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Viewpoint

The sustainability myth

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Fishery science, by which I mean the study of the dynamics of exploited fish stocks, may be unique among the scientific disciplines: it produced a corpus of theory that was taught in universities and applied at sea, but which has since proved to be wrong.

In his posthumous essay of 1998, Beverton discussed the '*gruesome story*' of the repeated stock collapses and depletions that started to take our attention during the 1980s; this was not at all what had been anticipated when he and others established the basis of contemporary stock assessment and management theory in mid-20th century. His analysis of what went wrong contains a key remark that is easily overlooked: during what he called the carefree period when modern theory was being established in mid-century, '*biology became subservient to maths*, *in both staffing* (of the laboratories) *and philosophy*'.

Beverton drew no specific conclusions from this important observation but it perhaps explains why concepts such as the unfortunately named surplus production model should have been applied so uncritically in the real ocean. Indeed, the consequences of the primacy of mathematics in fishery science are only now coming to be acknowledged, as in the essay on the use and abuse of fishery models by Schnute and Richards (2001). Because such models must contain states that can never be observed, and are dependent on arbitrary assumptions that influence their outcome, these authors argued that fisheries science must reach beyond mathematics.

This direct and unanswerable criticism of the fundamental tools of stock management represents one of the few real responses to the wise words of Francis in 1980 that fisheries science was '*reductionist*, *hierarchic*, *quantitative and homogenous*' and that this fact was sufficient explanation for '*our problems in coming to grips with environmental matters*, *exemplified by the failures of fishery science to date*'. He suggested that '*we might be better served to consider more primitive logical systems . . . holistic*, *non-hierarchical*, *qualitative and heterogenous*'. Francis concluded that all advances in fisheries science over the previous 20–30 years had occurred in the branches of the subject, rather than at its roots and I submit that not much changed in the subsequent 25 years: most of what is written today, even directly in response to the problems of global stock collapses, remains in the twigs of the tree.

It was perhaps the collapse of the northwest Atlantic cod stocks that finally convinced fisheries scientists that something was seriously amiss with their routine management models and spawned a feeding-frenzy of introspection, in which they were joined by economists, sociologists and others. The symposium held in 1996 at the UBC Fishery Center with its '*multidisciplinary themes*' and its '*fresh synthesis*' towards a '*new paradigm*' for fishery science is an excellent window into the tenor of these activities. At this symposium, and more recently, there is clear unanimity on one point: fisheries can be sustainable if the stocks are allowed to recover and if more sensitive management practices are put in place, involving all players—politicians, economists, scientists, fishermen at sea and fleet managers ashore: the idea of "*Reconstructing the past to salvage the future*" of Pitcher et al. (2001) has become a recurrent theme—and a thick primer for this difficult, or perhaps impossible, task is already available (Caddy and Agnew, 2004).

So, the cornucopism of the late 19th century remains alive and well, and we have not come so very far since a well-known fishery scientist commented at the Biology and the Future of Man conference in Paris in 1976 that "*We take only the interest on the natural capital. And it is a good interest*, *about 20% increase in fish weight each year: you don't make that everywhere!*" I was reminded of this comment when reading in a 2005 essay by Pauly that "*an emergent property of marine ecosystems*" was to "*produce a surplus that we can share*, *year for year*, *contingent on their continued existence as complex entities*". The critical point in that comment is the survival of complex ecological entities which must, surely, include a fish population structure sufficiently resembling the pristine state as to be viable? I shall return to this problem later.

Part of the fishery science community is at least starting to turn its attention towards ecosystem function. Perhaps because the Canadian federal fishery department initially blamed the collapse of the northern cod stocks on the unusually cold

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conditions that had prevailed for some years previously over the Grand Banks, and subsequently tried to blame the loss of more southerly stocks on predation by seals, it is just possible that their knee-jerk reactions helped to focus general attention on the idea of ecosystem-based fishery management (EBFM). The body of literature concerning this activity is now very large indeed, growing exponentially, and is building on the series of studies of large marine ecosystems (LMEs) initiated by Ken Sherman and others. Unfortunately, it has become – dare I say it? – somewhat surreal.

As has already been pointed out in these pages, concepts having succint, attractive titles like EBFM can mean almost anything (McIntyre, 2003). It has now become part of an expanding family of similar concepts with names that reflect public concern and agency image: integrated ocean management, environmental management system, ocean action plan and so on. Unfortunately, whether we like it or not, we have no option but to accept that EBFM is here to stay, because around the turn of the century it was incorporated into the dogma of several important national administrations. It has, consequently, become a source of rather detailed top–down instructions to working scientists in several national fisheries agencies.

The Founding Charter of EBFM may be said to be the 1996 Report to the US Congress of the Ecosystems Principles Advisory Board that was mandated by amendments to the Magnuson–Stevens Act. The principles expressed by the Board are unexceptional: (a) our predictive capacity for ecosystem behaviour is limited, (b) ecosystems have thresholds and limits which, when exceeded, can lead to irreversible change, (c) ecosystem components are linked and (d) ecosystems have open boundaries and change with time. A single goal is stated: to maintain ecosystem health and sustainability. Later, in 2001, NOAA issued technical guidance for the implementation of EBFM that specifies that to "*move beyond harvest-regulation management of single species*" must involve a "*three-dimensional approach*" because decisions are to include: (i) stakeholders, (ii) the health and vitality of ecosystems and (iii) "*the larger landscape*".

In Canada, the Oceans Act of 1997 entails obligations for ocean management: '*Fisheries are to be managed within the broader context of integrated ocean management of the aggregate ocean uses, ecosystem features are to be considered, and a precautionary approach applied*' (Sinclair et al., 1999). The Act then defines how management areas shall be established, and how conservation objectives shall be defined; since management objectives for the fisheries are also set by federal authorities this must leave very little flexibility for fishery scientists in confronting the fundamental problems that face them.

Following the 2002 Bergen Declaration, the Norwegian government became committed to an ecosystem approach in fishery management expressed in the Parliamentary White Paper '*Clean and Rich Sea*'. In the North Sea Ecosystem Plan, associated with the EU Common Fisheries Policy, the needs of '*stakeholders*' are prominent, but there is only a superficial recognition that fish are components of complex and varying ecosystems and an inadequate recognition of the primacy of natural constraints on resource extraction over economic considerations.

This adoption of an EBFM policy has resulted in a flood of interpretive publications from the staff of fisheries agencies who are tasked to implement the policy, replete with what Larkin (1996) called the "*quasi-religious language of a social crusade*".

A related growth-point in the fisheries literature concerns the definition and redefinition of '*sustainability*': it has become current coinage to associate fish, fishing industry, and consumers into a holistic and sustainable fishery system. Reference is also commonly made to the language of the international organisations: to manage the fishery in such a way as '*to sustain human needs into the future in a sustainable fashion*' (Caddy and Saijo, 2005). In what follows, I use the term in a very conservative sense, to refer to no more than the ability of a fishery to obtain a useful catch without depleting the target stock, a concept that nevertheless recognises natural variability in stock size, and hence in yields.

Despite such semantic side-issues, it is remarkable how confidently EBFM is being pursued, and how little response there is to the critical remarks that date back to the very emergence of the concept. Scholarly works that support the implementation of EBFM are now commonplace, although their purpose is often merely to clarify how it may be implemented. A typical response is to enquire how to incorporate EBFM within fisheries management plans and how to define Ocean Management Areas, or to formalise Ecosystem Objectives. Other studies are at least intended to move the process forward: a list of 64 time-series indices (1970–2005) has been developed for an Integrated Management Plan for the Scotia Shelf (Frank et al., 2005), although this list includes only three items that specify the population structure of any target species: '*length-at-age 6*' of haddock, pollack and cod. Others indices are the state of the North Atlantic Oscillation, the position of the shelf front, the CPR greenness factor and so on. Hall and Mainprize (2004) discuss how 20 reference points (or performance measures) proposed for EBFM shall be arranged to cover non-target species, yet these indicators again refer to no more than bulk properties of fish populations. Meanwhile, titles such as '*Operationalising an ecosystem conservation framework for the eastern Scotia Shelf*' emerge from the debate.

All this has diverted attention from what went wrong with fish stock management towards such projects as a high-resolution mapping of the sensitivity of the benthic habitat of the Scotia Shelf '*in a manner helpful to seabed managers and decision makers*' (Kostylev, 2005). Similarly, concern for the sustainability of '*holistic fishery systems*' by economists and sociologists has drawn attention away from the sustainability crisis in the only really critical element of such systems—the fish themselves, about which these people know very little.

For many, fisheries governance lies at the heart of implementing EBFM rather than the unpredictable behaviour of ecosystems; management scientists, economists and sociologists have all become involved in the task of redefining management of fish stocks. Although this influx has widened the discussion of EBFM to include such matters as the rights of stakeholders, it has not sharpened understanding of ecological realities. It is not surprising, then, that many studies of the feasibility of EBFM place more emphasis on the institutional challenges (e.g. Imperial,

1999) than on the scientific difficulty of the concept. A review of lessons learned from the Great Lakes (where the concept of EBFM first emerged) emphasised what were thought to be the essential principles of this activity: ‘*stakeholder involvement and satisfaction*, *top leader commitment*, *information network*, *strategic framework planning*, *progress indicators*, *and review and feedback*’.

But to return to the scientific aspects of EBFM. It is generally accepted that the essential tools will include the setting aside of marine protected areas (MPAs) as sanctuaries for portions of exploited stocks and, more importantly, the ability to model ecosystem behaviour so as to incorporate both external forcing (ocean processes and fishery stress) and internal reactions between fish species, their food and their predators, although it is still thought adequate to deal only in the bulk properties of both ecosystems (e.g. Christensen, 1998) and fish stocks (e.g. Link et al., 2002).

As for MPAs, the concept that was “*heralded as the saviour of global fisheries . . . seen as the solution to the perceived failures of current management methods*” is, for Kaiser (2005), no more than a red herring—at least for offshore fisheries. Although the concept of an MPA, to protect special habitat such as a unique reef, is clearly valid and is capable of functioning well, it does not translate satisfactorily to the scale of the habitat of the continental shelf species targetted by major fisheries. Apart from anything else, different species, having different and unique distributions, would require different and overlapping MPAs. Further, far from reducing effective effort, MPAs may simply displace effort to regions beyond those protected and so enhance stock depletion there.

The application of ecosystem modelling to EBFM is even chancier, although simple flow models such as ECOPATH are often quoted as having adequate potential. Those who believe that modelling of kind apparently required for EBFM is just around the corner should consult the work of the PARADIGM group of 21 biological oceanographers and state-of-the-art modellers who recently reviewed the field (Rothstein et al., 2006). On the one hand, even today, complexity must be reduced by recourse to functional groups of phytoplankton in order to capture any emergent behaviour of the system. Similarly, to represent herbivory adequately, rules must be established that govern the feeding behaviour of copepods down at least to generic level, and of filter-feeding thaliaceans, euphausiids, fish and others. Despite all this, fisheries interests appear to be confident that holistic ecosystem models will predict the behaviour of individual target fish species; of course, they are going to find that (like the Ross Sea model shown by the PARADIGM group) by far the largest part of the modelled energy flow goes to microbial respiration and detritus, which is more confidently modelled than the internal behaviour of the tiny fraction of total biomass represented by fish.

The gap between the reality of ecological processes and even the most sophisticated models of ecosystems is very wide and will remain so. One example of reality (among many that would come easily to mind to any pelagic ecologist) is the fact that fishery-induced modification of the age structure of fish stocks must have a knock-on effect down the food chain. It is known that the life history traits of copepods and cladocerans not only respond generally to the presence of predators, but respond characteristically to different predator types (Weber and Declerck, 1997). This occurs both as a phenotypical response and also a shift in genotype frequencies in freshwater plankton, and we must assume that similar changes occur, but have not yet been observed, in the marine plankton if the individual size, and therefore food requirements, of their fish predators is significantly modified by fishing. Such changes will be ultimately reflected in the production schedule of the phytoplankton, as it is in lakes, and must modify the basic productivity of the entire system.

In this context, fisheries science has always required a modification of the age structure of target fish stocks, because the key concept of fishing theory is that the growth rate of populations is density-dependent (Nikolskii, 1969) so that a reduction of pristine population biomass must induce the survivors to grow faster. The so-called ‘*surplus production*’ that may be taken from such populations, while maintaining their stock biomass, is central to the theory of fishery management.

That the truncation of the older year-classes of a stock may have consequences other than enhancing the population growth rates is apparently not of concern and it is universally accepted that a fishery may impose new values for each life history parameter: longevity, age at maturity, fecundity, etc. Some will go so far as to say that this is desirable, because likely to provoke genotypic change to ‘*enhance the productivity of the species*’ (Law, 2000) although, in a pristine population, these traits must be the expression of the genotype that evolved in response to the exigencies of a characteristic habitat: predation rate appropriate to each age group, food supply of each age group, probability of recruitment success, etc. The evolution of life history traits has, of course, been studied in many organisms from many habitats (Brommer, 2000), so that theoretical ecology can now describe how the characteristics of each organism respond to the requirements and resources of its habitat sufficiently well to ensure long-term survival there (Stearns, 1976, 1992).

Since we cannot believe that evolution of age of first maturity or of longevity in pristine populations is a matter of chance, should we not be concerned that fishing so consistently modifies these characteristics of each target stock, creating genetic novelties?

I submit that fishery science should be very concerned about this problem, because (as I have already discussed in these pages) if we believe anything from theoretical ecology, we must surely believe in the general relevance of Lotka’s observation that each population has a unique age structure, sex ratio and age-structured fecundity to which it will tend to return if these should be modified, as they are by fishing pressure: other age-specific life history traits (density and size of ova, consequent larval size and growth rate, seasonal spawning period, etc.) may be added to those evoked by Lotka (Chambers and Waiwood, 1996; Lawson and Rose, 2000).

Lotka was, of course, unaware of the possibility that genetic change could occur very rapidly and that a simple return to the *statu quo ante* might not be possible. He would not have expected that, during the collapse of Grand Banks cod populations, very high fishing mortality would provoke rapid evolutionary changes towards an earlier maturation age as well as spatial and sex-specific genetic variation (Olsen, 2004); indeed, fishery managers had been very reluctant to accept that this could occur until it was conclusively demonstrated in this very high-profile case (Hutchings, 2004). It had already been suggested by Witting (1997) that the genetic evolution of life history in populations of organisms like fish may be described by the game-theoretical concept of Evolutionary Stable Strategies (ESS). For a population perturbed from ESS to return to that state, it is necessary that a new perturbation should give selective advantage to mutations that carry the population back to its original state.

The expression of genetically controlled life history parameters in marine fish is complex, because individual stocks of each species display different genotypes; such population richness results from the colonisation of new areas of suitable habitat when these are created by the progressive shift of climate regimes at secular time scales (McQuinn, 1997). Reviewing these processes, Adams (1980) noted how natural selection operates at the level of life history pattern to maximise the numbers of surviving offspring of each species. To succeed, each stock that colonises new habitat must evolve a pattern of life history traits (age distribution, sex ratio and age-structured fecundity, for example) that maximises its fitness to all aspects of its new living space (Begg et al., 1999). Marine mammals cannot be excluded from the generalisation that fishing disturbs naturally evolved life history traits: part of the essential comportment of baleen whales that permits their occupation of their ecological niche is the establishment of social groups, within which complex interactions occur. These groups are deranged by industrial whaling, a fact ignored by whale stock analysts (Holt, 2006).

One of the most important factors to which each species in a natural ecosystem must respond is predation, so that the life history traits of each age group of each fish stock must be such as to enable it to accommodate to the characteristic rate of incursion of novel predators. Such events occur on the millennial scale in nature and, depending on the resilience of both the new predator and the ecosystem response, the invader is either successful or else fails to gain a permanent niche. The present evidence suggests that one new predator – the fisherman – has failed to gain a sustainable niche in any offshore ecosystem.

This is not surprising, because fishing mortality falls far beyond the limits to which target species have previously accommodated; recall that the rate of predation on large individuals of long-lived fish like cod may be very low indeed (ICES, 1997), and that these are among the individuals most exposed to novel predation by fisheries.

There are other reasons to be concerned about the artificial population age structure that is imposed by a fishery. In a pristine ecosystem, as each cohort ages and dwindles, changes occur in its reproductive physiology so that the survivors reproduce more efficiently. That large individuals produce larger numbers of eggs than small individuals is a trite observation, but the fact that relative fecundity – as ova produced per gram of body weight – increases progressively through life is not so well understood. Already in these pages, I have shown how a single cohort of cod under pristine conditions retains its group reproductive power during a period of 15 years or so—long enough to bridge gaps between years of adequate spawning conditions (Longhurst, 1999). Natural mortality and relative fecundity are allowed to vary appropriately—because the one thing we know for certain about these parameters is that they do not remain constant throughout life, even though this is what is usually assumed in age-structured VPA models. I have repeated this experiment with other species from warmer seas, and it works every time.

And older fish are also cleverer at reproducing than youngsters. The relatively small eggs of first spawning fish have low viability, but larvae resulting from the eggs of older fish are larger and survive better. There are many special cases illustrating the more effective reproduction of older fish, as in the case of Baltic cod: older females produce eggs having buoyancy characteristics different from those of younger females, so that they remain in suspension above the oxygen-deplete water masses of the deep basins rather than sinking and being asphyxiated (Vallin and Nissling, 2000). Finally, older females of many species produce batches of ova over a longer period each year, thus increasing the chances that one batch shall encounter the critical conditions for good recruitment (Trippell et al., 1997). "*Larger, older and repeat spawners make disproportionately larger contributions to production of viable eggs and larvae*" remarks the DFO Stock Status Report for 2003 for cod on the eastern Scotian shelf—so the phenomenon is accepted as real by at least some fish stock managers.

If, as occurs in most fishery regions, a majority of the species larger than, say, 20 cm when adult now exist as populations having a strongly modified age structure, the resultant ecosystem must be unnatural and we cannot assume any level of stability in its internal, between-species dynamics. We are like farmers, Larkin points out, except that the marine ecosystem cannot be managed in the same way as a farmer manages his fields: we cannot select the species mix that grows there, and we cannot manage the rate or distribution of fertilisers, which in the sea depend on the oceanographic processes that force the highly variable production of plankton and benthos.

For such reasons, we should be extremely wary of the concept of sustainability, however defined, that is part of the EBFM mantra. It is perhaps true that in certain restricted coastal fisheries, completely under the control of a cohesive social group (if any still exist), sustainability may be achieved. Perhaps some species, like tropical tuna, with exceptional life histories may last longer than the remainder. Nevertheless, we should be very suspicious of claims that all we have to do is to reduce effort and place large parts of the target species range under total protection.

Such statements are often supported by reference to the >400 years of apparently sustainable cod and other fisheries in the NW Atlantic prior to the advent of powered boats, although this suggestion ignores one very important fact.

The newly arrived European fishermen in the late 1400s were amazed at the wealth of the resources they found; they compared them favourably with the residual resources on the European shelves that have very similar dimension and relative productivity—as we now know from satellite studies of ocean phytoplankton. One must conclude, therefore, that artisanal fishing had already, during the mediaeval period, heavily changed the pristine ecosystem off northwest Europe, severely reducing the available fish stocks. Considering the extent of the destruction of coastal ecosystems even in the prehistorical period (Jackson et al., 2001) this conclusion should not surprise us, although it is necessary to be careful not to attribute long-term natural changes in abundance to the effects of fishing.

The case for the sustainability of the NW Atlantic during the period 1500–1900 may also be overstated, for body length of cod had already started to decline in the coastal populations in the Gulf of Maine during the period of early settlement, and useful species of marine mammals were rapidly destroyed, so that walrus were exterminated along the entire coast from New England to Newfoundland quite early on. Inshore fisheries progressively moved northwards, as the potential of the New England shelf became exhausted, rapidly to reach the Labrador shelf. Early in the 19th century, a halibut fishery was established off New England and Nova Scotia using sailing schooners and dories rowed by hand, not very different from the techniques of 400 years earlier, but "*by 1850, only offshore populations remained, and by 1890, demand was being filled almost entirely by fish from Iceland*" (Pauly and Maclean, 2003). As in the North Sea, already in 1862–1863 a committees of enquiry was established to investigate the reasons for falling yields, in this case of cod off New England and Nova Scotia. Although the overall regional yield of cod stocks remained remarkably stable for almost a century, this statistic conceals the progressive concentration on new grounds.

So much for the myth that unsustainability is a modern, diesel trawler-driven phenomenon! In reality, the entire history of fisheries has been one of depletion and moving on, and sustainability is mythic, despite claims to the contrary by those who have special interests in sustaining the myth.

For all these reasons, I have grave doubts that the future holds great promise for our industrial fisheries. The most serious threat to a rational evaluation of how best to react to the present situation is perhaps the centrist policy of fisheries agencies, designed to implement measures that respond more to agency image and political comfort than to the reality of the fishery crisis. This emphasis diverts attention from the simple and critical fact that any fishery, no matter how prosecuted, may be expected to truncate the age structure of the target stock: fishing always has had, and always will have, this effect.

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So fishery science seems once again to be headed off in a wrong direction. Those who laid the foundations of fish stock management in mid-20th century, like Plato's prisoners in their cave, mistook the shadows on the wall in front of them for the reality that lay behind their heads: in their case, it was the chains of mathematics that prevented them from turning round to see reality.

Today, it is social rectitude that binds fisheries scientists from seeing the reality of ecological commonsense. Instead of fine words, what is required now is a very critical examination of the relationship between fishing and the internal dynamics of marine ecosystems. Courage will then be required to admit that predictable and sustainable catches at levels approaching those that we enjoyed in mid-20th century are simply not attainable by conventional fish stock modelling, by ecosystem-based fishery management or by any other novel means. Only if that can be accomplished can we begin to plan commonsense measures for our extended use of offshore marine resources.

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