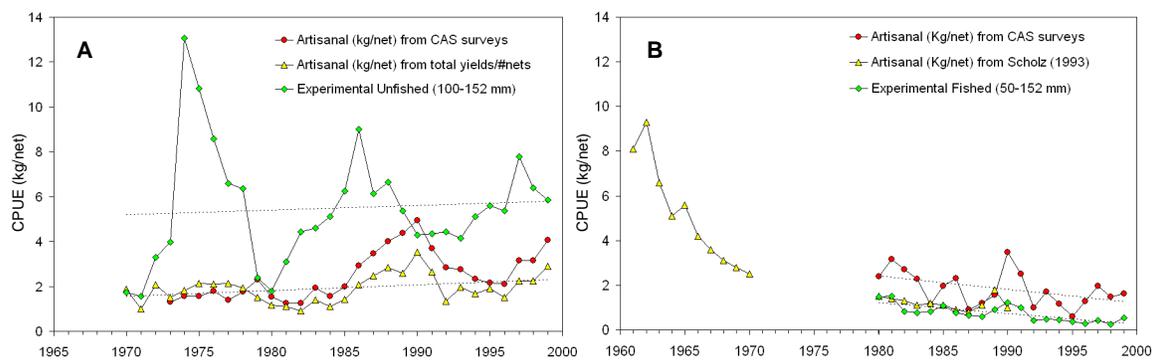
In conclusion, the predominant fishing pattern on marine resources is highly inefficient from an energetic point of view as >99% of the production is metabolized when reaching TLs 4-5. At the global level, the fishing pattern is strongly skewed towards high TLs, and a more balanced harvest regime can substantially increase yields while protecting the low productive large predators.

### 3.4 Maximizing fisheries yields while maintaining ecosystem structure

**Kolding, J.; Jacobsen, N.S.; Andersen, K.H. and van Zwieten, P.A.M.**

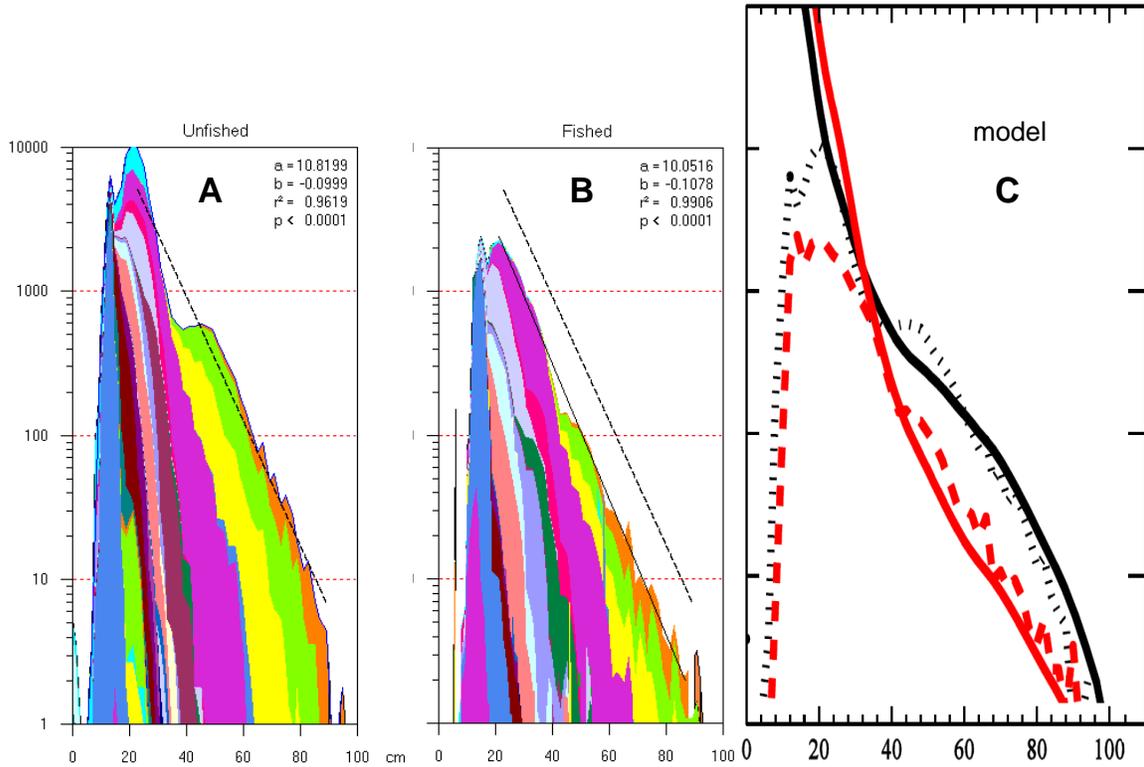
Under the Ecosystem Approach to Fisheries (EAF) an optimum fishing pattern is one that gives the highest yield while causing the least structural impact on the community. The question is then how to obtain such a pattern. Unregulated fishing on the Zambian side of Lake Kariba has shown consistent high inshore catches, in spite of an increase in effort and corresponding decrease in CPUE (**Figure 1**). The decreasing CPUE has caused artisanal fishermen to decrease the mesh sizes of their gear, and are targeting progressively smaller fish. On the contrary, on the Zimbabwean side the fishery has been regulated and enforced and CPUE kept largely constant, although fluctuating with lake level changes (Karengere and Kolding 1995).

Over the time series investigated (1980-2000) the unregulated Zambian side has harvested a mean total yield of  $\approx 6000 T yr^{-1}$  while the regulated Zimbabwean side has obtained a mean total yield of  $\approx 1000 T yr^{-1}$  (Kolding et al. 2003). Despite these facts, the size distribution of the fish community on the Zambian side is kept intact, i.e. the slope of the size spectrum is unchanged compared with an unfished protected area in the lake (**Figure 2**).



**Figure 1.** Catch per unit effort time series in Lake Kariba. A) Zimbabwe: Artisanal mean annual kg/net from Catch Assessment Surveys - CAS (circles), total annual yield / total number of nets (triangles, trend n.s.), and mean annual experimental kg/45

m net set (diamonds, trend n.s) in the mesh range 100-152 mm (comparable with artisanal mesh range) from an unfished area. B) Zambia: Artisanal mean annual kg/net from CAS surveys (circles, trend n.s), mean annual kg/net from Scholtz (1993, triangles), and mean annual experimental kg/45 m net set (diamonds, trend \*\*\*) in the mesh range 50-152 mm (comparable with artisanal mesh range) from the fished area. Redrawn from Kolding et al. (2003).



**Figure 2.** A: The observed size-spectrum in the unfished area. B: The observed size-spectrum in the heavily fished area (Zambia). C: The model size spectrum from the fished (red) and unfished (black) areas of Lake Kariba. Dashed lines represent the mean of the time series from 1985-2000 and full lines represent simulations from the size-based model. Smaller individuals are not well represented in the data due to gear selectivity. A and B after Kolding and van Zwieten (2014).

We use a size- and trait-based model (Andersen and Pedersen 2010, Hartvig et al. 2011) calibrated to the Lake Kariba fish community to simulate the fished and unfished community size distributions. With the model we predict that smaller size at entry to the fishery gives higher yields, and also causing less change in the slope of the community spectrum. The model results supports the observations that the fishing pattern with small mesh sizes on the Zambian side of the lake can give 6 times higher yields and maintain the size-spectrum slope, while only the intercept (standing biomass or CPUE) is decreased.

### 3.5 What are the ecosystem consequences of balanced fishing regimes?

**Rochet, M.J.; Collie, J.; Jacobsen, N.S. and Reid, D**

Balanced harvesting would require adjusting exploitation patterns to balance the pressures of all fisheries in an area with the relative productivities of the species and sizes of fish in the ecosystem. This contribution summarizes the work by the International Council for the Exploration of the Seas (ICES) Working Group on the Ecosystem Effects of Fishing (WGECO). WGECO reviewed the model results and empirical evidence about the ecosystem consequences of balanced fishing regimes available by the time of the meeting in April 2014, and provided some recommendations for future research (ICES, 2014).

Size-based and other models used to predict the consequences of contrasted fishing regimes have produced nuanced results (Blanchard et al., 2014, Garcia et al., 2012, Hintzen et al., 2013, Jacobsen et al., 2014, Law et al., 2012, Law et al., 2012, Rochet and Benoît, 2012, Rochet et al., 2011). Less concentrated (including balanced) fishing regimes tend to produce higher yields (measured by aggregate catch biomass, regardless of the catch composition and value), higher system biomass, smaller-sized catch, and a higher temporal stability, than more concentrated fishing patterns. The less concentrated fishing regimes also tend to have lower effects on the community size-structure and biodiversity, given the biodiversity metrics that have been examined in these studies. However, the magnitude of the predicted differences varies. Ultimately whether the differences in yield and/or impact are of significant magnitude is difficult to tell generally. Moreover, consequences may depend on the combination of the settings (structure and functioning) of a given community, and the details of the fishing regime.

Seeking empirical evidence for ecosystem consequences of fishing regimes requires, first, the development of metrics describing the exploitation patterns, that is, the distribution of fishing across ecosystem components. A number of metrics have now been proposed for fishing pressure, describing, on the top of fishing intensity, how fishing pressure is apportioned across species and sizes (Fauconnet et al., accepted; Collie et al., 2013; Rochet et al., 2013 a, b – **Table 1**).

Temperate shelf fish communities have been heavily exploited, but many experienced decreasing fishing pressure and changes in exploitation patterns in the most recent decade. Several studies have examined the consequences of these changes, taking either a historical approach (tracking the consequences of changes in exploitation patterns through time within a given system, Collie et al., 2013, Rochet et al., 2013 b) or a spatial comparative approach (comparing exploitation patterns and the associated community across marine ecosystems, Rochet et al., 2013 a). Fishing distribution was found to vary in space and time as much as intensity, but there was limited evidence that these changes actually affected the state of the communities as expected based on the model results. This was ascribed to the many other drivers which affected the community dynamics and potentially interacted with and/or confused the changes in fishing pressure. Besides, it was found that fishing distribution and intensity did not vary independently – *e.g.* increasing fishing pressure would be concomitant with a broadening of the exploitation pattern. As for the comparative approach, whether a more diverse catch is extracted from the more diverse communities because these communities comprise more species, or whether these communities are more diverse as a result of a more balanced exploitation, is difficult to conclude definitely.

Balanced fishing may be difficult to implement, both because it may result in less predictable ecosystem dynamics, and owing to the complexity of translating the concept into practical management measures. It may be precautionary to avoid too selective fisheries, but whether a balanced exploitation should be aimed at remains an open question. So far modelling studies of balanced fishing have relied mostly on size-based approaches. Other complementary approaches might be useful to investigate the concept further. Important management aspects like conservation of vulnerable species as well as consideration of fishing impacts on benthic habitats should be further investigated in more detail within the concept of balanced harvesting. Besides, it is generally agreed that achieving “perfect” balanced fishing in the real world will be difficult. An appropriate research question might be: Does partial progress towards balanced fishing yield at least some of the benefits expected of full balanced fishing? On the empirical side, broader scale analyses of the actual fishing regimes would be useful – for example, establishing how balanced fishing is in the North Sea.

**Table 1.** Metrics of fishing pressure to measure the intensity and distribution of fishing pressure on community components

Information source Type of metric	Stock assessments	Catch statistics
Fishing intensity	Average $F^*$ across species	- total catch weight per surface area
Fishing distribution wrt length	$SD^\dagger(F)$ across length classes	- length range of catch  - number of species that make up a given (high, e.g. 85%) proportion of total catch
Fishing distribution wrt species	$SD(F)$ across species	- percent total catch accounted for by the two most caught species - catch species richness - catch species evenness - percent total catch from species groups, e.g. predators, or other functional groups
Fishing target		- exploitation index $^\ddagger$ per species group - catch average length

\* $F$ : fishing mortality rate  $^\dagger SD$  standard deviation  $^\ddagger$  exploitation index: ratio of landings summed across species within groups to a group biomass index from e.g. a survey

### 3.6 Selective fishing and balanced harvest: Concepts, consequences and challenges

Suuronen, P.; He, P.; Pol, M; Graham, N. and Reid, D<sup>4</sup>

To reduce bycatch and discards that are viewed as a waste of fisheries resource and in some cases also a threat to biodiversity, the fishing industry is often required to use selective

gears and fishing tactics that reduce the probability of capturing unwanted species and sizes of fish in order to comply with regulatory frameworks. Selective fishing is practiced also to reduce catch sorting labour or to satisfy the market needs. This paper further explores the concepts of selective fishing and balanced harvest, and associated strategies, by comparing the trade-offs between these fishing strategies under specific circumstances, applications, and technological challenges.

### **Selectivity and selective fishing: Definitions**

Selection of fish by a fishing gear can be considered to be the process that causes the catch to have a different composition to that of the fish population encountered by that gear. The selectivity of a fishing gear is a measurement of the selection process.

Selective fishing is the ability to target and capture specific species, size or sex of fish (or a combination of these), allowing unwanted species to evade or escape capture. Unwanted species, sizes of fish, often referred to as bycatch may include small or juvenile fish, non-targeted species, seabirds, mammals, and other living organisms encountered during fishing.

Size selectivity is the ability of fishing gears to target and retain certain sizes of fish within a species, while species selectivity is the ability of fishing gears to target and retain certain species encountered. A perfectly species-non selective fishing gear would catch all species in equal proportion to their presence. This non-selectivity is seldom, if ever, observed. In general, most fishing gears catch species with different efficiencies. In highly species-selective fishing, only a few, desired species are retained by the gear. This selectivity is often the objective of fisheries management and as a consequence the target of research activities over the last half century.

### **Balanced Harvest and the Three-level Harvesting Concept**

We propose a three-level harvesting concept to interpret the Balanced Harvesting strategy:

- 1) **Size/species selectivity** – at the gear level; gear-related, one gear, one operation
- 2) **Vessel/métier** – gear, vessel, instrumentation, skipper, temporal/spatial distribution, availability to gear
- 3) **Harvesting pattern** – across all gears and fleets, over a period of time, within a defined management area or ecosystem

Balanced Harvest may be possible by managing the harvesting pattern as a whole, not by any individual element (gear, vessel or fleet). It is a strategy to manage the harvesting pattern (3) to encourage sustainability of all species over time within a management area or an ecosystem. Harvesting Pattern is a combination of (i) gear selectivity; (ii), fishing effort across all gears and fleets; (iii) spatial and temporal distributions of fish; (iv) vessel deployment and skipper behavior/skill; (v) availability of fish to the gear and to the fleet, and others. Changes in any of these factors or a combination of factors will affect harvesting pattern and potentially can “unbalance” fishing.

### **Fishing sector perspective and other challenges**

As Balanced Harvest is a relatively new concept, the views of the fishing industry have not yet been collected systematically but less regulations (if true) would likely be considered as positive. However, fishers will potentially incur increased costs due to more catch to sort,

possible loss of catch quality, higher fuel consumption, larger vessel hold capacity, and additional marketing costs for low-value catch. There are also practical issues on how to deal with non-marketable fish: can they be discarded, or used as feed for aquaculture? There are concerns that feed may become one more driver for overfishing by providing large quantities of low-cost feed for the aquaculture industry.

As Balanced Harvest should be achieved over the whole ecosystem and all vessels/gears, it may be that there will be little direct effect on what each boat or fleet actually catches. Balanced Harvest does not distinguish whether it is landed, just that it is taken. Rather than each vessel having lots of new species and sizes to catch, the likely issue is that they will have to be more flexible in the species mix that they take, so more polyvalent. To take advantage perhaps of the low uptake of some high productivity species, while others may already be “used up”.

There are also ethical and societal value issues regarding the Balanced Harvest of whales, turtles and other charismatic animals. Further, many species occupy different trophic levels throughout their life cycle, while species/sizes at the same trophic level often occupy different habitats and ecological niches. There also issues in defining and managing across ecosystem boundaries (biological) vs. management boundaries (political), and how to implement Balanced Harvest across them. Implementing a balanced harvest strategy is likely to lead to more complex management, a greater need for monitoring and enforcement, and increased scientific resources.

## **Conclusions**

Balanced Harvest broadens the selective perspective from the scale of individual fishing operation to all gear types and fishing patterns, and expands in temporal and spatial scales of ecosystem productivity and management. The practical implementation of Balanced Harvest would not be simple, and a consequence of its implementation, perhaps counter-intuitively, would be a need for even more selective fishing gears and practices.

We suggest that Balanced Harvest is an exploitation strategy that should aim to manage the harvesting patterns of multi gears and multi fleets as a whole, rather than aiming to control of individual gear or vessel selectivity.

Balanced Harvest is still an ambiguous concept in the fisheries management arena and needs further explanation and exploration. At the same time, we should remain skeptical towards the “common truths” of selectivity fishing. It is recognized that selective fishing does not necessarily mean better conservation.

Finally, alternative management models are valuable but unless there is political will to curb excessive capacity and fishing effort, neither selective fishing nor balanced harvest will resolve the problems of too many fishers chasing too few fish.

## **3.7 Discussion summary**

### **Reid, D. (Rapporteur)**

It was recognized by the workshop that any empirical evidence will generally be noisy. The sources of noise would likely include poor quality or uncertain catch and landing data.

Fishery independent data will be potentially valuable, but is itself subject to noise from both sampling errors, and from unknown catchability effects from the survey trawls. Other sources of noise could come from external drivers including climate change, management changes, technological creep in the fisheries, market conditions and constraints and many more. A potentially powerful source of data that might help underpin conclusions on BH, either positive or negative, could come from a meta-study of EwE models. There are some 200 of these now available worldwide. In many cases these models are populated by a large amount of genuine empirical data. However, the models the balancing process will change some of the original empirical values and missing values need to be estimated. These models should perhaps be regarded as semi-empirical but still remain models, rather than pure empirical data.

One possibility would be to look for single case studies where there has been a shift from a highly selective fishing pattern to a somewhat more balanced one or the converse. To be conclusive, these cases would need to be undertaken in places where there has been few or no confounding factors

In seeking empirical evidence, there is a need to know, in advance, the changes or metrics of changes that are important to focus on to deliver evidence for or against the BH hypothesis. Based on the discussions these should focus on ecosystem status and on yield. Ecosystem status would have to be in terms of a small number of concrete and discrete metrics that could be used as indicators for important characteristics of the ecosystem. E.g. biodiversity indicators, and food web status or ecosystem functioning indicators. Yield improvements through BH could be in terms of biomass (fish protein), economic yield (revenue, profit, and rent return), social objectives (e.g. employment, work safety) or societal objectives (e.g. food security; ecosystem health).

Based on studies to date, the indications are that some African lakes may be important source of empirical evidence, following the work of Kolding et al. If this is the case, then it would be important to examine other African lakes that have thus far not been examined to look for confirmatory or confounding evidence for the BH arguments developed from the Lake Kariba and Bangweulu swamps studies. A second additional possible source for new empirical evidence could be in marine coastal artisanal fisheries if data could be found for these. Also this need not necessarily be in the developing world. A first step might be to examine some promising cases studies to determine how close (or not) these followed the hypotheses of BH.

The other main potential for developing empirical evidence could be found in controlled experimental situations. For example experimental effects of simulated fishing could be carried out in tank based approaches. Although not designed specifically for investigating BH, tank experiments in Norway (Heino pers. comm., this meeting), may have potential for this type of work. More substantial field experiments could also be carried out in either artificial or natural lake systems. The requirements would be for an enclosed self-contained ecosystem with multiple species, where it was possible to both fish the populations and to accurately survey them, at periodic intervals. Possible candidate natural lakes might be found in Finland, Sweden or Canada.

Finally, the workshop identified the need to consider the long term implications of BH – i.e. the goal of maintaining ecosystem structure and functioning for long term sustainability rather than over short periods.

## 4. ECONOMIC, POLICY AND MANAGEMENT IMPLICATIONS

### 4.1 Balanced Harvesting in fisheries: Economic analysis and implications.

**Charles, A., Garcia, S.M. and Rice, J**

Adoption of the Ecosystem Approach to Fisheries (Garcia et al., 2003; FAO, 2003) and the Convention on Biological Diversity's *Malawi Principles for the Ecosystem Approach* (UNEP/CBD 1998) requires a broadened perspective on fisheries management, and a focus on "Conservation of ecosystem structure and functioning, in order to maintain ecosystem services". The challenge is to translate this into practical terms within fishery management. One strategy proposed for this is a shift to Balanced Harvesting (Zhou, 2008; Garcia et al., 2010; 2012), in order to distribute fishing mortality across a wider range of species, stocks, and sizes in an ecosystem (Garcia et al. 2010; 2012). This involves three key ingredients: (1) broadening the range of species caught, (2) broadening the range of sizes caught of each harvested species and (3) lowering the exploitation rates for some conventionally-targeted species, to ensure overall exploitation in the ecosystem is kept to a modest enough level.

The presentation explores the idea of Balanced Harvesting (BH) from an economic perspective, discussing (1) BH as a mechanism to achieve multiple objectives in fisheries, and resulting trade-offs, (2) economic aspects of BH performance measures and of BH implementation options, and (3) distributional impacts (between types of fisheries, and between the present and the future).

#### **Multiple Objectives and Trade-offs**

Fisheries, like most human pursuits, involve a multiplicity of economic, social, cultural and biological objectives (Charles, 2001). The CBD's objective of "conservation of ecosystem structure and functioning" is only one of twelve 'Malawi Principles' for the Ecosystem Approach (UNEP/CBD, 1998) and more broadly, only one among a range of society's objectives. This implies the reality of difficult tradeoffs among objectives and the likelihood that any single objective will be only partially realized. These trade-offs translate into choices of the extent to which corresponding strategies (such as BH) are implemented. What, then, is the desired extent of a shift to BH, when all objectives are considered? What are the consequences of different levels of implementation, across all objectives?

The economic concept of 'marginal' or incremental change is relevant here: what is the incremental net benefit (positive or negative) of each incremental shift toward BH, assessed across all societal objectives? This is important since from an economic perspective, as a strategy such as BH is increasingly applied, the marginal (or incremental) cost of implementation may increase, possibly making the 'optimal' level of BH somewhere less than 100%. Furthermore, the net benefit is actually not a single measure but rather multi-

dimensional: a shift to BH may have net benefits in certain dimensions (e.g. improved ecological and food provision benefits), but negative impacts in other dimensions (e.g. fishery profits). In that context, it is crucial to understand the range of costs and benefits, and how these interact across multiple objectives.

Further compounding the challenge of implementing BH, in a world of multiple objectives, is the complexity of human uses of aquatic systems. Typically, in any given location, the fishery sector is not alone in using the aquatic ecosystem – other activities such as shipping, tourism and aquaculture all impact on the system. Accordingly, when considering implementation of BH, we must assess the accompanying benefits and costs in relation to how other human uses impact on “conservation of ecosystem structure and functioning”. We cannot necessarily assert that a move of one part of the economy (the fishery system) in a certain direction is desirable, if other parts do not change. As with implementation of the Ecosystem Approach, the existence of these complexities does not provide an excuse for ‘doing nothing’, but it does highlight the need for integrated management of inter-related activities.

### **Economic analysis of BH performance measures**

Garcia et al. (2010; 2012) examined the performance of BH strategies across a range of harvesting intensities – as measured by ‘annual percentage removal’ from the ecosystem, from no removal (0%) to total removal (100%) – based on three aggregate performance measures, expressed as a percentage of the maximum theoretically possible. What is the economic relevance of each of these performance measures?

#### *Percent of maximum available system biomass*

A higher ecosystem biomass may have economic value in multiple ways: direct biodiversity use benefits (e.g. market value) and broader biodiversity protection benefits (e.g., ‘option value’ with a higher biomass keeping ocean use options open for the future).

#### *Percent of maximum extirpations*

A lower rate of extirpations can be seen in economic terms as providing ‘existence value’, since a lower level of extirpations keeps more species in existence within the system) and option value (since any given species has the potential to provide future economic value), although it may not normally translate directly into market value, or relate to conventional fishery economic or social objectives.

#### *Percent of maximum total yield from the ecosystem*

This measure would be relevant if applied to a single-species fishery analysis (since yield multiplied by market price gives total revenue), but here the total yield is from the ecosystem overall and thus includes species with no current market value. Hence, while total yield in this context tells us about the productivity of the ecosystem, and is relevant to food security, no conclusion can be drawn about the fishery’s total economic benefits without knowing the species composition of the harvest, and its human utilization.

### **Economic analysis of BH implementation options**

Since BH applies to (and only becomes meaningful at) the aggregate of all fisheries in a given ecosystem, it need not be imposed on a single fishing operation, a single fishing fleet

or a specific fishery. Instead, as a fishery mechanism, BH would require the overall fishing sector exploiting an ecosystem to adjust; this in turn has economic implications. An assessment will be needed of the options for implementing BH in a given context, and which parts of the species/size range to focus on. How do the implementation and the economic analysis of BH vary with fishery scale (small-scale versus industrial fisheries), area (coastal, offshore, high seas), domain (pelagic, demersal), and fishery culture? Here we consider the impact of shifts to BH, based on the three major directions listed earlier.

*Broaden the range of harvested species (and of sizes for individual species)*

A wide range of species and sizes are already effectively used and efforts are ongoing to expand that range, including on zooplankton and mesopelagic species, to satisfy a growing demand for ocean proteins and oils. Nonetheless, the key question here is: Why are currently unexploited or underexploited species and size classes not being more extensively harvested? Three major possible reasons are: regulations (fishers being kept from broadening the species caught due to existing regulations), technology (available technology unsuited to harvesting those species) and markets (no markets for the currently unexploited species).

If the issue is regulatory (e.g. rules preventing the landing of fish below a minimum size), changes can be made in those regulations, although attention will need to be paid to why those regulations are present in the first place, and the costs of change. If technology is the key factor (e.g., a lack of suitable catching and processing methods), the question arises as to why development of technology more suited to a broader range of species or sizes has not already occurred. Is there a need for new technological innovation, or is the issue one of costs? If the issue is a lack of market for certain species or fish sizes, ones that BH indicates 'should be' harvested, this may only occur through investments, incentives and/or subsidies. Options include development of new marketing channels, launching marketing campaigns, searching for new markets, and direct subsidization of consumer products, with varying possible costs. It will be important to assess whether this is in fact worthwhile, in a cost-benefit calculation of how far to shift to BH.

In considering broadening the range of species and sizes harvested, it is worth reiterating that the important matter is the aggregate results across the ecosystem; this does not necessarily require any given fisher, fleet or even fishery to change their practices. Furthermore, while broadening the range of species and sizes caught may have certain positive benefits, it may not be desirable overall, given the balance of societal objectives. For example, the costs of a BH strategy may be excessive if it requires catching species that society has no interest in or desire to utilize. On the other hand, modifications of the fishing regime such as protection of older spawners may be desirable to meet other goals (e.g., recuperate lost productivity, improve reproductive success, etc.) even if there is no BH strategy.

*Lower exploitation rates for target and non-target species*

Analyses of BH to date indicate that an accompanying reduction in harvest rates for some existing fisheries may be needed. Thus a BH strategy may facilitate rebuilding of some species; like any rebuilding strategy, this can be predicted to eventually lead to increased long-term profits, as well as improved conservation. On the other hand, a reduction in harvest rate may well produce a short-term loss of profits, and negative impacts on food

security. Compensation for such reductions may come from better overall fishery performance or from ‘new’ fisheries on other components of the ecosystem, but it is also possible that potentially-expensive subsidies and food provision may be needed.

### **Distributional Impacts**

A crucial issue to address in any shift of ocean policy and management is the distributional impact of such a change, both from a perspective of fairness, and in terms of subsequent responses of the actors to that change. Would a move to BH create negative (or positive) impacts for some fishers (or others in the value chain) more than others? If the difference between what is presently caught and what should be caught under BH is seen as an additional ecological “burden”, how should we allocate required changes in catch composition equitably? Addressing these issues depends on whether implementing BH takes place across all segments of the fishery, or by development of new fishery components specifically to meet BH needs. The former has the advantage of spreading the requirement of a shift to BH across the entire fishery system (which may be seen as equitable treatment across fishery components, but it imposes the change on everyone regardless of their capability to adapt or the cost of doing so, and does not deal with the need to broaden the species mix in the fishery sector. The latter approach (development of new fishery components) could involve entrepreneurial fishers developing new harvesting in order to ‘crop’ currently-unused components of the ecosystem for new markets. These new operations may be profitable on their own, or may require subsidies. In the latter case, one option would be for subsidies to be covered by taxes paid by those continuing their conventional operations of catching ‘high-end’ fish, but whatever the approach taken, potential positive or negative economic implications, eventually “modulated” by consumer awareness and preferences, need to be considered.

Also relevant from a distributional perspective is the reality that as with any investment, the benefits of BH would be produced later than the costs, and the higher the discount rate, the more impatient society will be about waiting for those future benefits. Analyses of BH to date have not addressed the transition issue of how short-term costs compare with long-term benefits, nor the long-term impact on the industry of either meeting or not meeting the goal of “maintaining ecosystem structure and function”.

### **Discussion**

This paper has outlined economic aspects in the possible use of Balanced Harvesting within fisheries management. Many questions were raised, in terms of both understanding BH in conceptual terms, and addressing practical implementation issues across a range of fishery circumstances. The following summarizes the major groupings of questions:

- What are the societal trade-offs between the CBD goal of “conservation of ecosystem structure and functioning” and the range of economic and social goals? In balancing these goals within a societally acceptable “sustainable operating space”, to what extent (if any) is implementation of BH desirable?
- What are the economics of implementing BH, in terms of interpreting performance measures and of assessing the costs and benefits of partially implementing BH? In assessing economic costs and benefits of BH, how does a market analysis compare with

an assessment of the economic value of ecosystem services? What are the appropriate transition paths if a move to BH is desired?

- On distributional issues, if BH is to be implemented, should all fleet sectors adjust equally or should some modify less while others start new fisheries, and what subsidies or other incentives may be needed?

Additionally, it will be important to understand how potential BH implementation interacts with management and policy tools (Garcia et al., 2014), such as MPAs, gear regulations, fishing rights and eco-labelling. Looking across multiple scales in the fishery system (Charles, 2012), what are the economic and livelihood implications of these interactions? Ultimately, understanding these economic aspects of the BH option will lead to more informed approaches to balancing across society's multiple objectives.

## **4.2 The Ecosystem Approach to Fisheries and balanced harvest: considerations for practical implementation**

**Bianchi, G.**

Balanced harvest is a harvest strategy that aims to balance fishing mortality or removals among different sizes and species at all trophic levels in proportion to their productivity. The concept is often represented using the trophic pyramid and showing how a balanced harvest should take place across the different trophic levels in a way that is proportional to their respective levels of productivity.

The concept of "balanced harvest" has recently been used in relation to the impacts of fishing on larger sizes and species (usually higher in the trophic pyramid and of higher economic value). It has also been argued that conventional fisheries management strategies, based on selective fishing practices such as minimum mesh sizes may contribute to altering the food chain structure with overall loss of productivity and resilience of aquatic ecosystems as well as phenotypic changes leading to fish growing faster, to a lower maximum size and maturing earlier. Hence, it has been proposed that management practices based on size selectivity should be abandoned. This proposal has raised debate and been seen as potentially undermining regulations that are enshrined in most fisheries legislation worldwide.

The idea that maintenance of ecosystem structure and functioning can best be achieved through a more balanced harvest strategy is intuitively meaningful and grounded in scientific evidence. The recognition of the need to move beyond single-species management to a more comprehensive perspective that includes wider impacts of fishing on ecosystems is also broadly accepted. What seems to be the real challenge is identifying cost-effective and practical fisheries management strategies and approaches that will result in the desirable fishing pattern while also taking into consideration the social and economic implications and constraints.

The Ecosystem Approach to Fisheries (EAF) (FAO.2003) is an integrated and holistic approach to fisheries management that aims at balancing ecological and human well-being. The approach is holistic in integrating the three dimensions of sustainability (ecological, social and economic) and encourages application of good (context-specific) governance to

achieve ecological and human objectives. Below is an example of EAF principles that are directly linked to the concept of balanced harvest (FAO, 2003):

- fisheries should be managed to limit their negative impacts on the ecosystem;
- to the extent possible ecological relationships between harvested, dependent and associated species should be maintained.

The EAF expands the scope of fisheries management to include impacts of fisheries on non-target species, on vulnerable species and habitats, impacts on community structure, and on ecosystem structure and functioning, including trophic relationships. The EAF explicitly addresses the need to take account of the interdependences of species and functioning of aquatic ecosystems when managing fisheries. Although not explicitly defined as “balanced harvest”, the EAF enshrines the concept, which, in fact, is at its heart.

### **Balanced harvest and selective fishing**

Balanced harvest arises very much to counter the idea that selective fishing is a desirable practice existing popularly in modern fisheries.

Fisheries are usually selective as they tend to target species and/or sizes yielding the highest economic returns. Selectivity is realized through different forms, e.g. through gear type, mesh size, operational time (day vs night), seasonal activity patterns, fishing areas. It should also be noted that non-selective fishing is impossible, i.e. no gear will be able to catch all ecosystem components, and in a way that would result in removal of species/individuals proportional to productivity (as required by balanced harvest).

There seems to be an ongoing confusion in the discourse between selective fishing at ecosystem level (that results in altered ecosystem structure and functioning) with selective fishing at the operational level. Balanced harvest should result from the sum of fishing mortalities across trophic levels generated by the various fisheries operating in a given ecosystem, including of bycatch species. In other words what needs to be considered is the total selectivity of fishing at ecosystem level, when all removals by all fisheries are taken into account. Optimal harvest strategies to move towards balanced harvest may entail a combination of highly selective fishing in relation to gear, spatial and temporal distribution of size and species etc.

### **Using the trophic pyramid as a conceptual model**

The trophic pyramid is a conceptual model of size and biomass at different trophic levels and it has been used to represent how different harvest strategies affect overall ecosystem structure, from primary producers to top predators. It is appealing as it is easy to understand also by stakeholders and non-experts. Unfortunately the trophic pyramid does not exist as a physical unit and species and sizes display dynamic and diverse distribution patterns in space and time. Many species occupy different trophic levels throughout their life cycle, while species/sizes at the same trophic level often occupy different habitats and ecological niches and are therefore not necessarily co-occurring in space and/or time. In this situation, the suggestion that fishing non-selectively will help achieving a more balanced harvest seems simplistic. Therefore spatial distribution of difference species and sizes in space and time need to be considered when developing management strategies coherent with the concept of balanced harvest. Furthermore, trophic webs are not self-contained and discrete

systems. For example often top predators move much wider ranges than other species they feed on. So defining what trophic relationships we are aiming at balancing needs to be given greater attention.

### **Balanced harvest: the way forward**

Management approaches and tools that have been in use in conventional fisheries management will still be relevant (input/output controls, gear selectivity, time and area closures etc.). However, management strategies coherent with balanced harvest approach will probably take different forms in different ecosystems.

For example, in highly productive systems, with low species diversity and high biomass of a few species a “pragmatic” approach could build on existing single species-management by adding, for example, predator requirements for forage species in a piecemeal fashion. More conservative sustained exploitation rates, significantly lower than the maximum sustainable yield (MSY), have been recommended in order to leave sufficient forage for marine predators (Smith et al., 2011)

On the other hand, tropical and highly diverse ecosystems, where fisheries are multispecies and multi-gear, a more viable strategy will be to look at vulnerabilities of the various species to the gears used within a fish assemblage and develop strategies that take those into account. Integrated community level indicators (such as slope and intercept of size spectrum) can be useful in this context.

The drivers of non-sustainable fishing are well known. They include: overcapacity of the fishing fleet; IUU fishing; the open-access nature of many fisheries; poverty in coastal communities of developing countries and fishing as a last resort; intra- and inter-sectoral conflicts with degradation of habitats and resources; and inadequate governance structures. These drivers are present in a situation of rising demand for fish by an increasing human population and escalating demands from local and international markets.

As one of the sectors having the most impact on marine ecosystems, capture fisheries can do their part by eliminating overfishing and overcapacity of the fishing fleets. This will probably be one of the most effective ways of dealing not only with overfishing of target species but also with most of the problems facing fisheries in an ecosystem context. Eliminating overfishing is also a prerequisite for benefiting from a balanced harvest approach. A balanced harvest can then be addressed using management tools that are no different from those of conventional fisheries management, but applied in the broader context of optimizing not only in relation to target species but within the broader context of sustainability at ecosystem level (Garcia et al. 2011).

## **4.3 Can dynamic management aid in the implementation of a balanced harvest in developed fisheries?**

**Dunn, D.C., Hobday, A.J. and Halpin, P.N.**

Movement toward a Balanced Harvest in developed fisheries will likely come through increases in the number of targets and size classes being fished, and the number of regulations associated with the management of these new facets of the fishery. This process will bring species with a wide range of productivities into the fishery. The ability of

fishermen and managers to fulfil harvest goals across this increasing range of more or less productive stocks will depend on their ability to increase their selectivity and target stocks with remaining quota when “choke” stock quotas have already been reached. In our presentation, we showed how spatiotemporal measures can be used to improve selectivity of fisheries, allowing them to target such productive stocks in the face of protected species, increasing depredation from rebounding top predators, and may support the implementation of a Balanced Harvest. Further, we introduced the concept of dynamic management (i.e., management whose implementation is defined based on spatiotemporally variable conditions and is this adjusted in near-real time) as a mechanism to increase the efficiency of these measures.

We described the utility of dynamic management measures by providing three examples: the yellowtail flounder (*Pleuronectes ferruginea*) bycatch avoidance program in the US Atlantic sea scallop fishery, theoretical improvements to move-on rules implemented in many fisheries, and the Eastern Australia pelagic longline fishery southern Bluefin tuna (*Thunnus maccoyii*) temperature-based zoning. The scallop fishery on the east coast of the United States was closed in specific areas before they caught their scallop quota for 4 years between 2006 and 2009 due to over-quota catch of yellowtail flounder. In an effort to address this problem, a voluntary daily to weekly grid-based hotspot closure program was developed, resulting in reductions in yellowtail flounder bycatch below the quota limit and allowing full utilization of the scallop quota (O’Keefe & DeCelles 2013). Empirical move-on rules were shown to have the potential to reduce catch of specific size classes or choke species by up to 62% at the expense of only 8% of the target catch (Dunn et al. 2014; Dunn et al., *in prep*). Further, this dynamic management measure was shown to utilize 2 orders of magnitude less space-time while reducing the target catch only half as much as high-resolution (10kmx10km) optimized (via Marxan) monthly closures. Finally, we described the development of a dynamic zoning measure used by the Eastern Australia pelagic longline fishery based on thermal niche modelling of SBT. The temperature preference of SBT was used to divide the fishery into three zones (core, buffer and ok zones) where access is restricted based on the level of the fishermen’s SBT quota (Hobday and Hartmann 2006; Hobday et al. 2010). Hobday et al. 2010 report that SBT catch per unit effort per thousand hooks in the three zones were 2.27, 0.89 and 0.0, respectively. These examples indicate very strong increases in selectivity and each affords the opportunity for a fishery to continue pursuing productive targets after quotas for less productive targets have been filled. Further work needs to be done to examine the use of dynamic management measures in a multi-objective environment, but the efficiency and selectivity of these examples suggests that the concept may be critical in moving forward with the implementation of a Balanced Harvest in developed fisheries.

#### **4.4 An introduction to the MSC Fisheries Standard: current requirements and future development toward a multispecies and ecosystem approach**

**Atcheson, M. and Agnew, D.**

The Marine Stewardship Council (MSC) is an independent non-profit organization which sets the most widely recognized global standard for sustainable fishing. The standard

consists of three overarching principles that every fishery must meet to be certified sustainable. Principle one considers the status of the target stock, Principle two considers the fisheries impact on the surrounding environment and Principle 3 considers the effectiveness of management. Currently, the MSC Fisheries Standard is written for single-species fisheries with the stock status requirements based around the concept of MSY and recruitment impairment. However, several fisheries target many species simultaneously, and it is unlikely that all species will be fluctuating around Bmsy or surrogate targets at all times. Consequently, MSC has undertaken a review to identify aspects of the Standard that are challenging for mixed and multi-species fisheries, and identify options for a modified multispecies Standard. The Balanced Harvest concept is appealing in its ecosystem approach to fisheries, as well as its potential to increase accessibility for fisheries not currently management under a traditional single-stock approach.

#### **4.5 Implementing Balanced Harvesting – Practical challenges and other Implications:**

**Graham, N. and Reid, D.**

This presentation is focused on the statement in Garcia et al (2012) “Issues regarding the potential benefits and **implementation** of balanced harvesting remain”, and explicitly focuses on implementation. Implementation information requirements in managed fisheries would be: (i) Productivity at size for all species; (ii) Target Fishing or Harvest Ratio for all species based on productivity; (iii) Biomass by species to derive catch advice; and (iv) Monitored removals by species and size. In the following sections, we explore two approaches to balanced harvesting: (i) at a species level, and (ii) at a size category level.

##### **At the species level**

One example “ecosystem” is in the Celtic Sea, which contains 170+ species, 15-20 commercial species, and approximately 30 “abundant” species. Only 8 commercial species have an analytical assessment, but we could develop abundance and Harvest Ratios from surveys.

We would need to define the management area, consistently for all species? We would need to have quantified CATCH from all vessels, for ALL species, or all fished species. Do we also need benthos, top predators and other fish species? Zooplankton, Phytoplankton?

Management measures: We would aim to bring all species close to BH targets on an annual basis. Possibly allow “unrestricted fishing” at first, and respond to observed fishing pattern. Then “Switch on/switch off” métiers? deploy selective gear modifications e.g. single species gears? Apply a “tolerance” margin by species?

Is it possible? BH in this context would require VERY good control of fishing, also very difficult to stop fishing on species x in a mixed fishery, and could lead to a discard incentive. In an ideal world – MAYBE just possible!

##### **At the size category level**

Alternatively, we could fish for size only, a size spectrum approach? We could assume productivity scales with size, and remove a proportion at each size, i.e. length based TAC.

We would probably still need biomass estimates from the species to fill the size classes, as well as catches for all species from all vessels.

Management measures: We would aim to bring all sizes close to BH targets on an annual basis. As catch is a function of catchability and effort, we could manage by reducing effort on choke sizes, or by changing catchability. For example with dome shaped selectivity, grids, panels, fishing behaviour etc. Again, we could apply a “tolerance” margin by size?

Probably easier to achieve than by species

### **Caveats for a size based approach**

Catchability is a function of size, behaviour and morphology of a given species. So different species will have different catchability. Catch is then a function of catchability and effort. So different species will have different CPUE, and hence subject to different fishing pressure. So we may well face serial depletion of the most catchable species. Fishermen MAY also tend to target high price species within a given size class. So we risk serial depletion of most valuable. In combination we may end up with a fish community dominated by low value, low catchability species! We could then try and reduce fishing pressure on some species. E.g. those that are high catchability, low SSB, sensitive, or valuable. But this essentially takes us back to species based management. “Relative size and species composition should be maintained” - Garcia et (2012) so we would need to manage for species AND size in the end.

Balanced fishing does not mean LESS selectivity, it means MORE! It is NOT “unselective fishing” as is often claimed although Garcia et al (2012) state “Balanced harvest is selective”<sup>2</sup>.

### **Conclusion**

Balanced harvesting in managed fisheries in the developed world, may be possible, but only with excessive micro-management, and probably not where many species are already seriously depleted.

## **4.6 Challenges to the implementation of balanced harvesting systems: some ecological and technological issues**

**Hall, M.**

If a scientist is asked to produce an image of an ecosystem, most scientists would produce a sketch of a trophic web; boxes connected by lines showing the trophic relationships among the component species. The degree of disaggregation may vary, and one could also discriminate different life stages, or age/size groups within the populations. The fact that these component populations coexist and interact with one another is what defines the

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<sup>2</sup> Note from the Editors: Indeed, BH remains necessarily selective at the level of the individual gear, vessel and specialized fleet (possibly more than traditionally, as stated here) but it is less selective than conventional fishing at the levels of the ecosystem and food chain as the range of species and sizes used is broadened.

ecosystem. But the boundaries of the ecosystems are blurry lines and porous planes, crossed by some components but not others.

Where the diagram may be misleading is in suggesting that all these components are present and interacting most of the time, and that they share the same space. This may be the case in some small lakes, but even these will have mismatches in time and space by some of its components. The implementation of a BH approach in real life fisheries will encounter these challenges. In order to implement a “complete” Balanced Harvesting system in a pre-existing fishery, it would be required to develop technologies, capture systems, and markets, to extend the harvest to all the components of the ecosystem. Some of these challenges will come from the lack of markets for some species or sizes (most plankton components, seabirds, etc.), from cultural constraints in some regions (e.g. marine mammals), from inaccessibility (deep water species; hydrozoans, etc.). In many cases markets can be developed, but other constraints are more difficult to change

As that is an extremely difficult goal, the most likely evolution would be towards a “partial balanced harvest” (*sensu* M-J. Rochet), or in other words a diversified harvest that would expand from its initial selective condition where the effort is directed to one or a few species in a narrow range of sizes, to another in which more species are harvested in a wider range of sizes. This process would move the harvest in the direction of BH, without the strict requirements of the complete approach, and with more realism.

If we imagine that the components of an ecosystem are represented by a matrix of species x sizes, and a third vertical axis represents the biomass harvested, a very selective fishery will be represented by a peak showing the biomass harvested over a small number of quadrats in the matrix. A partial BH approach would consist initially in “pushing down” this peak and distributing the harvest to more species and sizes, reducing the kurtosis or “peakedness” of the distribution.

The obstacles I am going to address are not those stretching the limits of technology and markets; they are “simpler” problems to be encountered in the first steps of the change process, and could be part of the initial stages of a progression towards BH, which is the extension of the harvest to a partial BH, defined above as consisting of an expansion of the species mix, and of the sizes harvested by the current fisheries.

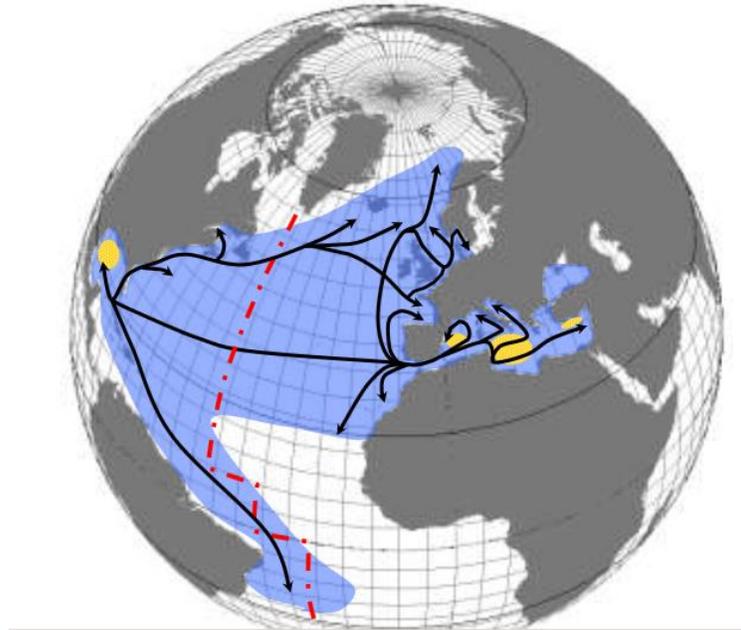
The obstacles to be addressed are not unsurmountable, but they require refinements in management beyond those in use in the current fisheries systems. I would like to present some of the challenges, and offer some potential solutions to bring the harvest system into one that allows for at least a “partial BH” approach.

The “extreme requirements” for BH that we can list are: all size classes of all species included in the BH strategy are present and vulnerable to the harvest all the time, and all “belong” exclusively to the ecosystem object of BH.

The deviations from these requirements include:

1. Size groups whose spatial distribution is unknown or not well-known (example: yellowfin tunas of sizes below 30 cm are not currently harvested in a significant amount by any fishery in the eastern Pacific, and their location is imprecise, so a decision to harvest them could not be implemented with the current level of knowledge and with the fishing gears in use in the region).

2. Species that are not vulnerable to the current fishing gears in use (example solitary species that do not take baits; deeper occurring species).
3. Highly migratory species that transit, because of movements or migrations, across several ecosystems during their life which I will call “multi-ecosystem species” such as Bluefin tuna (**Figure 1**), salmon, etc.

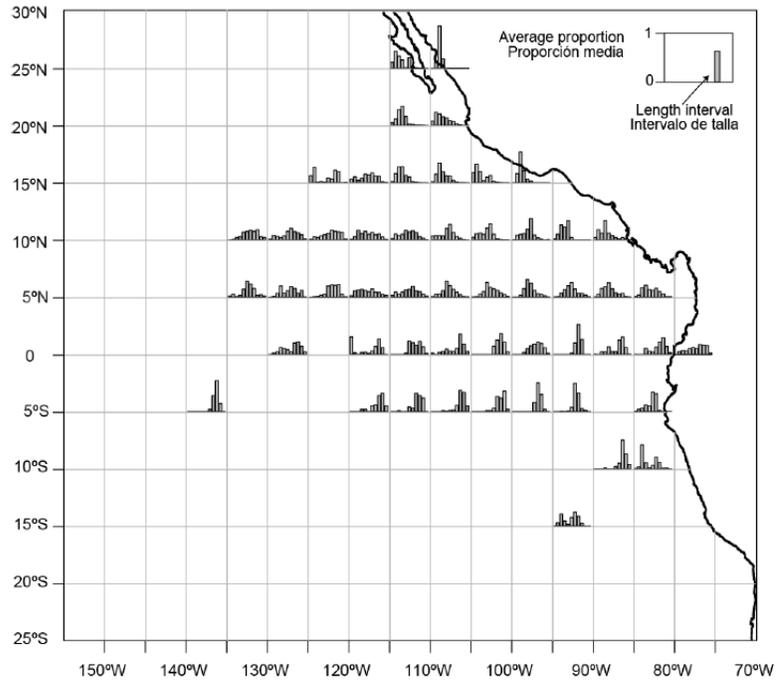


**Figure 1:** Bluefin tuna migrations in the Atlantic (Fromentin and Powers, 2005)

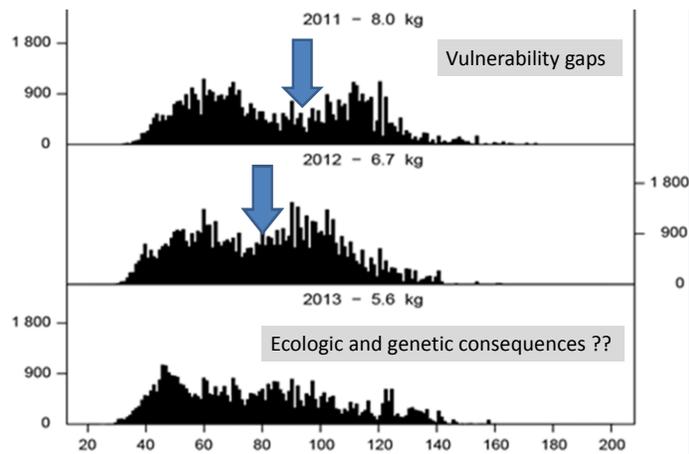
Perhaps species associated to the targets -a loose term that can include mixed species schools, predators or prey from the target species, etc.- could be the first to be added to the harvest. If we focus only in this subset of the ecosystem, then a first approach would be to apply the concept as a redistribution of effort among the subset of species that are currently taken by the fishery.

The sizes of the target species that are vulnerable are frequently distributed along spatial gradients caused by movements or migrations (**Figure 2**). This situation could be handled by controlling, through management, the spatial distribution of the effort/catches. The current management systems do not produce a harvest that is balanced across many sizes.

A more difficult case is the one where the length distribution of the catches is bi- or multi-modal, with a gap of sizes that are not captured by the combination of gears or modes of fishing in use (fishing with purse seines on Fish Aggregating Devices, on dolphins, with longlines, pole and line, etc.) (**Figure 3**). Unless technology/knowledge is developed to fill in the gap, it could create a distortion with potential genetic consequences.



**Figure 2:** Length frequency distributions of yellowfin tunas along a spatial gradient in central America (Lennert-Cody, Maunder and Aires da Silva, 2013).



**Figure 3:** Distribution of sizes caught in eastern Pacific bigeye tuna fisheries (IATTC, 2013). The middle-sizes gap is indicated by the arrows.

When the species cross one or more ecosystem boundaries, the challenge is to produce a harvest determined by the productivity in each system. This requires a coordination of the management in all the systems, producing a spatial and temporal mosaic of harvests that will require a complex (national or more frequently international) management of resources.

Some changes that are occurring as a result of economic or regulatory pressures (e.g. no discards/full retention requirements) are bringing a diversification of the harvests, but in the case of the purse seine tuna fisheries, the tonnages of the associated species are not very high (discards of 0% - 1.9%) to produce the desired distribution. Many of the resources of the region (e.g. the major components of the diet of the tunas) are not utilized or are utilized at a very low level, and there is no technology currently in use to increase their harvest.

Technological developments capable of producing live captures may facilitate a high degree of post-capture selectivity, and together with the development of acoustic and other instruments that can identify the species and sizes before the capture would be major factors in the evolution of the fisheries, allowing for better targeted harvests.

Finally, the harvested ecosystems are, in many cases, in less than optimal initial conditions, so a question is if BH may help in the recovery of some stocks, or if it will be necessary to rebuild some of the stocks before starting the transition to BH.

#### **4.7 Balanced harvesting and the tropical tuna fishery**

**Dagorn, L.; Ménard, F.; Chassot, E. and Filmalter, J.**

Tuna fisheries harvest 4.5 millions of tons annually, of which more than 90% consists of tropical tunas: skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*T. obesus*). Tuna fisheries are managed through five RFMOs: IATTC, WCPFC, ICCAT, IOTC, CCSBT (this latter being only focussed on a single species, the southern Bluefin tuna). The main fishing gears used for exploiting tropical tunas consist of purse seine, longline, bait boat (pole and line) and gillnets. Additionally other gears such as handline, troll, are used in small scale artisanal fisheries. The relative contribution of each main gear to total annual removals of tropical tunas and related species varies by ocean. All Tuna RFMOs make efforts to gather fisheries data, including catch data on target (skipjack, yellowfin and bigeye tuna) and non-target species (through observers), from the different fishing gears. Nonetheless, data gaps exist, which are primarily due to the large number of stakeholders from different countries, and, as such, greater effort is to improve data collection. The current management paradigm follows a single species approach, with a reduction of discards and conservation of sensitive species, such as sharks, forming recent priorities. Within this context, how far are tuna fisheries from being managed following the balanced harvesting approach?

A first urgent point, linked to the ecosystem approach to fisheries, is to improve our knowledge on the biology of some non-tuna species, as well as on the structure and functioning of the pelagic ecosystem. Improving this fundamental knowledge is key to identify which ecosystem indices and targets can be used in terms of management goals.

While catches of a single species from different gears are gathered for stock assessments, little consideration is given to how the shape of the F-at-age vector relates to the M-at-age vector. Balancing the exploitation at the single species level could already be an improvement and an initial step in changing the way tuna stocks are managed.

Different tuna fisheries can be characterized in a simplified manner according to their size selectivity and the fish community they exploit. Purse seiners fishing on FADs and bait

boats typically catch relatively small fish (50 cm FL, target and non target species). Alternatively, purse seiners targeting free-swimming schools or schools associated with dolphins, as well as longliners, usually catch larger fish (130 cm FL). Although the size selectivity of each gear is more complex and deserves more studies, the relative ratio of catches between gears that catch small fish and gears that catch large fish, could be used by managers to spread and balance fishing pressure across the size spectrum.

In terms of species, two points deserve some discussions. Firstly, it would be better to understand the ecological functions of the various exploited species (e.g. could the 50-cm tunas from the three different species, skipjack, yellowfin and bigeye, be considered as a single group?). Secondly, can overall fishing mortality at size be optimized simply by controlling effort of different gear types and strategies?

Considering the dispersed nature and vast numbers of stakeholders in this fishery, and under current management paradigms, tuna fisheries appear to be far from being managed in a balanced manner. Nonetheless, the wide range of gears used and their differing size and community selectivity presents a potential opportunity to manage exploitation of specific sizes and species according to gear type. In every Tuna RFMO, working groups in charge of ecosystem and bycatch should investigate mortality from fishing across a wider range of species and sizes in order to maintain the structure and function of the pelagic ecosystem.

#### **4.8 Preliminary reflection on a possible BH norm and harvest control rule**

**Garcia, S.M., Rice, J. and Charles, A.**

Preserving the marine food chain for human and ecosystem wellbeing is the central challenge of modern fisheries management. Scientists have struggled for decades to improve knowledge and propose solutions, responding to sectoral and societal demands. The adoption of the CBD and of the Ecosystem Approach to Fisheries has added new demands on the scientific agenda and new constraints for policy-makers and managers. As a consequence, the conventional approach developed to optimize fishing on single stocks needs to be adapted (or extended) to deal with whole species assemblages, trophic chains and ecosystems

The aim of this presentation is to promote some discussion on the practical implementation of BH, in case the concept is pursued in the near future.

##### **Two norms**

Two norms apply nowadays to fisheries and to conservation of biodiversity in fished ecosystems. On the one hand, the 1982 LOSC norm requires that “*stocks should be kept at biomass levels that can produce MSY*». The concept has been criticized by scientists since the early 1970s but it is still recognized in most national legislations and was confirmed in the 2002 WSSD Declaration § 31 (a). On the other hand, the CBD indicated, in 1998 that “*a key feature of the ecosystem approach includes conservation of ecosystem structure and functioning*». FAO adopted its Ecosystem Approach to fisheries (EAF) in 2001, including that requirement. Balanced Harvest is a proposal to operationalize this CBD norm. It aims at distributing *a moderate fishing mortality across the widest possible range of species, stocks,*

*and sizes in an ecosystem, in proportion to their natural productivity, so that the relative size and species composition is maintained* (Garcia et al., 2012)

Both UNCLOS and the CBD are instruments of international law which establishes the consensual principles and goals of the global community<sup>3</sup>. MSY is enshrined into the 1982 LOSC and has the “weight” of the Convention itself. By comparison, the 1992 CBD contained no specific article on marine and coastal biodiversity and these issues were integrated later through the 1995 Jakarta Mandate on Conservation and Sustainable Use of Marine and Coastal Biological Diversity and the 1998 Malawi Principles of the Ecosystem Approach. The decisional power of the CBD being limited to the EEZs, and the Malawi Principles being less binding than the CBD itself, the “bindingness” of the CBD “norm” is closer to that of the provisions of the FAO Code of Conduct for Responsible Fisheries than to that of MSY, particularly in the High Sea. However, as many other international law instruments, both the LOSC and the CBD are hard to effectively enforce and they gain effectiveness when reflected in national law. As a consequence, the CBD norm has high moral power and in the practice of international law, is useful to indicate the level of agreement reached at a certain time in an international community, in a step-wise process of maturation of international wisdom. For this reason, it is perfectly reasonable to scientifically examine that norm and its potential implications for implementation.

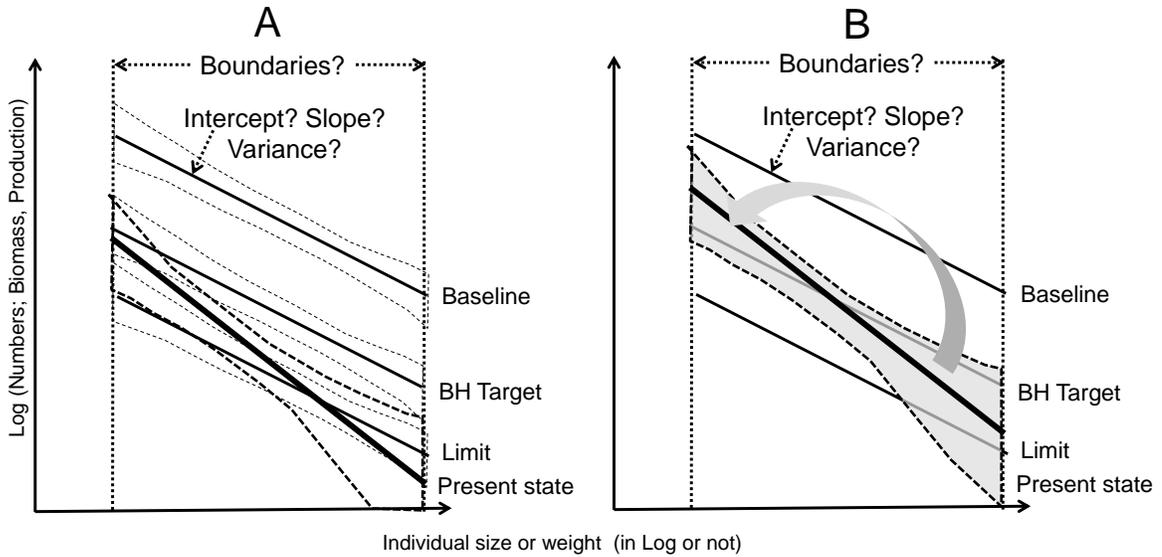
### **Parameterization of the norm**

In the following sections we will examine the CBD norm as expressed in a size-based model of ecosystem structure. The norm would be expressed by a slope of the size spectrum (in log) and its intercept. A number of issues emerge, however, in the specifications (**Figure 1**):

- The boundaries: the useful range for fisheries is from larvae (often used for food) to the largest predators (including mammals). However, for practical as well as local conditions (e.g. emblematic species) the practical boundaries will be a matter of societal decision, assessing the consequences for the ecosystem “structure and function” of any truncation of the ecosystem structure from the norm.
- A baseline state needs to be identified, either through modeling (e.g. for a “virgin” state) or empirically (e.g. based on early stages of exploitation). It will be necessary to consider variance in both slope and intercept.
- A minimum limit for slope and intercept, to avoid at any cost, would be precautionary and it could be determined through a risk assessment
- The Target state is the situation aimed at, either in the long term (it might then be identical to the “baseline” if the latter refers to an acceptable past situation), and/or in transitional periods.

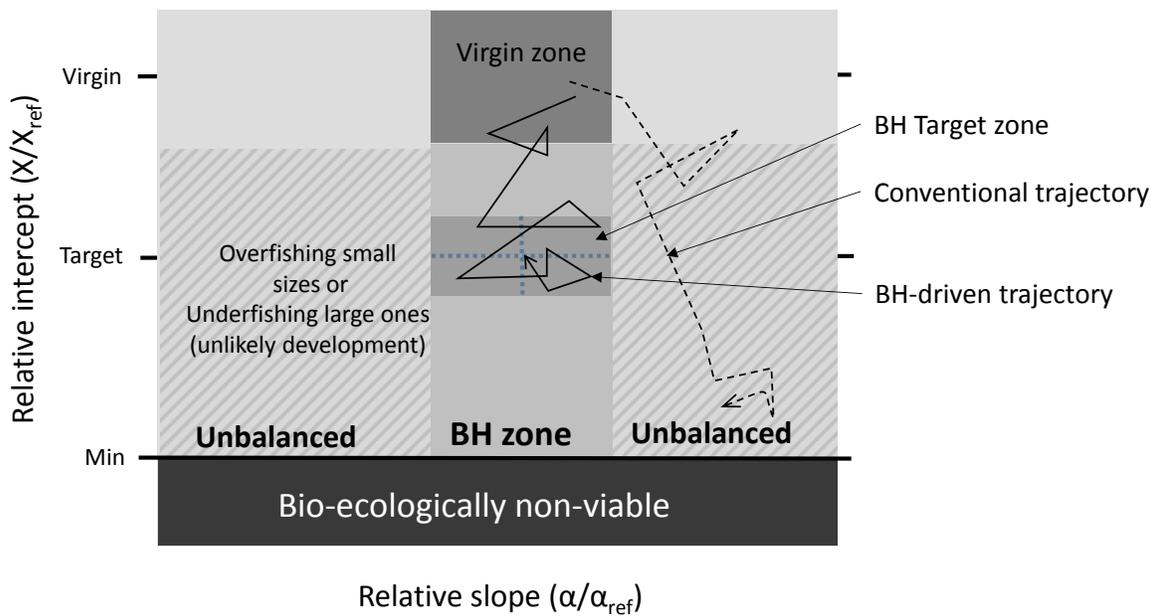
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<sup>3</sup> This section has benefitted from opinions provided by S. Beslier, R. Warner, D. Freestone and K.Gjerde



**Figure 1:** Simple sketch of a possible CDB “norm” representation by a size spectrum. A: Baseline, target and limit situations, with their variance. B: assessment of present situation. The variance of the references has been eliminated for readability.

The comparison between a “present situation” (most likely an average of a few years) and the target norm will indicate whether the norm is being violated or not and will give indications as to the size compartments in which corrections are needed. **Figure 2** illustrates the trajectory of theoretical fisheries under conventional management and under BH.



**Figure 2:** Graphic representation of historical trajectories on a CBD norm reference diagram

## Scientific considerations

The reflection given above illustrates the fact that applying such a norm is, fundamentally not conceptually different from that of the conventional Harvest Control Rules (HCRs). The differences, however, are not insignificant and relate mainly to the change of scale, from stocks to ecosystems. The issues relate to:

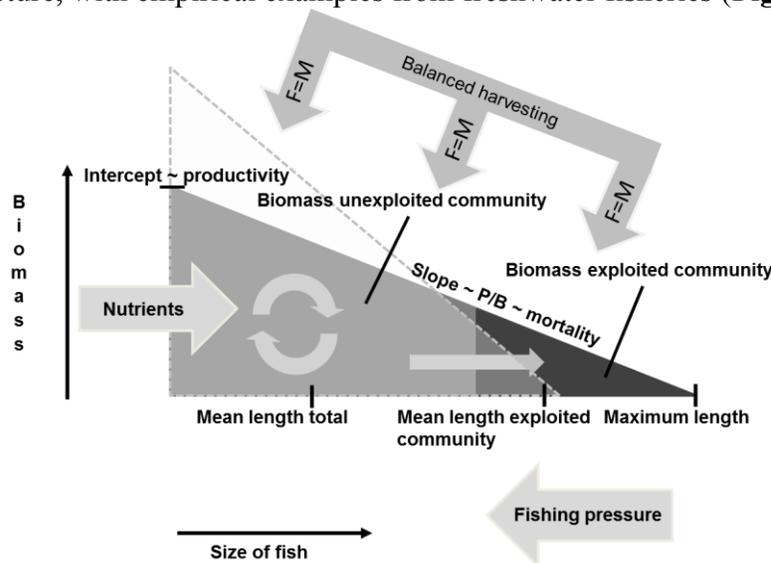
- Versatility: The norm would need to be applicable to benthic, pelagic, coastal, high seas, polar, temperate and tropical ecosystems and in data-poor as well as data-rich systems;
- Species and/or sizes: These are the two dimensions of BH, A species-based norm for the ecosystem structure would have different implications and need to be developed. The size and species norms may need to be combined;
- Nesting: The ecosystem-based CBD norm should probably complement the stock-based LOSC norm, and, because of its larger scope, should be implemented at a longer, more strategic time scale;
- Response time: Considering the frequencies of natural oscillations in a given ecosystem and of business cycles, medium-term oscillations should be expected, generating “noise” around the central trends. The management response time to changes will need to be carefully considered to avoid generating chaotic developments;
- Ambiguity: If the norm appears violated (e.g. the slope has increased) should the response focus on reducing pressure on large individuals or increasing it on small ones? Or both? With what impact, at what cost and for whom (which segment of the fisheries)?
- Boundaries: what are the consequences on the norm of excluding certain species/sizes from the norm such as large mammals, seabirds? Fish eggs and larvae?
- Assessment: Even though the norm “sounds” ecological, it will be important to look also at socioeconomic and operational impacts;
- Low-cost application: Could the norm be applied partially to reduce costs? Could it be applied progressively, starting from some a few fisheries in the ecosystem and progressively scaling up? Could we safely use catch composition as a proxy for ecosystem composition? With what risks?
- Realism: How do plankton and benthos as well as mammals, crustaceans and mollusks fit in length-based and mass-balance models mostly based on fish? How much can we “trust”, for example, the predictions of mass-balance models which assign each species to a single one trophic level (TL), denying ontogenetic changes in TL? Can size-based models realistically assume that a single theoretical «species» process can represent processes within the entire trophic system (or trophosystem)?
- Complexity: May such a Cartesian approach correctly deal with system complexity, assessing states and predicting responses? In other words, can ecosystems be predicted and manipulated with enough confidence?

Many of these questions, particularly those regarding complexity, apply equally to conventional fishery science but are rarely addressed.

## 4.9 A framework of indicators for balanced harvesting in small scale fisheries

van Zwieten, P.A.M. and Kolding, J.

The idea of balanced harvest, harvesting all components in the ecosystem in proportion to their productivity, has been promoted as a unifying solution in accordance the ecosystem approach to fisheries. While this may require a fundamental change to management, many ecological indicators already have been proposed to detect and describe the effects of fishing on aquatic ecosystems. Based on the theoretical background, and practicalities of securing high yielding fisheries in inland waters, we propose a framework of ecological indicators to assess the extended objectives of minimal impact on community and ecosystem structure, with empirical examples from freshwater fisheries (**Figure 1**).



**Figure 1:** A framework to analyse change in a fish community: the fish community is depicted as a biomass-size distribution with decreasing biomass (or numbers) over size and affected by external (nutrients, selective fishing pressure from large size downwards and balanced harvesting) and internal (competition and predation) drivers (grey arrows). System stability is shown by the steepness of the slope in the triangular distributions, where the dotted triangle is the unstable r-selected system with high productivity and overturn, while more stable K-selected systems will have lower slopes and P/B ratios. A range of size and CPUE (= relative biomass) based indicators as well as the slope and the intercept of the biomass size distribution with their interpretations are shown with which changes (and fishing patterns/pressure) in the fish community can be evaluated. Under balanced harvesting the fishing mortality (F) is proportional to the natural mortality (M) over the whole size range, leaving the slope unchanged, but the intercept lower. Modified from Kolding et al. (2008) and Kolding and van Zwieten (2014).

Indicator performance is dependent on the ability to detect trends in key variables, or ecosystem and community attributes of interest. Recent work on the performance of ecological indicators suggests that indicators at the community level rather than the population level of organisation are most reliable (Fulton et al., 2005). At the same time it is necessary to use a range of indicators simultaneously to capture all variables of interest to assess impacts of fishing over the full community or ecosystem of interest. An indicator assessment thus entails a predefined framework of indicators that are known to be specific and sensitive to state changes of attributes of interest set against well-known expectations from ecological theory or experience that can explain these trends in the light of to the pressures and drivers of interest and are responsive to management action (Shin et al., 2005; Trenckel et al. 2007).

Key issues remain the integration of a suite of indicators to an overall description of and assessment of system state against reference levels; assessments and strategic and tactical management advice under data poor conditions (Smith et al. 2007; Zwieten et al. 2011) and the inclusion of livelihood and lifestyle indicators in fisheries assessments (Plagányi et al. 2013).

Limiting ourselves to the ecological part of the assessments of fishing pressure: it is claimed that balance harvesting leads to higher yields, higher resilience under fishing pressure (focussing on community processes), and limited disruption of ecosystem structure, subject to varying levels of productivity (Law et al. 2013). A framework of indicators of small scale fisheries therefore includes *driver* indicators to assess changes and trends in productivity; *pressure* indicators that assess the overall aggregated fishing pattern a system is subjected to and associated size structured yield; and *state* indicators that assess ecosystem structures and processes.

The stability of an ecosystem will be the major determinant of the size range of the fish community, the variability and distribution of biomass over that size range as well as the resilience to additional disturbances from fishing (Jul-Larsen et al. 2003) as fish production is increasingly sensitive to variation in primary production when primary production is higher. To position a particular system on a stability scale indicators expressing such variability, as for instance the relative lake level fluctuation index (RLLF) developed for inland fisheries, are informative (Kolding and van Zwieten 2012). RLLF is significantly correlated with the productivity of a system (Kolding and van Zwieten 2012), while productivity is strongly correlated with the slope of the biomass-size spectrum (Jul-Larsen et al. 2003; Kolding and Zwieten 2006). The RLLF index can therefore be used as a predictive indicator for classifying lakes and reservoirs along a productivity/stability gradient. As effort density in small-scale inland fisheries in Africa appears to be correlated with RLLF as well, reference levels for total pressure can be derived, for instance catch-per-unit area averaged over all fishing patterns yields an average catch per fisher of 3 ton·year<sup>-1</sup> for African lakes.

Other indicators of system *drivers* are a recruitment index showing the annual production of recruitment by species in the fishery will give indications of the maintenance of the productivity of the community. Such an index is also expected to be strongly related to environmental changes in system productivity, such as nutrient inputs indicated by fluctuating water levels. The coefficient of variation (CV) in biomass or catch rates over

size or trophic groups is an indicator linking changes in productivity and fishing pressure. *Pressure* indicators could be found in the proportion of gears targeting specific size ranges over the size-spectrum, or yield by size category.

In general, indicators that summarise fishing patterns over the size-spectrum and relate these patterns to system states are still lacking, but the slopes of a logarithmic plot of yield versus production (Law et al. 2014 and Kolding et al. this volume) is promising. *State* indicators based on size, community structure, and abundance (CPUE) (Trenkel and Rochet, 2003; Fulton et al. 2005; Shin et al. 2005; Charnov et al. 2012) can be used to evaluate community resilience to fishing and disturbance of primary structure. Measures of attributes of community structure (biomass, diversity, size, trophic and spatial structure) for instance can be devised from combinations of indicators related to size (e.g. average length in the catch), size distributions (length signature), P/B ratios (equivalent to total mortality or intrinsic rate of natural increase under steady state) and C/P ratios (equivalent to F/Z or exploitation fraction) over size classes and trophic level of the catch (trophic signature) of gears.

Measures of disruption of a community relate to species diversity, predator to prey ratios, length by categories of r- or K-selected species; maximum length in the community/by species; slope of the biomass size distribution as a measure of total community turnover rate (P/B or total mortality), and internal structure of the size-spectrum as a measure of the maintenance of cascading effects. Some re-interpretation of suggested indicators may be necessary: for instance the fishing down process is quantified by the mean trophic level (MTI) in the catches in combination with the Fishery in Balance (FiB) index (Pauly et al. 2000): a decrease is considered as a negative development. From the theory of balanced harvest a decrease in MTI combined with a stable or increasing FiB index of the catches could well be indicating a move towards more a balanced harvest (*sensu* Garcia et al. 2012).

#### **4.10 Fisheries management for Balanced Harvesting: the case of Japan**

**Makino, M. and Okazaki, R.**

Two case studies from Japan were discussed in this study. The first case was the EEZ fisheries in the national level, in which the results of the official stock assessment were used for calculating the catch/production ratio. Also, the relationships between the stock level and the harvesting strategy were discussed. The second case was the coastal fisheries in the Shiretoko World Natural Heritage, in which an Ecopath model was constructed to calculate the catch/production ratio. Also, the influences from the top predator to the ecosystem were discussed.

We found that the high-Trophic Level species were generally over-utilized and the low-Trophic Level species were under-utilized in both cases. In order to regain the balance, the recovery of the over-utilized and depleted species such as Spanish mackerel should be prioritized. On the other hand, squid and anchovy should be utilized more. Low-Trophic Level pelagic species with low stock levels, such as Chub mackerel and sardine, should also be recovered. TAC and IQ are important management tools for this. Taking the fisheries infrastructure (i.e., fish meal plants) into account, chub mackerel recovery, which is more profitable resources than others, should come first. Then, after the investment from the

processing sector to the fishmeal plants, sardine and anchovy can be fully utilized in the society. Human consumption, including the creation on new food culture and new processing technologies, should be facilitated to fully utilize the low- Trophic Level species (such as anchovy, sandeel and saury).

Fisheries managements by the local fishers' organization for the coastal small-scale gears fishers are more easy and flexible than that of the offshore large-scale fisheries by the government. Especially, the new fishing gear development for small-scale fishers' flexible switching of target species is important. The population of the top predator, such as Steller sea lion, should be properly managed and balanced.

To conclude, in order to achieve the Balanced Harvesting, we need the combination of the management measures from the resource reproduction to the plate on the dinner table. In other words, the biodiversity conservation needs the diversity of the management measures from the top to the bottom of the fisheries system.

## **4.11 Discard bans and balance harvest: a contradiction in (more than) terms?**

**Borges, L.**

### **Introduction**

Balance harvest and discard ban as fisheries management strategies seem to be a contradiction in (more than) terms, since one promotes a proportionate approach to fisheries removals in relation to ecosystem components, while the other limits removals by prohibiting discards to occur. But why focus on discard bans? Because full catch retention policies are usually associated or implicit in a balance harvest discussion (Garcia et al., 2012). The reasoning is that all catches should be landed and utilized in a perspective of food security. However, balance harvest is about fishing mortality and not about what you do with the catch. On a balance harvest perspective it is important to know the impact of not discarding the catch back to the sea, and instead land it. Does it make the system more unbalance? The answer is that it depends on the ecosystem, depending on the importance of its scavenger benthic community. But the focus on full catch retention polices is also due to the recent trend that they seem to be having in fisheries management, namely with its introduction in European Union waters from 2015, while it is being considered in the USA. The talk tried to analyze the impact of the prohibitions to discard around the world in relation to the balance harvest concept.

### **Examples of discard bans around the world**

#### *Norway*

The Norwegian discard ban had the initial objective to increase cod biomass, as fisheries CPUE were decreasing and there was the need to save an incoming cod year class (and decrease the resulting discards) to safeguard stock recovery. It was introduced in 1987 originally on cod and haddock, but has expanded since then to all commercial species. Management authorities however implemented at the same time a number of technical

measures: minimum mesh sizes, sorting grids and real time closures (RTC) for juvenile cod. It also coincided with the introduction of individual transferable quotas (ITQs) that decreased overcapacity (EC 2011). Norway has also a general compliance culture regarding fisheries laws and has single-species fisheries.

With the introduction of the discard ban there was a significant increase in at-sea inspections and there was a reduction in discarding of cod and haddock below the minimum legal catch size. However, evidence suggests this occurred in response to the supporting system of area closures, rather than the ban. The effect of the Norwegian discard ban in providing incentives towards more selective fishing is also difficult to quantify due to a lack of data (Condie et al., 2014). Nevertheless, there was a general increase in selectivity due to the combination of all the management measures. And the ban was successful in achieving its objectives as the cod (and haddock) stock increased and catches also. However, at present, not all stocks are exploited sustainably and a few are even overexploited (ICES, 2014b).

### ***Iceland***

The original objective of the Icelandic discard ban was to revert the declining trend in cod and haddock stock biomass. It was introduced with the introduction of TACs and ITQs in 1984, but it was only really implemented in 1996 with changes to the fisheries law that increase general compliance (EC 2011). The discard ban initially started for cod and haddock. Over time, the list of species to which the discard ban was applicable grew, and has now evolved into a list containing only species for which discarding is allowed, i.e. species with no commercial value. Like the Norwegian ban, a number of technical measures were implemented at the same time: minimum mesh sizes, sorting grids and RTC. Iceland has also a general compliance culture regarding fisheries laws, but perhaps more mixed-species fisheries which may result in a more challenging implementation of the discard ban.

In Iceland there are observers on board fishing vessels and at-sea inspection are carried out, but it is unclear how they are organized and what level of coverage of the fishing activity they reach. With the introduction of the discard ban there was a reduction of discards. However, the discard levels were originally very low and discards continue at present for most species at low levels. There was also an increase in selectivity by changing gear and fishing operations (MRAG 2007). However, information on the landing weights of undersized individuals and bycatch species is sparse. In its absence it is difficult to assess whether fishers avoid the capture of this unwanted catch or simply land more of it (Condie et al. 2014). Again the ban was successful as there was an increase in cod stock, but fishers in the meantime directed fishing effort to haddock and the stock is now harvested unsustainable.

### ***Canada***

Regarding the Canadian discard ban, there was no specific objective stated except for the general aim of increasing stocks biomass. It accompanied the introduction of an ITQ system to the British Columbia groundfish fishery and was applicable to all commercial species, and again was complemented by additional technical measures. Prohibited species, which cannot be legally retained, are excluded from the ban and mitigation measures are required to maximise their survival rates. In the west coast of Canada compliance is generally low and they have predominantly mixed-species fisheries.

The Canadian discard ban has a 100% monitoring at-sea programme, including observers and electronic monitoring. With the implementation of the discard ban, there was a general reduction of discards and incentives have been provided to promote more selective fishing but the role of the discard ban in this change is unclear. Constraining bycatch limits and facilitated through a full observer programme, have encouraged fishers to match catches to available quota and avoid excessive bycatch (Condie et al., 2014). Under this management system the majority of groundfish stocks are now considered to be in a healthy condition, however not all stocks are being adequately protected.

### ***New Zealand***

As with Canada, there was no specific objective stated for the New Zealand discard ban except for the general aim of increasing stocks biomass. It was introduced with a TAC and ITQ system in 1986, and was applicable to all commercial species, but only over minimum landing sizes. And, as all the other before, technical measures were implemented at the same time. I would argue that in New Zealand there is a general non-compliance culture to fisheries laws and the presence of very mixed-species fisheries.

New Zealand has a relatively modest enforcement regime. After the introduction of the discard ban discarding actually increased for legally sized fish (discards under minimum legal size are not reported). There was a somewhat increase in selectivity but since accurate statistics on discards are unavailable, it is difficult to assess the impact of discarding policy (MRAG 2007; Condie et al. 2014). Nevertheless, 70% of their stocks (619) are presently experiencing high biomasses, so I would conclude that the general objective of the discard ban was achieved.

### ***Chile***

There is no specific objective stated for the Chilean discard ban except for the general aim of increasing stocks biomass. It was introduced with the Fisheries Law in 1991 and it prohibits the discards of all commercial species. However, the law was never implemented and fishing operations (with discards) continue as normal. In 2012, the law was reviewed and now allows for exceptions to the ban by fishery if a monitoring programme is implemented. In Chile there is a strong non-compliance culture for fisheries law and their fisheries are extremely mixed.

The impact of the Chilean discard ban is yet to be seen as it is yet to be implemented. Before 2012 heavy fines were applied for anyone caught discarding. This made fishers very uncooperative, discards were a taboo for the industry, and the observers programmes were difficult and their data likely to be biased, while discarding continued widespread. However, the new fisheries law that has been reformed recently has come to recognise these issues, and has allowed for monitoring programmes where participating fisheries are exempted from the ban. There is a huge interest from the fishing industry on these programmes, as they can continue discarding, and there is a huge potential to increase catch data (Cocas, personal communication).

### ***European Union***

The practice of discarding part of the catch at sea is presently legal in European waters (except when high grading the catch), and in some circumstances compulsory. However, this will change from 2015 with the planned introduction of the landings obligation foreseen

in the revised EU Common Fisheries Policy (CFP). The landing obligation main objective is to reduce unwanted catch (not stocks biomass increases). It is applicable to TAC regulated species in the Atlantic waters and to minimum landing size species in the Mediterranean Sea only. It is implemented progressively by species and fisheries, starting with pelagic fisheries and fisheries in the Baltic Sea from 1 January 2015. In the European Union there is a strong non-compliance culture for fisheries laws and the presence of very mixed-species fisheries.

If (and it's a big IF) the ban is fully implemented, i.e. is monitored at-sea at significant levels, it is likely that fishing operations will change to maximize the space on board and quota available for high price species and sizes. I would argue that this is undoubtable the biggest push to more selective fishing in the European Union than the implementation of all the technical measures adopted in the CFP in almost 30 years. There will be a significant change in fleet diversity, i.e. in the global harvest pattern, as many fishers are stating they will change fishing gears for more selective ones. And there will also be an impact on the ecosystem megafauna and seabed communities. Heat et al. (2014) showed that landing the entire catch while fishing as usual in the North Sea has conservation penalties for seabirds, marine mammals and seabed fauna, with no benefit to fish stocks.

### **Discussion and Conclusions**

In summary, it seems that the objectives for adopting a discard ban are to achieve an effective TAC implementation, to limit fishing mortality and reach sustainable fisheries. There is also the global objective of reducing discards for whatever reason, but there is also always an implicit objective of increasing selectivity of the fisheries involved.

It is clear that the implementation of a discard ban requires significant at-sea monitoring, and in most cases it required an increase of existing programmes. It will also increase fisheries selectivity significantly with perhaps a decrease in the global harvesting pattern, where only some trophic levels will be exploited. If implemented it is likely there will be an impact on the benthic and megafauna diversity, depending on the ecosystem. And it will increase stock biomass by reducing fishing mortality, particularly on juveniles. But the question remains: will there be more balanced harvest? On the other hand, if the discard ban is not monitored at sea, there will be a significant increase in fishing mortality, and likely an increase in overexploitation.

In the European Union, the primary objective of the CFP landing obligation is to reduce unwanted catch instead of utilizing unused catch as argued in the balance harvest concept, since many stocks are still in need of recovery, while the use of otherwise discarded catch requires changes in the market that will take time to occur. The implementation of a landings obligation requires also either high levels of monitoring and control at sea, and/or economic incentives to fish more selective, neither which are likely to be available in Europe. This associated to the fact that from 2015 TACs will be increased to account for discards, one can only conclude that the landing obligation will create more unbalance harvest.

In conclusion, full catch retention policies seem to be in contradiction to balance harvest. But perhaps this is because its original objectives are set in opposition to balance harvest, namely to increase selectivity in order to achieve a more focus harvest pattern. Perhaps if these goals are set differently in line with balance harvest, and/or established in

management regimes and ecosystems that can minimise its negative impacts, such as high compliance and relatively less important benthic and megafauna components, perhaps it is after all a fisheries management policy that can help reach balance harvest.

## 4.12 Management implications of Balanced Harvesting: The Common Fisheries Policy (CFP) as a sounding board

Garcia, S.M.

This presentation is based on a series of reflections which emerged as the BH concept was presented to policy-makers, managers, and the industry since 2011. It relies also on a vulgarisation report produced by MacGarvin (2014) who offered a reflection of BH implications in the new European Common Fisheries Policy (CFP). The reflections, it presents, however, are largely applicable to other fisheries management frameworks.

The presentation highlighted first a number of misunderstanding or misconceptions about BH calling for clarifications. It then looked at compatibility with the EU CFP. Finally, it examined the implications for management.

### Misconceptions

The misconceptions are surprisingly numerous, highlighting the fact that early papers barely touched on practical implications but also the difficulty for the actors to bootstrap themselves out of the conventional science and management paradigm to reflect objectively on this new one. Some of the misconceptions are given below, **in bold**, and followed by a clarification.

- **BH is unselective.** No. BH can probably not be achieved by random fishing. Individual vessel/fisher fishing practices will always be selective in species, time and space. But the fishery sector as a whole, in an ecosystem, will be unselective in that the total catch composition will, on average, better reflect the ecosystem species and size compositions;
- **BH implies the design of gear to reduce species selectivity?** Fishers may have to innovate in gear design to optimize their operations but BH aims to ensure that the SECTOR as a whole is unselective (*vide supra*) and not each vessel or gear. It is the total catch taken in the ecosystem on average that needs to be balanced and not each fishing unit catch;
- **Protection of spawning sites or juveniles, would become redundant,** as recruitment success would be assured by the better survival and abundance of large individuals (BOFFFs)<sup>4</sup> biomass rebuilding: probably case-specific. Spawning reserves cannot be excluded.
- **BH modeling deals with fish and not with other components of the food chain.** Analytical ecosystem models (Ecopath et al.) are comprehensive and some (e.g.

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<sup>4</sup> Big Old Fat Fecund Females (BOFFFs)

Atlantis) are very comprehensive. The question remains as to whether length-based models proxies could be over-simplistic.

- **BH aims to remove a defined proportion of the biomass of each size class of fish, regardless of species.** This seems to imply, wrongly, that BH disregards species. The expression “maintaining species composition” would be less confusing.
- **BH implies the removal of technical measures and their replacement with an obligation to report on total catch by size.** Same comment as above even though some deregulation might be possible (e.g. on minimum market sizes)
- **Why should fishers not be as “selective” as natural predators are?** Indeed, predators have individual preferences but as a whole, they are effectively unselective at ecosystem level and crop populations proportionately to their natural productivity. In fact BH intends to mimic Nature!
- **Discard bans make no difference as whether or not we eat the fish that is caught, it is dead.** However the ban burden may prompt good innovations to reduce bycatch and may be needed to facilitate the collection of the data necessary data to check BH implementation performance.
- **BH will be a license to kill more mammals and forage fish.** The norm parameters (including boundaries) are a societal prerogative. Questions are: How much freedom could there be in excluding groups (species or sizes) from the norm? Can the CBD requirement be only partially met? What coherence is required between conservation and sustainable use? Does conservation always meet the CBD norm itself?
- **BH will facilitate fishing practices** (reducing the selectivity burden): This is not obvious. As individual fishing gears and practices will remain necessarily selective to some degree, BH will call for the acquisition of by operators of a range of fishing skills, multipurpose vessels (or fleets) and portfolios of quotas/species.
- **BH implies simpler management targets:** The norm is not simpler than the MSY one. It adds explicitly the requirement to obtain coherence between the exploitation levels of ALL stocks (that was only implicit in UNCLOS). It may not dispense from having fishery-based management targets.
- **BH could reduce cost and conflicts in the management system.** This is connected to the preceding point. There are few elements to prove or disprove this statement. It probably depends on how BH will be implemented (e.g., in collaboration with fishers or not);
- **BH will allow simpler performance assessment:** Also linked to the above. The assumption that BH would lead to manage undifferentiated biomass by size containers is misleading.
- **BH would be applicable only AFTER stocks have been rebuilt and not as part of a rebuilding strategy.** Rebuilding is a *sine qua non* condition. But it might be possible, a priori, to apply a dynamic BH strategy aiming simultaneously to rebuilding and improving balance. Complexity will significantly improve, though.

- **The needed delegation of powers to operators will reduce the responsibility of (and blame to) the management authority.** Legally, the State and delegated management agency or organization remains responsible for poor performance

### **Compatibility with the new CFP**

A superficial examination of the BH promises and requirements against the CFP principles and challenges indicates that a majority of them are compatible, none appear incompatible and some require further examination, probably case by case. These conclusions are probably applicable to many if not all national or regional management system. In any case, it would be advisable to have an open and structured discussion on concerns by all stakeholders, from both the fishery and biodiversity conservation points of view.

A key question is: We are looking for a way to meet the CBD norm requiring adaptation of the conventional fishing regime at ecosystem, trophic chain level. Would there be a way to achieve the same result just managing perfectly at MSY, or using only biodiversity conservation measures (e.g. MPAs)? Most practitioners would probably reply NO to both ideas. Could therefore the two approaches be synergetic?

### **Implementation instruments**

BH implementation is likely to require the use of generic, conventional instrument and approaches such as: fishing capacity control; good governance; Resources allocation (could an allocation of sizes AND species be conceived?); Fishing rights (in portfolios, to achieve balance) and institutionalized performance assessment. It will also require a formal re-definition of management units, at a higher (more ecosystemic) level than the present ones.

BH will also require the use of conventional technical measures: mesh sizes, gear design, fishing operations, spatio-temporal restrictions, and habitat protection. The question of minimum landing size remains open. BH will probably require less specialization and more opportunistic capacities.

Implementation will be more complex for highly migratory top predators, or large mammals, which feed at the top of many different trophic chains during their large scale migrations.

It will require a two-way rescaling system, to aggregate fishery-specific data and information for ecosystem-wide assessments and for transforming ecosystem-based management advice into fishery-specific regulations.

It will also require analysis of various transitional pathways from the present unbalanced state to a balanced one, considering benefits, costs, their distribution and operational timeframes.

## **4.13 Discussion summary**

**van Zwieten, P.A.M. and Rochet, M.J. (Rapporteurs)**

### **Definitions**

This wide ranging session raised many questions on the operationalization of balanced harvesting. There are still many questions that need to be answered as is clear from the

previous sessions as well: what exactly is meant by scaling fishing patterns to productivity? What is the scale at which selectivity should be assessed? What is the relation between individual selectivity of a fishing operation to the overall selectivity of a fishing pattern across the ecosystem? A range of misconceptions on management implications were discussed by Garcia (this meeting) that are to some extent related to these definition issues. For example, the misconception about BH being “unselective” fishing reflects an incorrect reading of Garcia et al (2012) in which it is stated that that BH should be understood as broadening the selectivity perspective from the individual operation (gear and vessel scales) to the community-level selection of the overall fishing pattern (at trophic chain and ecosystem scale).

### **Objectives**

The CBD requirement, within the Ecosystem Approach, to maintain ecosystem structure and functioning, is only one of the 12 Malawi Principles, each of which could give birth to an objective. Its specific consideration lead to a discussion on the trade-offs between the multiple objectives of the approach, as reflected also in the FAO guidelines for the Ecosystem Approach to Fisheries. BH is a tool to address the objective of maintaining ecosystem structure and functioning. The latter implies a practical definition of the structure and functioning to be maintained (the parameters of the norm and possible harvest control rule) and BH, as presently developed, offers different preliminary possibilities. The EAF evolved from a basis in single species considerations to species assemblages, where the BH approach, when operationalized, can be guiding to broaden considerations to marine communities. Therefore an operationalized BH assessment of fish or marine communities and overall exploitation patterns would have to be a strategic, eco-system-based assessment with longer (5-10 years) cycles of evaluation, on top of and informing current fisheries management approaches that have shorter cycles of evaluation (e.g. MSY based, one-year cycles). In other words, short-term single species management would be nested within longer term ecosystem level management.

### **Implementation**

Several presentations made clear that implementing a BH approach top-down, by fleet, size, species or both, given the spatial extent of stocks, and given allocation issues and existing rights, would lead to extreme micromanagement of fleet sizes and selectivity and be nearly impossible. Spatial rules – static or dynamic – currently focussed on the management of single species fisheries and that can reach high levels of managerial sophistication could be counterproductive in a BH context and should be evaluated across species, adding another layer of complexity.

A question was raised several times: how much freedom could there be in excluding groups (charismatic species) and sizes (juveniles, adults) from the “balance”. Likewise the paradigm to protect juveniles in order to maintain stocks may be so deeply rooted in management and conservation plans and current mainstream political positions that it has become “cultural” and may be extremely hard to overcome. At the same time, issues around protection of spawning and nursery areas in specific cases are still highly relevant and require a nuanced approach. In open ocean pelagic systems, the lack of knowledge about marine communities and the spatial complexity of the pelagic food web may limit a BH implementation. That being said, it is clear that a highly species- and size-selective fishery

will be the opposite of BH, and should be avoided. Other questions around BH revolved around the main goal of many fisheries around rebuilding stocks: can both the slope and the position of the size-spectrum be managed at the same time?

The session made clear that there is a need for (1) experimental approaches (e.g. lake experiments) to test assumptions in size-spectrum models and (2) pragmatic, adaptive approaches (see e.g. Makino, this volume), where fishing patterns are assessed on their catches over a whole fish community and advice is given on shifting away pressure from overharvested to less harvested resources and resource components, eventually developing incentives and markets to achieve the agreed balance. This is not just a matter of “having fishers wanting to make it work”: there are societal trade-offs and issues as well as distributional effects, costs of incentives, transition costs between short and long term benefits that need to be accounted for, while incremental change towards BH (a possible strategy to make transition costs more affordable) may not be beneficial in itself. On the other hand, the cost of not complying with the CBD requirement, a potentially important element of any cost-benefit analysis of BH, will depend on how stringent this requirement might be made, e.g. in an international trade regulation of ecolabelling schemes.

## **Evaluation**

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The degree of “balance” in harvesting patterns (locally defined) would be one component of assessing the ecosystem-related performance of a set of fisheries if BH was agreed as a target or tool in a given ecosystem-based management framework. One concern was expressed: is BH going to make ecosystem-impact evaluation any easier? If BH was part of a suite of approaches at a strategic, long term policy level then how could the link between strategic and operational objectives and indicators be made? Many *state indicators* - as species and size-based (abundance) indicators, slope, size and shape of the size-spectrum etc. - are available for fish and fish communities that probably can be fruitfully utilized in a BH context. *Pressure indicators* to assess or characterize ecosystem-level fishing patterns are less developed (i.e. what is the equivalent of a single species F in a balanced harvesting context?) though some promising indicators were presented in sessions 2 and 3.

## **5. WRAP-UP DISCUSSION SUMMARY**

### **Charles, A. and Garcia, S.M. (Rapporteurs)**

The following elements were discussed at the end of the meeting. Some of the points made had already have been discussed, in greater or lesser detail, in earlier discussion sessions, just after the related presentations (in **Sections 2.5, 3.7 and 4.13**) but are nevertheless reported here for completeness in covering the wrap-up discussions.

### **What is Balanced Harvest?**

Some participants felt that there was still a need to clarify definitions in relation to BH. In the presentations and subsequent discussion, Balanced Harvest appeared in different forms and roles:

- **A formal requirement:** The CBD requirement for the sustainable use of biodiversity under the ecosystem approach is that, in the course of fishery harvesting, ecosystem structure and functioning should be maintained. No specific name was given to that Principle by the CBD. BH is one practical interpretation of it. It tends to reflect that requirement. The same requirement is expressed in Article 5f of the 1995 UN Fish Stock Agreement. BH is one practical approach to applying this Principle which is only one among others related to the other dimensions of sustainability -the overall balance of which is a governance decision.
- **A norm.** As a means to implement an ecosystem-based norm, BH is comparable to the harvest control rules (HCR) used in conventional fishery management. The graphic representations of BH (the size structure) can be used to express the expected outcome of a fishing strategy at an ecosystem level and also provides an instrument against which to assess ecosystemic fisheries performance and to graphically report on it.
- **A goal.** For the CBD requirement to be met, BH must become an explicit goal in a management plan. Adopting it implies a specific aggregate outcome for the fisheries in an ecosystem, the achievement of which may require additional or alternative measures.
- **A fishing regime.** BH proposes to fish all species/sizes in proportion to their natural productivity. It defines therefore a vector of exploitation rates. The minimum and maximum size of the vector and hence the species to exclude from the norm, as well as the overall level of fishing pressure are decisions for the society concerned.

### **Relations between EAF and BH.**

The debate on the nature of BH, whether as a Principle, a norm an approach, etc. raised the issue of its relation to the Ecosystem Approach to Fisheries (EAF).

EAF underlines the spatial dimensions of fisheries and their management and the need to face bycatch, habitat degradation, pollution, natural oscillations, and climate change. EAF recognizes uncertainty, includes the Precautionary Approach, introduces risk assessment and stresses the societal, social and economic dimensions of the ecosystem approach and the need for equity.

All these considerations are relevant to BH implementation. In particular, a key principle and goal of EAF is that of maintaining biodiversity and *protecting and conserving ecosystem structure and functions* (FAO, 2003:6, 84, 85). It recognizes the need to reflect *differences [in vulnerability and productivity] and address desired ecosystem related objectives (such as maintaining food webs)* (FAO, 2003:34). BH addresses exactly this point by offering a way of materializing both the requirement/goal and the harvest control rule. The implications for research, planning, management implementation and performance assessment are similar to, albeit more specific than those already developed for EAF. Indeed, if adopted, BH should fit into the EAF implementation process described in the FAO technical guidelines.

### **Multiple objectives and trade-offs**

A central issue with EAF implementation is the recognition of multiple objectives and the consequent trade-offs. The CBD requirement is only one of the principles and goals of the Ecosystem Approach. There are synergies between these principles and goals, particularly in the long term, as for example between resource conservation and stability of food sources. There are also trade-offs, particularly in the short-term, during the transition towards more sustainable use patterns, for example between ecosystem rebuilding and loss of livelihood.

To the extent that BH is proposed to balance an “intermediate” level of fishing pressure broadly across species and sizes, a reasonable question to ask is: how much is BH related to maximum potential biological output of the food web? Or to the MSY of single species? There may also be trade-offs between short- and long-term benefits as a BH implementation which might increase yields ultimately but not during the transition phase, particularly if rebuilding is necessary.

There could be a need for conflict resolution (between sectors and between industry and management) and for adapting present management strategies for large and small-scale fisheries, within an overall ecosystemic framework. The consistency between discard bans and BH needs to be examined.

### **BH time frame**

BH, as a part of an ecosystem approach, is a strategic, ecosystemic instrument. It does not replace but complements other current norms (such as those related to MSY). The implication is that, like EAF, it requires longer time frames and implementation cycles than the more tactical conventional fisheries management. The policy/management cycle of assessment and adaptation will necessarily be longer (e.g. 5-10 years depending on latitude) than the present annual management cycle. The two processes will need to be functionally nested, as already required for EAF.

### **Implementation issues**

Many presentations addressed implementation issues in a more or less systematic manner. Some stressed the increased complexity involved. Others, on the contrary assumed that BH would lead to simplifications. The debate is far from closed as to whether BH (or more broadly EAF), by adopting a broadened scope, would make fishers’ and managers’ task easier or not.

It was stressed that while many indicators were available for fish populations and communities, less information has been collected regarding fishing patterns (particularly at ecosystem level), socio-economic factors and governance performance. The lack of an agreed framework for using such indicators has also been underlined. A particular problem resides in the conceptual and functional linkage between the strategic objectives and indicators (of EAF and BH) with the more operational indicators of single fisheries management.

The pragmatic approach used by e.g. Kolding, Bundy and Makino using available conventional fisheries data and ecosystem models to check whether and how far present fishery systems might be from an ideal Balanced Harvest situation is useful and accessible in a large number of fished ecosystems. It might help getting a first idea of the present

ecosystem distortions, if any, and of the potential directions for corrective policies and management.

It was also stressed again that the adopted species and size range within balance will be sought) were a matter of societal decision, assessing case-by-case assessing the consequences of that decision on the ability to maintain ecosystem “structure and functioning”.

### **Partial implementation**

Some participants noted that the possibility and feasibility of partial implementation of BH needed more attention, either as a long-term strategy (e.g. to reduce its costs) or to facilitate the shorter-term transition towards a full BH implementation. There should be ways to make incremental progress. This need arises across all components of the workshop, i.e. in modelling, empirical data collection and analysis, policy analysis, etc. Most of today’s fisheries and ecosystems are already examples of the implications of not balancing harvest across all sizes and species? It is also important to keep in mind the short term versus the long term implications of partial implementation.

The boundaries within which BH could be applied were also discussed as the size/species spectrum could, in principle range from phytoplankton to whales. Considering (1) the difficulty of sampling plankton regularly and (2) the existence of emblematic species to protect, what is the actual scope of BH? To what extent could species groups and sizes (e.g. the smallest and largest) be excluded from BH implementation while still allowing the CBD requirement of maintaining ecosystem structure and functioning to be met?

### **Feasibility**

The question was raised a few times: If BH is to be reflected in a linear relation between size and abundance or biomass, can we manage both the slope and the position of the line to approach the required balance (correcting both fishing intensity and fishing pattern)? The question is particularly relevant when BH is envisaged in an overfished system in which the structure is unbalanced. Can balancing and rebuilding be aimed at together? Or should overall fishing pressure be reduced as a priority before attempting to balance the systemic fishing pattern? No conclusions were drawn and this important question remains to be answered.

### **Governance, participation and incentives**

Although no analysis was presented, there was a rather general feeling that implementation of BH in a top down governance system may be difficult (whether by size or species or both). Most discussions were in line with the idea that fishers, their traditional knowledge and their innovation capacity will need to be harnessed, through effective participation and appropriate incentives. The key point is to have fishers want to make that strategy work (see also the question of costs and benefits) and this might be possible only in cases in which particular efforts are made through participative forms of management. Dedicated subsidies or transitional compensations might be needed in case BH would result in temporary but large losses but care will be needed to avoid perverse consequences.

### **Pelagic ecosystem**

It was mentioned that, in open ocean (and straddling) pelagic ecosystems, lack of knowledge on assemblages and trophic chains, particularly for “roaming” large predators, may complicate BH implementation, e.g. in tuna fisheries.

### **Non-fishery impacts**

Aquatic ecosystems are subject to other drivers than fisheries such as pollution and resulting contamination, hypoxia, etc., coastal degradation and climate change (including warming, sea-level rise, acidification, etc.). The requirement to *maintain ecosystem structure and functioning* as expressed by the CBD is not specific to fisheries but applies to sustainable use of biodiversity, overall. The question arises, therefore, as to whether fisheries can alone aim at balancing ecosystem composition and to what extent can an observed “imbalance” be attributed to inadequate fishing strategy alone and resolved by fisheries adjustment alone.

### **Guidance for future investigations**

While no attempt was made to prioritize actions across the large range of needs, the following actions appeared as requiring particular attention (in no priority order):

1. **Empirical validation.** It is crucial to validate model conclusions against empirical data, looking at case studies both with and without BH strategies. While this seems difficult, *a priori*, experiments involving fishers, in ecosystems small enough to be well controlled could be put in place (e.g. small lakes). For case studies to look at with respect to BH, two ideas expressed were: (1) projects aiming at improving fisheries and (2) MSC pre-certification inquiries. In terms of looking at when, where and how BH may be feasible, current Ecopath-based work could look at why some fisheries/ecosystems may be more balanced than others. It was noted that related work with a trawl fishery was already being undertaken in the Mediterranean.
2. **Connections with ongoing environmental efforts.** BH should also be seen in relation to other environmental management initiatives, with their objectives and indicators. For example, environmental quality standards could contain descriptors to monitor in terms of ecosystem structure and functioning with a specific focus on fisheries and sustainable use, however, and not in a generic development angle.
3. **Connections with other fisheries reforms.** The fisheries reforms proposed up to now deal only with single stock/fisheries optimization, typically focussing on catch limits without considering overall optimization across a complex ecosystem. On the other hand, BH deals more explicitly with how than with how much to fish, even though it leads to recommendations of “intermediate” levels of fishing pressure (i.e. levels lower than the theoretical MSY of each species). The possible linkages between conventional reforms at the stock/fishery level and viable partial implementation processes for BH remains an open question. In any case, more attention should be paid, in conventional fishery research systems, to the ecosystem-level fishing patterns that emerge from conventional fisheries management.
4. **Social and economic aspects of BH.** It was highlighted that little had been done yet on social and economic aspects of fishing. Food security and subsistence livelihoods needs are crucial considerations for small-scale fisheries, so social and economic factors may favour a BH approach. For commercial fisheries, in which fishers try to optimize their output in money, not yield, total yield from the ecosystem is unlikely to be perceived as

relevant, particularly when additional yield comes from less profitable species and sizes. In many cases, such fishers will not willingly go along with fishing more of the low-value fish and less of the high-value ones, thereby losing revenue. They might do so only during a transitional period and/or with subsidies and compensations allowing them to maintain livelihoods. These are complex questions requiring a transdisciplinary approach.

5. **Nested governance.** It was suggested that broad strategic directions should be set for BH and related strategies, and then subsidiarity approaches should be used to get to the operational level. It was also stressed that while micro-management of numerous specialized fishing fleets (“métiers”) -which didn’t work well in the EU- should be minimized or avoided altogether, nevertheless, the ecosystemic nature of BH (shifting away from how fishing is usually organized) implies the desirability to maintain a broad oversight role of the State, at least until fishing becomes better organized at the ecosystem level.
6. **Management operations.** In terms of annual fishery management cycles, what should be changed to implement BH? What is the broader range of goals being pursued? How far away from single-species MSY would management systems need to go? How should bycatch/discard issues be addressed? Gear-based assessments will probably still be needed as well as fishery-based selectivity in relation to fishery-specific conservation issues. How could we nest short-term management (e.g. dynamic management) within a longer-term BH strategy to improve reactivity, adaptability and efficiency?

### **Meeting outcomes**

The workshop discussed briefly the sort of outcomes the meeting could be looking for:

1. **A report.** First of all, a standard scientific meeting report, to be published jointly by FAO and IUCN-CEM-FEG in digital format and perhaps also as an FAO Report. This report would need to be available in early 2015.
2. **A special Theme/Issue.** Second, efforts could be made to produce a set of papers to be jointly published in a special issue (or special theme) in a scientific journal. The ICES Journal of Marine Science was mentioned. Soon after the meeting, that possibility was confirmed and many participants committed to write a scientific paper for that special theme. A letter of invitation has been broadly distributed inviting the meeting participants but also, more broadly, all those with some interest in BH matters.
3. **Policy advice.** It was considered too early to elaborate any specific advice for fisheries policy and management at the present stage. More progress and consensus-building would be needed in the science of BH before progressing in that direction.
4. **Small-scale fisheries guidelines.** Because of the importance of the SSF examples of BH or quasi-BH situations, it was suggested that further work might be done by those concerned to see what would be the BH implications for the implementation of the recently adopted FAO Voluntary Guidelines for Securing Sustainable Small-scale Fisheries In the Context of Food Security and Poverty Eradication (FAO, 2014).

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## ANNEX 1 – THE MARINE SIZE SPECTRUM AND BIOMASS PYRAMIDS

### Jacobsen, N.S.

Here, I will describe a definition of the marine size spectrum used in the literature to distinguish it from the term “biomass pyramids”, often used in the context of balanced harvesting. The description is largely based on appendix A in Andersen and Beyer (2006), but similar definitions are used in other works on marine size spectra (Blanchard et al. 2009, Law et al. 2012).

A marine size spectrum can be described in three different ways (**Figure 1**): a number spectrum, a biomass density spectrum and the biomass spectrum. For these spectra it is important to notice that the biomass is grouped in logarithmic size classes instead of linear classes. This causes the biomass spectrum to be a Sheldon spectrum (flat slope; Sheldon et al. 1972) rather than a biomass pyramid (declining slope).

The number spectrum (often called the size spectrum) has the unit  $\# g^{-1} vol^{-1}$ , the number of individuals per weight per volume. Empirically, this size spectrum can be constructed by taking the numbers observed in a logarithmic size bin and dividing by the width of that size bin.

The theoretical expected slope of the unfished size spectrum scales as (Andersen and Beyer 2006)

$$N(w) = \kappa w^{-\lambda}$$

Where  $N$  is numbers,  $w$  individual weight,  $\kappa$  is the carrying capacity of the background spectrum and  $\lambda$  is the slope  $\approx 2.05$ .

The biomass density spectrum can be found by multiplying the size spectrum by the individual weight (figure 1B), theoretically the slope is  $B(w) = \kappa w^{1-\lambda}$ . From a size spectrum simulation the biomass density is be calculated as

$$B(w) = N(w) w$$

Integrating the biomass density spectrum then gives the biomass spectrum in logarithmic size bins (Figure 1C).

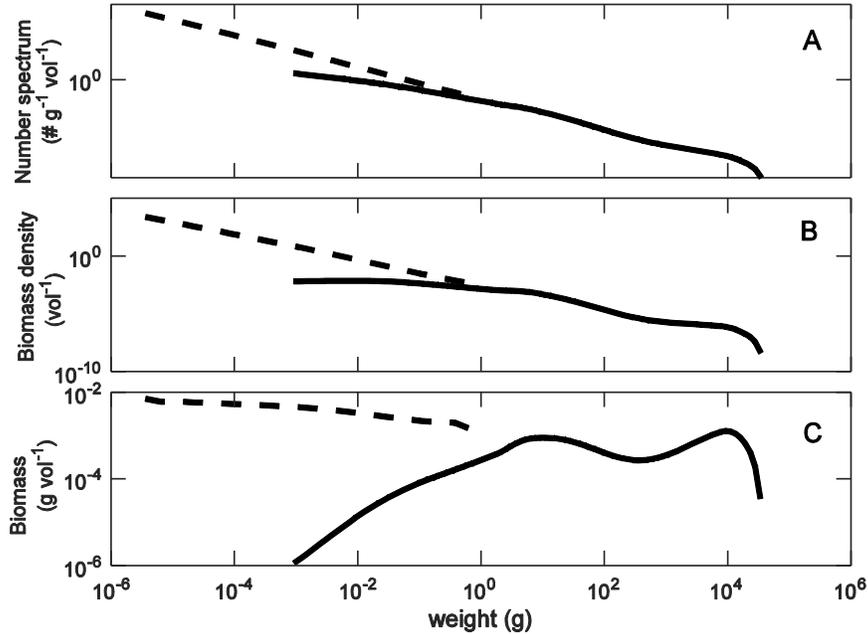
$$B(w)_{\log} = \int_{w_{\max}}^{w_{\min}} N(w) w dw$$

The slope of the biomass spectrum is close to zero.

Exactly how a “biomass pyramid” is defined is not clear, but assuming that it represents trophic level from the bottom to the top of the pyramid, it would be equivalent to the x axis in Figure 1, where individual size is proportional to trophic level. Therefore the “biomass” in the “biomass pyramid” must correspond to the biomass density at a given trophic level (figure 1B), since the actual biomass spectrum (figure 1C) has slope close to 0 and would therefore not represent a pyramid. This definition would correspond to data points collected from a trawl survey, plotting trophic level (or weight on log scale) on the x axis and

numbers multiplied by the weight in on the y scale. The same convention is used in Law *et al* (2012), where the biomass pyramid is further accentuated by plotting on a linear scale.

Alternatively, a pyramid can be constructed by describing the number density (figure 1B), in which case it can be referred to as a “number pyramid”.



**Figure 1:** Simulated size spectrum in the model and parameters used in Jacobsen et al (2014). A) Number size spectrum, B) biomass density, C) Biomass in logarithmic size groups. Dashed lines are the background spectrum, full lines represent the fish community. The simulation here is run with a maximum asymptotic size of 30 kg for the largest cut-off.

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## ANNEX 2 – IMPLEMENTATION OF BALANCED HARVEST

### Zhou, S.

A possibly feasible approach to moving toward balanced harvest is to undertake much broader Sustainability Assessments for Fishing Effects (SAFE) (Zhou et al. 2007; Zhou and Griffiths 2008; Zhou et al. 2009, 2011) to ensure sustainability for all affected species. Such assessments evaluate each species' intrinsic capacity to sustain fishing impacts based on their life history traits, and identify vulnerable species depending on the temporal and spatial distribution and intensity of fishing activities.

The SAFE method consists of two major components: indicators and reference points. The concept is essentially the same as stock assessment in traditional fishery management. It reflects the general approach advocated for ecosystem-based fishery management (Garcia and Staples, 2000). SAFE focuses on one single indicator — fishing mortality rate because of lack of data for estimating biomass for the majority of bycatch species. However, the population reference point based on biomass and the fishing mortality rate-based reference points are inextricably linked. The latter represents the level of mortality that would theoretically cause a population to eventually equilibrate to the associated population reference point level. Instead of using time series of catch data and age composition, the SAFE derives fishing mortality rate through estimation of spatial overlap between species distribution and fishing effort distribution. This overlap can be fine-tuned by habitat and behaviour-dependent probability of encounter with fishing gear and size-dependent gear selectivity. For the second component—reference points, SAFE derives reference points from life-history parameters that are widely available for many species rather than from time-series of fisheries data. The reference points have the same meaning as traditional fishery management, i.e.,  $F_{msy}$ ,  $F_{lim}$ , and  $F_{crash}$ .

The SAFE method is carried out in a batch process, i.e., it can be simultaneously applied to hundreds of species in a fishery. This batch process requires that input data for each species be prepared in the same manner. Of the two components, the major uncertainty is associated with fishing mortality rate estimation. The default method assumes that fish is homogeneously distributed in their habitat and the probability of being caught (i.e., gear efficiency or catch rate) by a specific fishing gear can be determined from fish size, perceived behaviour, and morphology in relation to gear specification.

For a small number of species that are believed to be at high risk, the default SAFE method can be enhanced to examine these species more rigorously. Rather than assuming that fish density is the same within the entire distribution range, heterogeneous density can be estimated from historical surveys and observer data (Zhou et al. 2013a, 2013b). Gear efficiency may also be estimated by repeated catch from historical surveys or observer data, if available (Zhou et al. 2014).

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## ANNEX 4 - MEETING ORGANIZATION AND PROCESS

### Focus of the meeting

The first scientific workshop (Nagoya, 2010) focused on modeling of BH strategies and limited empirical evidence. This meeting should review progress in modeling and focus on the practical implementation issues (operational, legal, economic, etc.).

### Process

The workshop will be organized in five sessions:

1. Theory/models
2. Empirical evidence
3. Economic, policy and management implications
4. Final conclusions

Each session will be organized around a series of **presentations**, each of which will be followed by a **discussion** for clarifications. Provisionally, 20 minutes will be allocated for the presentations and 10 minutes for discussion. Each session will end-up with an **open debate** aiming at an integration of the views expressed in the presentations, identification of coherence, convergence, divergence, conflicts and, possibly consensus. A **final wrap-up session**, at the end of the meeting will give an opportunity to decide on, e.g.: (i) main messages; (ii) post-meeting communication strategy (meeting report, joint publication, etc.) and any other matter the group would want to discuss.

Each session will be moderated by a participant preferably not involved in presenting. Before then end of the meeting, each presenter will submit an executive summary with the key points of his/her presentation (up to a page plus figures) for the meeting report. The discussions following each presentations and each session will be summarized by rapporteurs.

### Office-bearers

The Scientific Steering Committee consisted of: Serge M. Garcia, Gabriella Bianchi; Anthony Charles; Jeppe Kolding; Marie-Joelle Rochet; Jake Rice; Shijie Zhou and Despina Symons.

The meeting will be co-chaired by Gabriella Bianchi (for FAO) and Serge M. Garcia (for IUCN-CEM-FEG). The co-chairs' proposals for the different sessions, to be finalized at the meeting, are as follows:

Session	Moderator(s)	Rapporteur(s)
Theory & models	A. Bundy	G. Delius
Empirical evidence	M. Hall	D. Reid
Economic, policy & management	J. Kolding	M-J. Rochet
Conclusions	G. Bianchi	A. Charles / S.M. Garcia

The meeting will be coordinated by Despina Symons (Director EBCD) and Paolo Mattana (EBCD, meeting officer) and FAO (Valérie Schneider).

**Venue:** FAO Premises, Via delle Terme di Caracalla (India Room). FAO will prepare passes for each participant and send an information about access to the FAO premises.

### Annotated agenda

<b>Monday 29 September</b>	
<b>09:00 - 09:30</b>	Opening welcomes: S. Garcia (Chair IUCN-CEM-FEG); D. Symons (Director EBCD) and G. Bianchi (FAO)
<b>09:30 - 09:45</b>	Nomination of a Meeting Chair(s) and session Rapporteurs
<b>09:45 - 10:00</b>	Adoption of the Agenda. Expected outcomes. Chair & rapporteurs
<b>10:00 - 10:30</b>	<b>Coffee break</b>
<b>SESSION 1: THEORY AND MODELS</b>	
<b>10:30 - 11:00</b>	<b>1. Balanced harvesting promotes coexistence of interacting species.</b> Law, R ; Plank, M. and Kolding, J.
<b>11:00 - 11:30</b>	<b>2. A reappraisal of fisheries selectivity in light of density-dependent regulation.</b> Andersen, K.H.; Jacobsen, N.S. and Beyer, J.
<b>11:30 - 12:00</b>	<b>3. Do unregulated, artisanal fisheries tend towards balanced harvesting?</b> Plank, M.; Law, R. and Kolding, J.
<b>12:00 - 14:00</b>	<b>Lunch</b>
<b>14:00 - 14:30</b>	<b>4. Effect of fishing intensity and selectivity on community structure and fishery production at trophic and species levels.</b> Zhou, S. and Smith, T.
<b>14:30 - 15:30</b>	<i>Discussion on Theory &amp; Models: Summary of theory available; identifying gaps and needs for further modelling work. Implications for research and management</i>
<b>15:30 – 16:00</b>	<b>Coffee break</b>
<b>SESSION 2: EMPIRICAL EVIDENCE</b>	
<b>16:00 – 16:30</b>	<b>5. Changes in productivity and life-history traits in experimentally harvested guppy populations.</b> By Diaz Pauli, B. and Heino, M.
<b>16:30 - 17:00</b>	<b>6. The Barents sea ecosystem - balanced harvest?</b> By: Mauritzen, M.
<b>Tuesday 30 September</b>	
<b>09:00 – 09:30</b>	<b>7. Exploitation patterns in fisheries, a global meta-analysis from Ecopath models.</b> Kolding, J.; Bundy, A.; Christensen, V.; Steenbeek, J.; Law, R.; Plank, M. et al.
<b>09:30 – 10:00</b>	<b>8. Maximizing fisheries yields while maintaining ecosystem structure.</b> Kolding, J.; Jacobsen, N.S.; Andersen, K.H. and van Zwieten, P.
<b>10:00 – 10:30</b>	<b>9. What are the ecosystem consequences of balanced fishing regimes?</b> Rochet,

	M.J.; Collie, J.; Jacobsen, N.S. and Reid, D.
<b>10:30 – 11:00</b>	<b>COFFEE BREAK</b>
<b>11:00 – 12:00</b>	<i>Discussion on Empirical Evidence: 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.</i>
<b>12:00 – 14:00</b>	<b>Lunch</b>
	<b>SESSION 3: ECONOMIC, POLICY AND MANAGEMENT IMPLICATIONS</b>
<b>14:00 – 14:30</b>	<b>10. Balanced Harvesting in Fisheries: Economic insights and policy Implications.</b> Charles, A.; Garcia, S.M. and Rice, J.
<b>14:30 – 15:00</b>	<b>11. The Ecosystem Approach to Fisheries and balanced harvest: considerations for practical implementation.</b> Bianchi, G.
<b>15:00 – 15:30</b>	<b>COFFEE BREAK</b>
<b>15:30 – 16:00</b>	<b>12. Dynamic management as a means to implement the multiple objectives of a balanced harvest in developed fisheries.</b> Dunn, D.C.; Hobday, A.; Boustany, M. and Halpin, P.N.
<b>16:30 – 17:00</b>	<b>13. An Introduction to the MSC Fisheries Standard: current requirements and future development toward a multispecies and ecosystem approach.</b> Atcheson, M.; Agnew, and Lefebure, D.
	<b>Wednesday 1 October</b>
<b>09:00 – 09:30</b>	<b>14. Implementing balanced harvesting. Practical challenges and other implications.</b> Graham, N. and Reid, D.
<b>09:30 – 10:00</b>	<b>15. Challenges to the implementation of balanced harvesting systems: some ecological and technological issues.</b> Hall, M.
<b>10:00 – 10:30</b>	<b>COFFEE BREAK</b>
<b>10:30 – 11:00</b>	<b>16. Balanced harvesting and the tropical tuna purse seine fishery.</b> Dagorn, L.
<b>11:00 – 11:30</b>	<b>17. Preliminary reflection on a possible BH norm and harvest control rule.</b> Garcia, S.M., Rice, J. and Charles, A.
<b>11:30 – 12:00</b>	<b>18. A framework of indicators for balanced harvesting in small scale fisheries.</b> van Zwieten, P. and Kolding, J.
<b>12:00 – 14:00</b>	<b>Lunch</b>
<b>14:00 – 14:30</b>	<b>19. Fisheries management for BH: case of Japan.</b> By Makino, M.
<b>14:30 – 15:00</b>	<b>20. Discard bans and balance harvest: a contradiction in (more than) terms?</b> Borges, L.
<b>15:00 – 15:30</b>	<b>COFFEE BREAK</b>
<b>15:30 – 16:00</b>	<b>21. Management implications. The CFP as a sounding board.</b> Garcia, S.M.
<b>16:00 – 17:00</b>	<i>Discussions: Summary of economic, policy and management implications</i>

	Thursday 02 October
	<b>SESSION 4: WRAP-UP DISCUSSIONS. CONCLUSIONS. MEETING OUTCOMES</b>
<b>09:00 – 10:00</b>	<p><b>Wrap-up session</b></p> <p>This session will intend to derive, from the available knowledge, the priority issues and practical advice for policy and management, identifying knowledge gaps and potential collaborative work.</p> <p>Additional questions to be addressed will be decided at the meeting but may include:</p> <ul style="list-style-type: none"> <li>• The message that could be delivered to the community regarding the scientific progress as well eventual policy and management implications of balanced harvesting;</li> <li>• Research questions (including data collection, modelling, empirical assessment.</li> <li>• Consideration of: (i) a report, (ii) elements for a joint publication.</li> </ul>
<b>10:00 - 10:30</b>	<b>Coffee break</b>
<b>10:30 – 12:00</b>	<b><i>Wrap-up session (Continued)</i></b>
<b>12:00 – 14:00</b>	<b>Lunch</b>
<b>14:00-17:30</b>	<b>FEG coordinating meeting</b>

**Social events:** A cocktail will be offered by EBCD on Monday evening. Time and place to be specified at the meeting.

## ANNEX 5 – LIST OF CONTRIBUTORS

### 1. List of participants

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Bartley, Devin	FAO, Rome, Italy
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Zhou, Shijie	CSIRO, Australia

### 2. List of additional contributors

The following authors contributed to the meeting outcomes as co-authors of the presentations.

Andersen, Ken H.	DTU Aqua, Copenhagen, Denmark
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