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Introduction

Balanced harvest: utopia, failure, or a functional strategy?

Jeppe Kolding[1,2]*, Serge M. Garcia[2], Shijie Zhou[3], and Mikko Heino[1,4]

[1]*Department of Biology and Hjort Centre for Marine Ecosystem Dynamics, University of Bergen, PO Box 7803, Bergen N-5020, Norway*
[2]*IUCN Commission of Ecosystem Management, Fisheries Expert Group (IUCN-CEM-FEG), Gland, Switzerland*
[3]*CSIRO Oceans and Atmosphere, GPO Box 2583, Brisbane, QLD 4001, Australia*
[4]*Institute of Marine Research and Hjort Centre for Marine Ecosystem Dynamics, PO Box 1870 Nordnes, Bergen NO-5817, Norway*

Corresponding author: tel: +47 47409902; e-mail: jeppe.kolding@bio.uib.no

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Since "balanced harvest" was proposed in 2010 as a possible tool in the operationalization of the ecosystem approach to fisheries (EAF), the concept gained extensive international attention. Because maintaining ecosystem structure and achieving maximum sustainable yields have become two of the key international legal obligations in fisheries management, balanced harvest is as topical as ever. An international workshop on balanced harvest, organized by the IUCN Fisheries Expert Group at FAO headquarters in 2014, reviewed the progress in the field and discussed its prospects and challenges. Several articles in this theme set, mostly based on presentations from the workshop, discuss ecological, economical, legal, social, and operational issues surrounding the key management goals. Progress is being made on understanding of the theoretical underpinnings of balanced harvest and its practical feasibility. Yet, a basic debate on the concept of balanced harvest continues. To move the EAF forward, we anticipate and encourage further research and discussion on balanced harvest and similar ideas.

Keywords: balanced harvest, discards, EAF, fishing pattern, management, MSY, multispecies, selectivity.

Background

Balanced harvesting (BH) is in many ways an old idea that has recently been revived. We all know that fish stocks do not live in isolation, and many authors have contemplated the best ways to manage and harvest a multispecies community (e.g. Dickie, 1972; May *et al.*, 1979; Pauly, 1979; Jones, 1982; Clark, 1984; Caddy and Sharp, 1986; Sainsbury, 1988; Link, 2010). Yet, despite considerable effort in constructing multispecies models (Plagányi, 2007; Fulton *et al.*, 2011; Plagányi *et al.*, 2014), fisheries management worldwide is still almost entirely based on single-species advice and regulations (King, 2007; Cochrane and Garcia, 2009; Skern-Mauritzen *et al.*, 2016)—for historic, practical, and economic reasons. The plethora of parameters necessary for constructing realistic models of complex exploited ecosystems, and their drivers, makes such models expensive and inconvenient in operational management (May, 1984; Hollowed *et al.*, 2000; Collie *et al.*, 2016). Furthermore, the practical implications of uncertainty in understanding ecosystem dynamics and multispecies fisheries, and the consequences of disregarding them in conventional management, has rarely been addressed (but see Clark, 1984; Charles, 2001; Hill *et al.*, 2007; Garcia and Charles, 2007).

Nevertheless, the limitations of the old single-species paradigm in coping with the new challenges arising from environmental ethics, environmental economics, and even climate change, in a more holistic perspective, are being increasingly recognized. Fishery policies and harvest strategies are evolving rapidly from a conventional stock-based management to a more ecosystem-conscious context, and the concept of the ecosystem approach to fisheries (EAF) has entered the fishery policy framework. EAF, as formulated by the Food and Agriculture Organization of the United Nations (FAO), was first presented in the Reykjavik Declaration in 2001 (FAO, 2003). This policy development reflects the conservation perspective of the Ecosystem Approach (EA) adopted by the Convention on Biological Diversity (CBD) in 1992. Both EA and EAF are now firmly embedded in the discourse of natural resources governance (Garcia *et al.*, 2014). However, while politically and strategically accepted, the overarching challenge is still to make these goals operational and to formulate practical solutions for their implementation (Murawski, 2007; Zhou *et al*., 2010). A recent global review (Skern-Mauritzen *et al*., 2016) showed that tactical fisheries management is still predominantly single-species oriented. Thus, while EAF is highlighted in policies and plans, its influence on fisheries management in practice remains generally limited.

Conventional fisheries management has many objectives. From a purely food production perspective, the basic goal is to define the maximum quantity of fish that can be sustainably caught from a fish population or community, within economic and ethical constraints. In the short term, catch depends on the available biomass and the applied fishing mortality. Consequently, there are only two concrete options for regulating a fishery: setting catch limits (total allowable catch) and the fishing mortality (F) by controlling gear selectivity and effort (Kolding *et al*., 2015b). The relative probability of capture a species and/or size relative to their occurrence in the ecosystem, resulting from the constellation of fishing methods applied, is called the fishing pattern. One of the central questions in all fisheries is thus to determine the "best" combination of fishing pattern (how to fish) and effort (how much to fish). The result has been a strong focus and emphasis on selectivity in conventional fisheries management. In fact, selectivity has been part of the fisheries lore for >600 years (Kolding and van Zwieten, 2011), much longer than catch quotas. Hardly, a fishery exists without some kind of selectivity regulation in the form of gear and/or target size restrictions (Misund *et al*., 2002). In addition, fishers themselves are often highly selective due to cultural (e.g. skills and experience) and economic preferences. Nonetheless, selectivity is imperfect and most fisheries generate bycatch of non-target species—some of which might be endangered and protected—that is often discarded, usually dead or moribund. This creates technical interactions between fisheries and single-species management schemes and raises ethical issues. For these reasons, most fisheries policies and strategies highlight the importance of increased selectivity, such as, for example, the Code of Conduct of Responsible Fisheries (FAO, 1995), the FAO Guidelines on discards (FAO, 2011), and the revised Common Fisheries Policy in Europe (Vasilakopoulos *et al*., 2015).

One of the key goals of EA is to conserve ecosystem structure and function. However, as applied today, EAF is widely used to recommend highly selective fishing on economic species and sizes to protect non-target, low-valued ecosystem components. This seems paradoxical because selectively killing one group of fish while protecting another group unavoidably alters community structure, which is at odds with the EA goal of preserving ecosystems. There is increasing evidence that our selective harvesting pattern is causing deep structural, and possibly evolutionary, changes to harvested populations and communities (Jørgensen *et al*., 2007; Fenberg and Roy, 2008; Link, 2010; Zhou *et al*., 2010; Heino *et al*., 2015). We are, therefore, in a situation where international conventions and principles for conservation are in potential conflict with conventional practices and policies in fisheries governance. The conflicts are also within the conventions and principles themselves, i.e. between the goals and strategies proposed to achieve those goals.

The general idea of balancing multispecies harvest has been suggested in several papers since the 1950s (e.g. Swingle, 1950; Caddy and Sharp, 1986; Misund *et al*., 2002; Jul-Larsen *et al*., 2003; Bundy *et al*., 2005), and Zhou *et al*. (2010) first formally proposed the concept of "balanced exploitation" across species. Consequently, an international workshop organized by the Fisheries Expert Group of the IUCN Commission on Ecosystem Management (IUCN-CEM-FEG) was held in 2010, just before the 10th Convention of the Parties of the Convention on Biological Diversity. Presented with a diversity of modelling and empirical evidence, the workshop discussed the potential advantages, in both yield and maintenance of ecosystem structure and functioning, of distributing fishing pressure broadly across ecosystem compartments. BH was then defined as "a strategy that distributes fishing pressure across the widest possible range of trophic levels, sizes and species, in proportion to their natural productivity, reducing fishing pressure where it is excessive" (Garcia *et al*., 2011, 2012). This critical rethinking of current approaches to fisheries management has since gained rapid international attention (IUCN, 2012; Borrell, 2013; Cardinale *et al*., 2013). However, a number of unresolved questions emerged from the ensuing debate (Jacobsen *et al*., 2014; Burgess *et al*., 2015). For example, how do selectivity and the fishing regime interact with fishing pressure? Should balanced harvest be applied to both species and sizes? What should be the reference system that we aim to achieve under EAF? How do we combine ecological and economic objectives at the fishery and ecosystem level? How do we regulate targeted selective fishing at the vessel level to obtain an overall balanced harvest at the ecosystem level?

To address the scientific, policy, and operational issues associated with the balanced harvest concept, IUCN-CEM-FEG, in cooperation with FAO, organized a second international workshop in 29 September–2 October 2014. The workshop considered progress made on the scientific underpinning of the BH concept, including theory, modelling and empirical observations, and explored the potential economic, policy and management implications of BH that simultaneously takes ecosystem conservation into account (Garcia *et al*., 2015). This article theme set is based on presentations made at the meeting, and includes an article criticizing BH (Froese *et al*., 2016a), with a subsequent comment and reply. One of the workshop presentations has been published elsewhere (Kolding *et al*., 2015a). Here, we briefly present the main ideas and findings from the individual articles, before summarizing where the research on BH currently stands and perhaps where it is going.

The articles in this theme set

Ecosystem control rules as a bridge between the UNCLOS and CBD requirements

Garcia *et al*. (2016a) outline the international legal obligations on sustainable fisheries and how BH can help to fulfil these requirements. The Law of the Sea Convention (UNCLOS, 1982) requires maintaining stocks at the level at which they could produce MSY, whereas the Convention on Biological Diversity (CBD, 1992) requires maintaining ecosystem structure and functioning. They examine these prerequisites and briefly present four system-level relationships, representing ecosystem structures that might guide management decisions aiming to meet both obligations. They show how such ecosystem indicators would fit in the widely accepted framework of the EA, enshrined in the CBD, and adopted by the FAO Code Conduct for Responsible Fisheries. As an example, they present a multispecies size-spectrum harvest control rule to illustrate its potential to support strategic management decisions at the ecosystem level, complementing rules currently used at the stock/population level.

A global ecosystem perspective on the conventional fishing pattern

Kolding *et al.* (2016) use empirical data from 110 published Ecopath models, representing marine ecosystems throughout the world, to explore fishing pressure and pattern at the ecosystem level. They show that the overall pressure exerted by human exploitation across trophic levels is highly unbalanced and strongly skewed towards large, high value but low productivity apex species in the trophic pyramid. Well-managed fisheries from temperate ecosystems appear more selectively harvested (hence more "unbalanced") with higher exploitation rates than tropical and upwelling fisheries, confirming that, in these fisheries, value is more important than volume. Highly selective temperate fisheries, therefore, have higher potential risks of inducing long-term changes to the ecosystem structure and functioning. While only relatively few stocks (18%) appear as technically overfished, the results indicate a very inefficient utilization of the potential marine production in terms of tonnages and global food security. Kolding *et al.* (2016) suggest that changing fishing pattern closer to BH could significantly increase global marine fisheries catches, while reducing overexploitation on the high value stocks.

Management implications of BH

Earlier research on BH has essentially focused on its bio-ecological and modelling aspects, with little on policy, economic, and operational implications. However, BH has many, often conflicting, implications for conventional fisheries management, e.g. in relation to selectivity, protection of juveniles, models of harvesting strategies, discarding, and threatened, endangered and protected species as well as operational complexity. Garcia *et al.* (2016b) raise and explore these issues in relation to the overall goals of conserving ecosystem structure and function while securing sustainable yields. They also consider partial implementation, ecosystem rebuilding, and relationships with other management frameworks. The paper closes with a broader discussion of BH implementation, concluding that several separate ongoing initiatives need to be integrated to move fisheries into a more ecosystem-conscious context. Challenges in implementing BH will be encountered, but there are lessons to be drawn from fishery systems that are already close to BH, as in some tropical multispecies fisheries. In addition, many of the challenges are already addressed in well-managed areas where the process towards EAF has begun.

Economic and policy implications of BH

Modern fisheries are predominantly a commercial activity, whereas BH so far has focused on ecological productivity and conservation goals motivated by the CBD. Charles *et al.* (2016) explore the potential economic implications and trade-offs between conventional selective fishing patterns aiming at a market goal (value) and balanced fishing aiming at food production and conservation. They focus on six main themes: (i) assessing benefits and costs, (ii) factors affecting the economics of BH, (iii) economic issues in implementing BH, (iv) effects of incremental and/or partial implementation of BH, (v) transition options within the harvesting sector, and (vi) distributional impacts arising across fisheries, fleet sectors, and fishing gears, and between the present and the future. BH is expected to face several major economic barriers as it basically involves changing the composition of fish harvests from a focus on larger, valuable fish to much more lower-valued catch, including sizes and species not currently harvested. While total yield may rise, it is not clear whether aggregate revenues would rise or fall. Management costs may be prohibitive, and the basic nature of currently favoured species-specific catch rights systems such as ITQs is likely to conflict with the ecosystemic nature of BH, unless a significant level of flexibility is introduced in their implementation. As the few empirical examples of fisheries that approach a BH are all found in poorly developed areas where the pressure to meet food security is high, it appears that balance-distorting market forces increase with economic development. The paper concludes that the trade-offs between CBD objectives and socio-economic objectives must be evaluated to address "how much" BH is desirable and how to make such a transition where necessary. A partial implementation of BH on a case-by-case basis may be considered as a first step towards EAF.

Practical challenges and pragmatic solutions

Strongly related to economic considerations are the practical challenges involved for implementing BH. This is particularly so for fisheries based on highly selective fishing patterns practiced in most of Europe and North America, where a strongly price-differentiated market entails a sharp distinction between commercial and bycatch species. Reid *et al.* (2016) examine and evaluate the feasibility of implementing BH in such fisheries. First, they find that a "laissez-faire" approach, analogous to the African lakes where a sort of "natural", unenforced BH has emerged, is inappropriate in developed world fisheries for economic (market), practical and management capacity reasons. Next, they consider two alternative approaches, focusing on distributing an exploitation rate proportional to the productivity of either the species or the size structure of the resources. They conclude that: (i) focusing on species only, using conventional approaches, would require a degree of micromanagement that is likely unachievable; and (ii) focusing on sizes only might be easier to implement, but problems may arise due to the faster capture of the more easily catchable fish and more valuable species within a size class. Having concluded that neither "laissez-faire" management nor over-detailed management would be practicable in developed world fisheries, they identify a "broad brush", métier-based approach, combining many different fishing strategies in specialized fleets/fisheries (métiers) as a possible compromise with the most potential. Such an approach, however, would also depend on available markets for all the additional fish landed (particularly if BH was combined with discard bans). Other challenges include the collateral issues of ensuring the conservation of protected, endangered, and threatened species (including mammals, reptiles, and birds), the rebuilding of already severely depleted stocks, and the possible integration of benthic invertebrates in the BH management strategy. However, they point out that many of the generic challenges are not principally different from those faced by current management approaches.

Howell *et al.* (2016) also discuss challenges to be overcome before BH could be considered practical in a large-scale, industrialized fishery. They use the Barents Sea, arguably one of the world's best-managed fishery systems, as a case study. The challenges relate to a range of issues: incorporating standard fisheries protections for depleted and recovering stocks into BH, evaluating how the uncertainties in the data (and especially on the data poor stocks and the early life stages of the stocks) impact on the ability to manage a balanced fishery, and the practicalities of how typical selective, economically driven ocean fisheries could deliver a BH. Since any implementation is likely to be imperfect, the most viable route to possible implementation could be to first consider which parts of balanced fishing are the most practical to implement. They conclude that until the gaps between theoretical modelling approaches and practical management schemes are filled, it remains impossible to evaluate the utility of BH in real-world industrial fisheries management.

The potential role of discard bans

The highly species- and size-selective, price-differentiated, and market-oriented fishing pattern that characterizes most commercial fisheries, combined with practical limitations of obtaining perfect gear selectivity, have caused issues with bycatch, sometimes discarded at sea either voluntarily or mandatorily. This has raised ethical concerns among the public, who see discarding as a waste of resources. As a result, discard bans have been introduced in several countries, such as Chile, European Union, Norway, and New Zealand, with the aim of improving selectivity and reducing bycatch. Based on experiences from these countries, Borges *et al.* (2016) discuss whether discard bans support or contradict BH. They stress that when discard bans are fully implemented, it is expected that fishing operations do become more selective, typically targeting bigger individuals of main commercial species, consistent with their objective of reducing bycatch. From this perspective, discard bans are in contradiction with BH. On the other hand, if discard ban goals are set differently, in line with BH objectives of balancing fishing pressures, they may indeed be a management tool that can help reach and maintain balanced harvest. Thus, discard bans *per se* do not conflict with BH; they are only a tool serving management policies.

Controversial issues associated with BH

In their critique, Froese *et al.* (2016a) question the available evidence of the virtues of BH in general, and assumptions of size-based models in particular. They suggest that BH will not help but actually hinder the policy changes needed for the rebuilding of ecosystems, healthy fish populations, and sustainable fisheries. Froese *et al.* ground their critique on what they call *basic population dynamics* developed by Beverton and Holt (1957). From these alternative assumptions, they argue that the new size-based models use unrealistic settings with regard to life history (peak of cohort biomass at small sizes), response to fishing (strong compensation of fishing mortality by reduced natural mortality), and economics (uniform cost of fishing and same price for all species and sizes). They also consider that the empirical evidence of BH is scarce and questionable. They conclude that evolutionary theory, population dynamics theory, ecosystem models with realistic assumptions and settings, and widespread empirical evidence do not support the BH approach. Froese et al. state that at the heart of arguments about the benefits of BH is a critical assumption about how fishing affects natural mortality rates of organisms via cascading changes in trophic interactions. Their main critique is that BH is inconsistent with the results obtained from basic population dynamics.

Andersen *et al.* (2016) respond to the Froese *et al.* critique of size-spectrum models by arguing that the assumptions of these models are realistic and consistent. They stress that conclusions from size-based models, at the community-level, should not be confused with conclusions from conventional fishery models on single stocks. They further show that the disputed early peak in cohort biomass again depends on an assumption on whether density-dependence is described by a stock–recruitment relationship (as assumed in the basic population dynamics) or not. Finally, they stress that ecosystem-based harvest strategies should not be dismissed based on lack of conformity to the conventional (stock-based) set of assumptions, but should be further explored using a wide suite of ecosystem models, where objective evaluation of strengths and weaknesses and better communication of assumptions would help to prevent future misconceptions.

In the reply to Andersen *et al.* (op cit.), Froese *et al.* (2016b) maintain that the size-spectrum models used to justify BH are highly unrealistic and not suitable for evaluating real-world fishing strategies, and that BH, therefore, is unlikely to be a useful guiding principle for ecosystem-based fisheries management.

Summary and conclusions

BH was suggested as a unifying ‘bridge’ mechanism for meeting Principle 5 of the CBD EA (UNEP/CBD/COP, 1998) together with an MSY-related objective of UNCLOS (1982) but at the ecosystem level, merged into the strategic goal of maintaining structure (and it is to be hoped functioning) while extracting high, sustainable yields. BH was, therefore, intended as a possible tool in the operationalization of EAF. However, the contributions presented here suggest that this is not a straightforward process. First, there is a need for the scientific community to examine if the definition of BH is indeed accurate and provide more evidence (such as using a range of alternative models) to evaluate its performance in terms of ecological, social, and economic benefits, and the trade-offs between these. BH is a high-level principle, providing a direction for fishery management, rather than a precise destination (Zhou *et al.*, 2015). If it is deemed a viable strategy for implementing EAF, there will be a range of hurdles to overcome in the application and transition, particularly in developed industrial fisheries.

One constraint is the asymmetry between theoretical and empirical evidence. Balanced harvest has not been a conscious strategy in any fishery. Because of the longstanding strong focus on selectivity in fisheries management (Misund *et al.*, 2002), “emergent” BH is also rare; the existing examples are from weakly enforced small-scale fisheries in inland Africa that defy centrally imposed regulations (Jul-Larsen *et al.*, 2003; Kolding and van Zwieten, 2011, 2014; Kolding *et al.*, 2015a, b). Thus, due to scarcity of empirical data, BH has mostly been studied using theoretical approaches, either size-based models (Law *et al.*, 2012, 2014, 2015; Jacobsen *et al.*, 2014; Garcia *et al.*, 2015) or ecosystem models such as Ecopath and Atlantis (cf. Garcia *et al.*, 2012).

The empirical observations from African lakes, and most of the model results, indicate that BH could support the intended goals. A basic problem, however, is whether the theoretical models can realistically represent the relationships expected in complex multi-species communities. Much of the opposing discourse boils down to which underlying assumptions one adheres to, as the papers by Froese *et al.* (op. cit.) and Andersen *et al.* (op. cit.) illustrate. For example, where the *basic population dynamics* models have exogenous (often constant) growth and mortality functions, the size-based models have growth and mortality as emergent properties from trophic interactions (a fish can only grow if it eats a prey that consequently dies); a question is, then, whether these interactions are modelled realistically enough? This discussion has only recently started and we expect that much effort will be invested in resolving these issues soon. On the other hand, the expected benefits of BH vs. conventionally selective fishing can be evaluated indirectly by describing the actual fishing patterns and pressures on various components of the ecosystem in relation to their productivity, as done by Kolding *et al.* (2016). Such analyses of existing fishery systems, already recommended at the first BH meeting in 2010, could clarify to what extent current fishing and management practices deviate from the EA requirement to maintain ecosystem structure and function, and also promote a concrete suggestion on ways to better comply.

Another related constraint is the degree of economic development of the fishery. Situations similar to BH were first observed in small-scale multi-gear fisheries, which all have a relatively large number of fishers with low technological development who supply a local market with little size-based price differentiation. Thus, much of the ensuing debate has concentrated on whether the concept is applicable in more developed, industrial fisheries with stronger top-down management and market differentiation (Jacobsen *et al.*, 2014; Burgess *et al.*, 2015). Many of the challenging economic, practical, policy, and management implications of implementing BH raised and discussed in this article theme set (Charles *et al.*, Garcia *et al.*, Reid *et al.*, Borges *et al.*, and Howell *et al.*) all relate to the multiple problems of implementing BH in such settings. Still, while highly developed commercial fisheries are the least balanced at the ecosystem level (Kolding *et al.*, 2016), they are also those where the strongest concern is raised on ecosystem health, good practice guidelines, and certification schemes. It is a dilemma that fisheries management remains based on single stock rationales (exacerbated by species-based entitlements) while conservation requirements call for an EA to sustainable use. It is also a concern to see that modern, rich nations' consumer selective preferences and related price differentials in a globalizing market tend to distort ecosystem structure (and function?). This debate illustrates the difficult process of implementing an EAF and the many hurdles and choices to be addressed and solved before we can reach a consensus for an overarching strategy.

Nevertheless, work and thoughts on BH, as well as EAF, are evolving as more insights are gained. With the EAF policies accepted, we now have to formulate appropriate concrete management objectives at the ecosystem level and affordable approaches to reach them. BH, as a strategic mechanism, is not intended to replace conventional management, but provides a mean to help reconfigure it into a fuller ecosystem-based framework using ecosystem harvest rules and performance criteria. In some fisheries, particularly in 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 behaviour but, in an ever more globalized fish trade, state intervention might be unavoidable. In other fisheries, implementation challenges will be significant, and in some cases overwhelming. The key will be to find the way to nest the tactical (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 many, the proposal has only appeared recently and progress is already being made, with a range of potential instruments identified (Charles *et al.*, 2016; Reid *et al.*, 2016). The various complexities should not provide an excuse for maintaining an unsatisfactory status quo. Finding and demonstrating alternative ways to maintain ecosystem structure and function should be encouraged. It might be useful to remind ourselves that this is an obligating requirement of CBD, integrated into the EAF, not a fanciful objective of BH. The discussion is not closed. Markets, technologies and societal preferences can change as well as our notions of what we want our ecosystems to look like.

Modern fisheries science, based on what Froese *et al.* (op. cit.) call *basic population dynamics*, was established during the 1950s. According to Rothschild (1986), later advancement has mainly been of a computational character, at the possible expense of conceptual development. Sissenwine (1978) concluded that "what seems really needed [in fisheries] is not further mathematical refinement, but rather robustly self-correcting harvesting strategies - that can operate with only a vague knowledge of population processes" (ibid. p.38). More recently, Link (2010) stressed that: (i) most fisheries are multispecies fisheries managed with single-species instruments; (ii) *focusing solely on managing one species of fish stock at a time has become a less viable option for many reasons*; (iii) single-species approaches *will never be able to provide insights into a broader suite of pressing issues* [*as*] *for example changes in ecosystem structure and function*; and (iv) that *there is a need for more holistic and broader approaches,* squarely addressing the emerging trade-offs. We think that BH could qualify as such a strategy, as a sort of control rule established at the ecosystem level, resulting in a fishing regime producing the outcomes mandated by UNCLOS and CBD. We hope that this article theme set will inspire continued research and discussion on how to maintain ecosystem structure and function while optimizing yield, with BH as one possibility to achieve that.

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