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TEN COMMANDMENTS FOR ECOSYSTEM-BASED FISHERIES SCIENTISTS

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INTRODUCTION

Who in blazes are we to have the audacity to issue 10 commandments? Well, we certainly do not believe that we are Yahweh et al. Rather, our humble intention is to stimulate much needed discussion regarding the explicit details of ecosystem-based fisheries science as a bonafide new discipline. We perceive a need to bridge the gap between general principles, which are already well-articulated, and specific methodologies for full implementation, which is the present challenge and beyond the scope of this paper. Our intention is to foster the implementation of ecosystem-based fisheries management by proposing tangible action items regarding natural science.

Despite some resistance toward ecosystem-based approaches by some fisheries biologists, single-species fisheries science and management is increasingly seen as necessary yet insufficient. Although ecosystem-based fishery concepts have existed for many years and have been implemented in some regions for some time, there has been little definitive exploration of explicit action items for a full transition to what we call "ecosystem-based fisheries science" (EBFS). We believe that EBFS should not replace traditional fisheries biology per se, but rather that conventional single-species approaches should be incorporated into the broader and ecologically more realistic discipline of EBFS. In an effort to clarify the essential components of EBFS, we offer the following 10 "commandments" to both the revolutionaries and the reactionaries in this evolutionary paradigm shift.

COMMANDMENT 1: KEEP A PERSPECTIVE THAT IS HOLISTIC, RISK-AVERSE, AND ADAPTIVE

This fundamental commandment provides the necessary worldview and general context for all others. EBFS is more an issue of context and mindset than of method, and thus does not require vast quantities of additional data and funding. An ecosystem approach to fisheries science involves a more holistic view of managing resources in the context of their environment than presently exists. This approach must take into greater consideration the constantly changing climate-driven physical and biological interactions in the ecosystem, the trophic relationships between fished and unfished elements of the food web, the adaptation potential of life history diversity, and the role of humans as both predators and competitors. Recognizing that all management decisions have impacts on the ecosystem being exploited, an ecosystem-based approach seeks to better inform these decisions with knowledge of ecosystem structure, processes, and functions. Once fisheries are viewed from such a holistic perspective, then EBFS necessarily becomes both risk-averse and adaptive. Fishery science will always be severely data-limited and uncertainty will always be high. Therefore, the onus is on fishery scientists to encourage implementation of risk-averse management approaches that set fishing quotas, gear restrictions, and fishing zones in ways that are relatively conservative compared to traditional approaches. Hand-in-hand with a precautionary approach is the adaptive approach, which calls for learning by doing in the face of incomplete knowledge, encouraging implementation of management policies that test hypotheses regarding sustainable fisheries in a cycle of informed trial-and-error.

COMMANDMENT 2: QUESTION KEY ASSUMPTIONS, NO MATTER HOW BASIC

This is a critical commandment for any scientist, but is particularly true for science that is advisory to fishery management. For example, the most common and sophisticated single-species stock assessment models often assume that: (a) recruitment is solely a function of spawning biomass, (b) natural mortality is constant over the time frame of stock assessment, (c) unexploited biomass is constant, (d) if exploitation ceases, the stock biomass will rebuild to that unexploited level due to endogenous density-dependent mechanisms, and (e) for any given level of fishing effort, stock biomass will approach an equilibrium at which it will remain in perpetuity. Violations of these assumptions have been well documented, and ecosystem models have indicated that widespread application of the contemporary Maximum Sustainable Yield (or MSY-proxy) single-species management approach can lead to dramatic impacts on ecosystem structure, particularly where such approaches are applied to forage species. The lesson is that fisheries scientists should exercise caution in recommending MSY policy based on single-species assessments that ignore the ecosystem roles of exploited species. There are at least two perspectives on coping with this issue, both of which are held by different authors of this paper. One is to view MSY as an evolving and viable paradigm that has not always been implemented properly in the past, but is nonetheless essential in fisheries science. The other is to replace MSY with a more holistic "ecologically sustainable yield."

COMMANDMENT 3: MAINTAIN OLD-GROWTH AGE STRUCTURE IN FISH POPULATIONS

Recent (and even not so recent) studies belie three implicit assumptions of traditional fisheries biology regarding spawning females of relatively long-lived species: (1) all eggs are identical, and in particular, eggs from younger smaller females and older larger females are equivalent, (2) all mature females are equivalent in terms of spawning behavior, and (3) long-lived individuals per se are not essential for an exploited stock to persist. Increasingly documented violations of these assumptions, and new data showing the relatively high reproductive success of larger, older female fish underscore the importance of old-growth age structure in replenishing fished populations. The obvious conclusion is the need to minimize what has conventionally been seen as an expected and harmless side-effect of fishing to maximize density-dependent surplus production -- age- and size-truncation (the loss of older age classes and larger size classes) -- which is now recognized as leading to "longevity overfishing." Marine protected areas are seen as an effective means of conserving old-growth age structure, but at the very least, ecosystem-based fisheries scientists should monitor age and size structure and incorporate these considerations into stock assessments.

COMMANDMENT 4: CHARACTERIZE AND MAINTAIN THE NATURAL SPATIAL STRUCTURE OF FISH STOCKS

Traditional fisheries biology was founded on the assumption of unit stocks: regionally interbreeding populations that are reproductively closed (in modern parlance, a "metapopulation" comprising local populations linked by larval dispersal). Recent genetic and otolith microchemical studies indicate that marine stocks have complex spatial structures at much smaller scales than previously assumed. The important implication of these findings is that a decline in fish abundance in one region may not be replenished quickly or inevitably from another region. Thus, averaging stock assessments among regions may result in localized overfishing. Management fallout from this scenario is that the fishing community in one region may be unfairly penalized for overfishing that occurs in another, ecologically distinct region. Therefore, the artificial spatial scale of stock assessment and management must better align with the natural spatial scale of target populations. Such ecologically-based regions should define the spatial units of stock assessment and management, rather than the arbitrary political regions presently used. In any case, continuing to rely on traditional stock assessments that either ignore or artificially delineate the true spatial structure of fish populations is clearly a recipe for disaster.

COMMANDMENT 5: CHARACTERIZE AND MAINTAIN VIABLE FISH HABITATS

Within the biogeographical region inhabited by a particular stock, the different kinds of fish habitat and their spatial distributions must also be incorporated into fisheries science if sustainability is to be ensured. An ecosystem-based approach includes identification of nursery habitats, spawning sites, and other areas required to maintain stock integrity, and protection of those areas from bottom-gear impacts and other deleterious activities. Importantly, much seafloor habitat is biogenic, created by corals, kelps, seagrasses, and other structure-forming organisms, so protection of fisheries habitat is truly equivalent to conserving the biodiversity of seafloors. Additionally, stock assessments of demersal species should take into account the fact that the seafloor is heterogeneous, thereby increasing the accuracy of assessments via integration of spatially explicit population sampling with seafloor habitat mapping. In short, ecosystem-based fisheries science is inherently place-based at multiple spatial scales.

COMMANDMENT 6: CHARACTERIZE AND MAINTAIN ECOSYSTEM RESILIENCE

The concept of "resilience" is a useful scoping device for integrating ecosystem and social system complexity in fisheries management. "Resilience" is defined as the extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping into alternate states. Resilience includes not only the nature of the stability domain of the existing food web --

how broad is it, how resistant is it to change, and how close the current food web is to reorganizing -- but also panarchy, cross-scale effects that can occur in both time and space. A pressing example of panarchy is climate change, which comprises a major marine ecosystem perturbation occurring at very different temporal and spatial scales than those that previously dominated the structure and function of most marine fishery ecosystems. Evolving ecosystem indicators will provide useful tools for monitoring resilience, but in any case, the emerging paradigm is one in which marine biodiversity per se at the genetic, population, and ecosystem level is valued by fisheries science as an essential requisite for the resilience of fisheries.

COMMANDMENT 7: IDENTIFY AND MAINTAIN CRITICAL FOOD-WEB CONNECTIONS

One of the most important tasks of EBFS is to understand food-web relationships, and subsequently use that knowledge to form a context for setting fishery management policy. Food-web modeling is an imperfect but useful tool for exploring the consequences of various fishery management policies. In any case, there is ample evidence in both North Atlantic and North Pacific ecosystems that overfishing has altered food-web processes and affected both the resilience and productivity of fisheries. This evidence underscores the importance of maintaining the integrity and biodiversity of marine ecosystems, not only by conserving obviously important top predators and forage species, but also by protecting the entire the food web on which fishery species depend. In this sense, it is imperative to keep in mind that target populations not only may be regulated and stabilized by their predators and competitors, but also may in turn affect population sizes and biodiversity of their prey.

COMMANDMENT 8: ACCOUNT FOR ECOSYSTEM CHANGE THROUGH TIME

The issue of time presents itself to fishery scientists in at least two ways. First, time challenges the conventional scientific method in terms of our inability to predict the behavior of complex adaptive systems. The dilemma of complexity and persistent uncertainty can be approached by running scenarios -- narratives of plausible futures consistent with ecological understanding and their estimated probabilities based on current knowledge. Importantly, scenarios encourage action whereas uncertainties sometimes lead to doubt, inaction, and further analysis. Scenarios also provide a context for the future by stimulating broad thinking. Second, time stretches the traditional domain of management in terms of the effects of the physical climate on ecosystem structure and dynamics. Climate variability clearly has a huge impact on the structure and dynamics of marine ecosystems; what is true today may not be true tomorrow. The degree to which long-term climate change is affecting the world's oceans and their ecosystems relative to other forms of variability is currently a major concern, and the consequent interactions among monotonic (global warming), interdecadal (e.g., Pacific Decadal Oscillation), and interannual (e.g., El Niño-Southern Oscillation) climate variability are difficult to disentangle. To take these phenomena into account despite ever-growing uncertainty, the first step would be to reject any notion that we have the capacity to fine-tune allowable biological catches to the razor edge of MSY. Rather, the risk-averse approach to MSY is to set targets with sufficient margins of error to reflect variations in life history and recruitment of target species, ocean productivity, and errors in estimation and implementation.

COMMANDMENT 9: ACCOUNT FOR EVOLUTIONARY CHANGE CAUSED BY FISHING

Traditional fisheries biology has not fully recognized the potential of fishing mortality to cause directional selection in fish populations. A truly ecosystem-based fisheries scientist takes a Darwinian perspective of how fishing affects target populations, acknowledging that most fisheries are selective by their very nature, and therefore comprise large-scale uncontrolled manipulations of life-history evolution via artificial selection. Available evidence suggests that heritabilities of traits affected by fishing are large enough to lead to observable evolution over mere decades of fishing. There is also ample evidence that large phenotypic changes have occurred in major fish stocks due to differentially targeting larger and older size and age classes (i.e., size and age truncation), including reduction in length and age at maturation and overall reduction in size-at-age. Because fisheries-induced genetic changes in stocks are not easily reversed, precautionary catch quotas and other efforts to sustain old-growth age structure, including life-history reference points in stock assessments, are important tools to avoid unwanted artificial selection.

COMMANDMENT 10: IMPLEMENT AN APPROACH THAT IS INTEGRATED, INTERDISCIPLINARY, AND INCLUSIVE

The kinds of issues raised by moving to a more holistic ecosystem-based approach to fishery science cannot be addressed adequately by a single disciplinary perspective. These issues require an integrated view to bridge perspectives and disciplines both within and among the natural and social sciences, synthesizing knowledge from disparate disciplines into an emerging field of "integrated assessment." Add to this synthesis the fact that fishery science is only useful to the extent that it can help facilitate resource management decisions, and the reach of ecosystem-based fishery science broadens even more. Effective implementation of ecosystem approaches to fisheries management must necessarily embrace the full range of stakeholders and all concerned citizens.

Although the shift in worldview embodied in these 10 action items can occur immediately, full implementation will require an expanded empirical basis as well as novel approaches to modeling. This expanded knowledge base must include mechanistic ecological studies in the field. Ultimately, we believe that ecosystem-based fisheries science must be fully implemented as soon as possible to avoid -- or at least to delay -- critical declines in seafood for an ever-expanding human population.

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