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Assessment Methodologies and Fisheries Management: How to Keep Making Sense[1]

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Introduction: The First 100 Years

The onset of fisheries science as a field of its own began, in the second half of the last century, in various areas of the North Atlantic, when fishers asked naturalists to identify the cause(s) of the reduction of their catch rates (Smith 1988).

This led in the North Sea, via the founding in 1902 of the International Council for the Exploration of the Sea (ICES), to a flurry of activities, ranging from studying fisheries catches to releasing fish larvae into the ocean to enhance recruitment, and from mapping the distribution of fish eggs to precise salinity measurements (Went 1972). Similar activities, all initiated to help the fisheries, occurred in North America.

In the process, the specific question of the fishing industry (why does the catch per effort of specific fleets decline?) was recast as a more general "recruitment problem" (i.e., "why do fish populations fluctuate?") whose solution became closely linked with understanding the factors influencing the survival of fish larvae (Hjort 1926).

However, the first operational success of fisheries science occurred when H.R. Hulme, R.J. Beverton, and S.J. Holt, unknowingly following up on similar, earlier work of F.I. Baranov, identified an approach for managing fisheries—and for dealing with diminishing catches rates—which largely avoided the recruitment problem (Hulme et al. 1947; Beverton and Holt 1957). Rather, "yield-per-recruit analysis," as their method became known, offered an approach for making rational decisions even in the complete absence of information as to why fish populations fluctuate (Figure 1).

The surplus production models, based on the work of M.B. Schaefer which also emerged in the 1950s, also shied away from the stock fluctuation problem, and maybe because of this could provide some guidance for managing fisheries (Figure 2).

Numerous scientists still work on yield-per-recruit and surplus production models, and their variants and hybrids have enabled their use even in areas where application of the original versions was problematic (Anonymous 1992a, and see Figure 3).

Successful and Less Successful Research Programs

Since the major conceptual breakthroughs alluded to above, the publications of fisheries scientists can effectively be split into two sets, i.e., those consciously written

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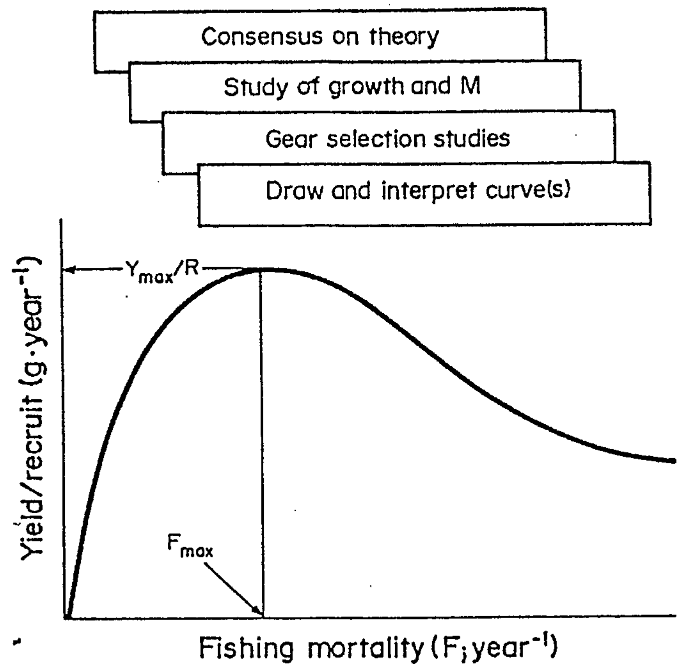

FIGURE 1.—A graph that "makes sense" if the client is the manager of a fishery.

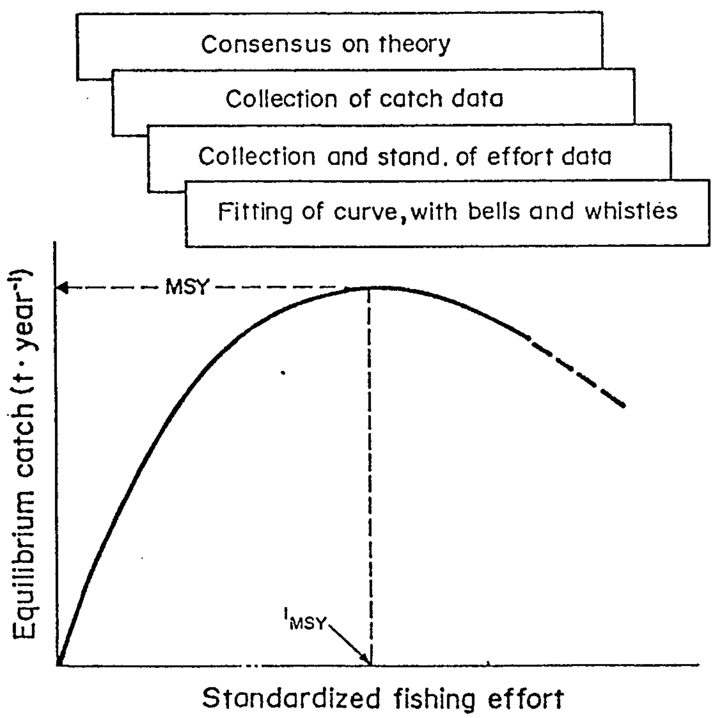

FIGURE 2.—Another graph that "makes sense" if the client is a fishery manager.

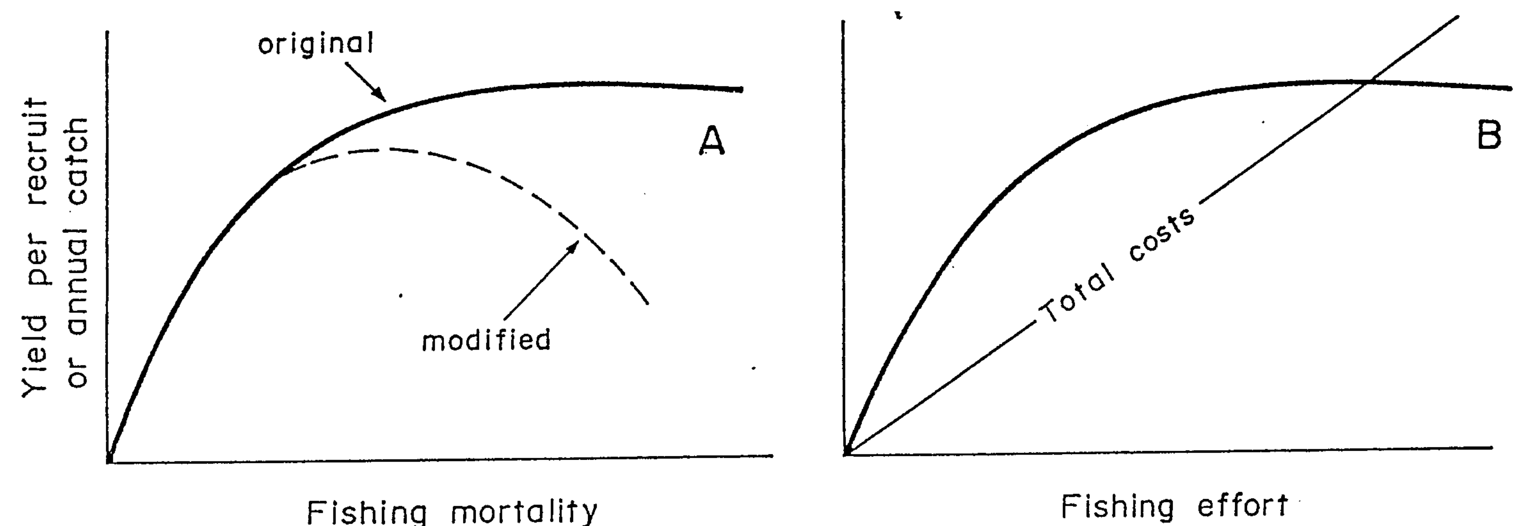

FIGURE 3.—Showing how flat-topped yield curves, originally providing little guidance as to the location of an optimum, can be made easier to interpret (in A) by replacing the knife-edge assumption with a proper selection curve, leading to a modified curve or by introducing a higher price for large fish, leading to the same type of modified curve, or (in B) by adding cost of fishing, which leads to a net revenue curve with a well-defined maximum ("Maximum Economic Yield").

to support fisheries management, which generally relied on fishery-derived data [especially catch-at-age or catch-at-length data used for Virtual Population Analysis (VPA) or catch-and-effort data, used for production models], and those dealing with the "recruitment problem." The latter can be further separated into two subsets:

(i) those still dealing with the cause of mortality of early life-history stages (eggs, larvae, postlarvae); and
(ii) those dealing with the biology of juveniles and young adults.

It does seem that the research in (i)—except perhaps for the comparative approach of A. Bakun and coworkers (see Bakun 1985)—may be dealing with an intractable problem—at least the symptoms are there:

(a) the pioneering research in this field continues to be heavily debated, rather than absorbed into a body of consensual knowledge (Garfield 1975);
(b) the spatial and temporal scales required for samples that can be used to test current hypotheses are getting smaller and smaller [e.g., centimeter-thin, food rich microlayers lasting a few days to address Lasker's (1978) hypothesis, individual larvae to test starvation hypotheses using RNA/DNA ratios, etc.].

Given what is now known about the chaotic behavior of natural systems, item (b) is serious indeed, as it implies that (large-scale) prediction of recruitment would be in principle impossible from even an enormous number of synoptic observations at the smaller scales. This naturally also implies that classical stock–recruitment relationships will continue to be a test of one's faith (Figure 4).

On the other hand, the area of emphasis in (ii) obviously has components of direct relevance to fisheries management, e.g., via studies of migrations or of schooling

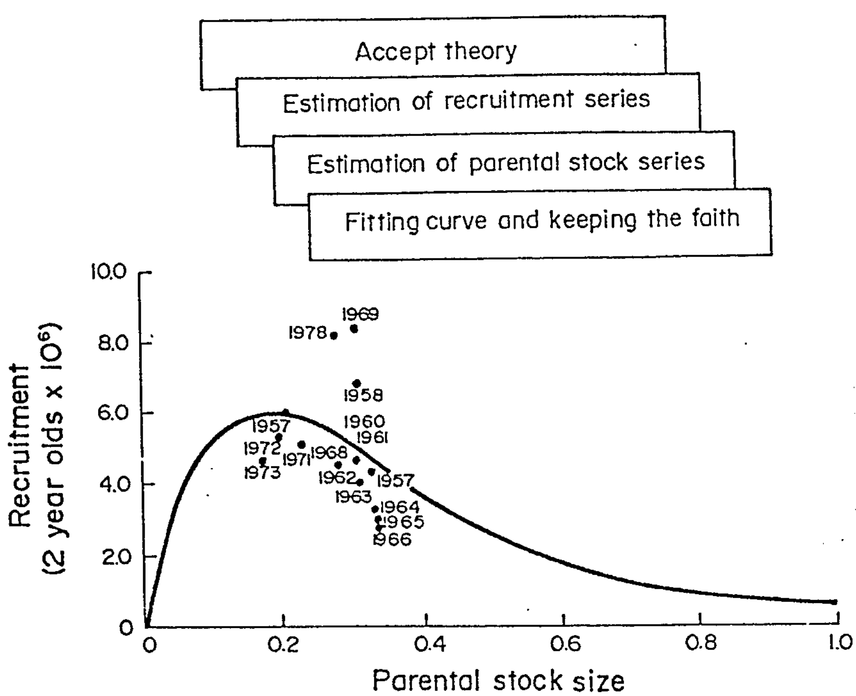

FIGURE 4.—A graph which may or may not "make sense", depending on the intensity of one's belief in stock–recruitment relationships (from Murphy 1982).

behavior. However, it is through the study of predation that this area of emphasis has again become part of management-oriented fishery research.

Meaning, Sense and Value in Fisheries Science

As masterfully argued by T. Kuhn (1962), a scientific discipline is more than a set of methods used by a defined group of practitioners; rather, the paradigm of a discipline also provides meaning, by defining which questions are worthwhile, and which answers are acceptable, i.e., "make sense."

Fisheries science, for example, defines as meaningful the counting of rings on the otoliths of fish and their seasonal shifts, because this is used to estimate growth, which is required for yield-per-recruit and other analyses. On the other hand, fisheries science does not give any meaning to e.g., testing whether there are seasonal differences in the tendency of hagfishes to knot their slimy bodies (Figure 5). Thus, any graduate in fishery biology asking for funds to study hagfish knotting would be considered not only to be planning to waste money, but also to be challenging a system of values—a fatal flaw!

Linking predation with classical Beverton and Holt type dynamics enabled turning the suspiciously constant parameter M into a dynamic quantity, varying with the biomass (Munro and Thompson 1973), and the size preferences of a species' predator(s) (Ursin 1973). This work, which culminated in the 1980s in the multispecies VPA model (MSVPA) of the ICES Multispecies Working Group, is certainly one of the most fascinating achievements of fisheries science—matching in scope the achievements of W.E. Ricker, R.J. Beverton, S.J. Holt and M.B. Schaefer a generation earlier.

However, it is my contention that MSVPA quite unwittingly destroyed the system of sense-giving values upon which fishery biology and fishery management

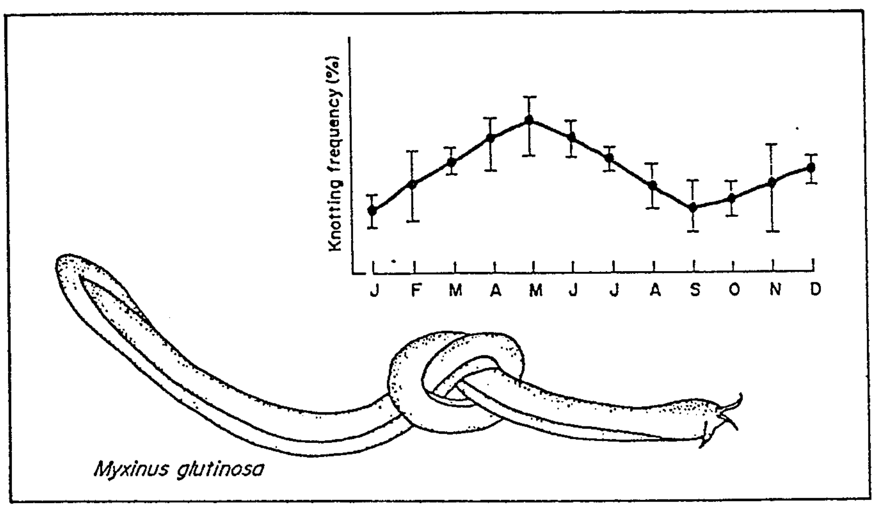

FIGURE 5.—An (imaginary) representation of seasonal changes in the knotting behavior of hagfish, with results that make scientific sense, but which are not assimilable into fisheries science.

have been based since at least the mid-1950s, when the paradigm of fishery biology emerged, and which Holt (1960) magnificently summarized: "I believe the fundamental premises of the theory of fishing are that fish breed, grow, and die, and measurements of the rates of these processes or the relations between those rates, either direct or indirect through their common relation with such quantities as population density, food abundance, and measures of other environmental factors, can be used to compute the changes in characteristics of catch which would be expected to result from changes in fishing practices. I do not believe the time is ripe to abandon these premises. Our methods of estimating parameters, of making predictions, and particularly of testing and verifying or rejecting predictions, are, however, still inadequate to the demands now being made for advice on scientific conservation measures." Note, incidentally, the form chosen for this, reminiscent of other well-known value-laden statements such as "We Hold These Truths To Be Self-Evident That All Men" ... etc.

There have been many critiques of this credo, which have often been described as suitable only for engineers (see e.g., Bradbury and Reichelt 1981). Most of these critiques refer to the fact that the growth, mortality, and especially recruitment rates are assumed to be more or less constant in yield-per-recruit and related models but do in fact vary in time and space. Often the variability has been shown to be a response to environmental variability, as known since Johan Hjort, and restated—now with chaos and fractals thrown in—at every recent meeting on the "recruitment problem."

But this is not our concern here. Rather, it is the fact that fishery management advice based on analysis of one given single species ceases to make sense (even when natural variability can be neglected) when several species which feed on each other are considered simultaneously—a special case of the more general problem of tradeoffs in multi-objective situations (Mendelssohn 1980).

Multispecies Interactions and Some Consequences

Let's look at North Sea cod: fisheries biologists have studied its growth and mortality for decades, as well as the catches of its fishery. Armed since the late 1950s with the Y/R model of Beverton and Holt (and later with its more powerful derivatives, such as VPA), they have concluded that the North Sea cod fisheries would immensely benefit, in terms of higher catches and much reduced costs, if the mesh sizes used to catch cod were larger. Young cod wouldn't be caught, would instead keep growing and be caught at large "optimal" sizes. This was good applied science and it made sense, and in the last decades, fishers were gradually turned around. Or let's look at herring, also in the North Sea: fisheries biologists, in the late 1970s, had concluded that the stock was being severely overfished and that a closure of the fishery would help boost recruitment. The North Sea stock was thus protected for several years and it gradually recovered, its recovery again attesting that management-oriented fishery biology makes sense.

Given such successes, how could fisheries scientists be held back, and not look, e.g., at what cod do to herring? or herring to cod eggs? or cod to codlings? This was done by Daan (1975), Andersen and Ursin (1977) and many others, and the main result is that at least as far as the North Sea is concerned, we do know that one can catch lots of cod, or lots of herring, but not lots of both (Figure 6).

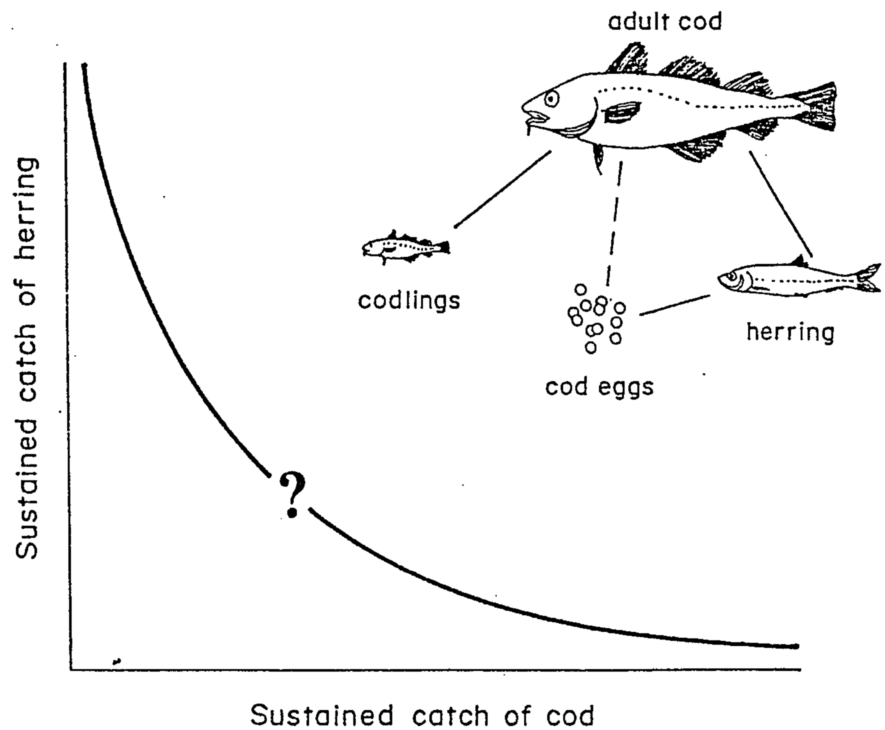

FIGURE 6.—Schematic representation of interactions between cod (*Gadus morhua*) and herring (*Clupea harengus*) in the North Sea, illustrating the lack of an optimum level of effort on either cod or herring, due to their biological interactions.

These considerations obviously do not apply only to cod or herring, or to North Sea fishes—similar results were reported from the North Pacific, where large sea mammals consume huge quantities of commercial fishes (Figure 7), or indeed from any multispecies system exhibiting replacement, e.g., of K- by r-selected species (Figure 8).

Thus, one can generalize: given sufficient field data and a large computer, it is possible to account, when doing stock assessments, not only for the effect of fishing, but also for the direct and indirect effects of predation, i.e., the consumption of fishes and invertebrates by various predators such as fishes or sea mammals acting as competitors to humans (see contributions in Daan and Sissenwine 1991).

The Multispecies Symposium organized by N. Daan and M. Sissenwine on behalf of ICES in the Hague in October 1989 was meant to review the impressive recent work in this field; it was a great scientific success in that most contributions confirmed that yes, multispecies fish resources and their interaction can be modelled, and coherent and relatively precise predictions made. The problem is that these results cannot be used to guide fisheries management—or at least not straightforwardly so, because they do not provide any MSY, of F_{max}, but rather offer a range of options as a basis for societal choices, e.g., between fishers aiming at cod or herring.

Only one symposium participant made this problem explicit—a former biologist, then administrator in the great European bureaucracy in Brussels. Thus, in his

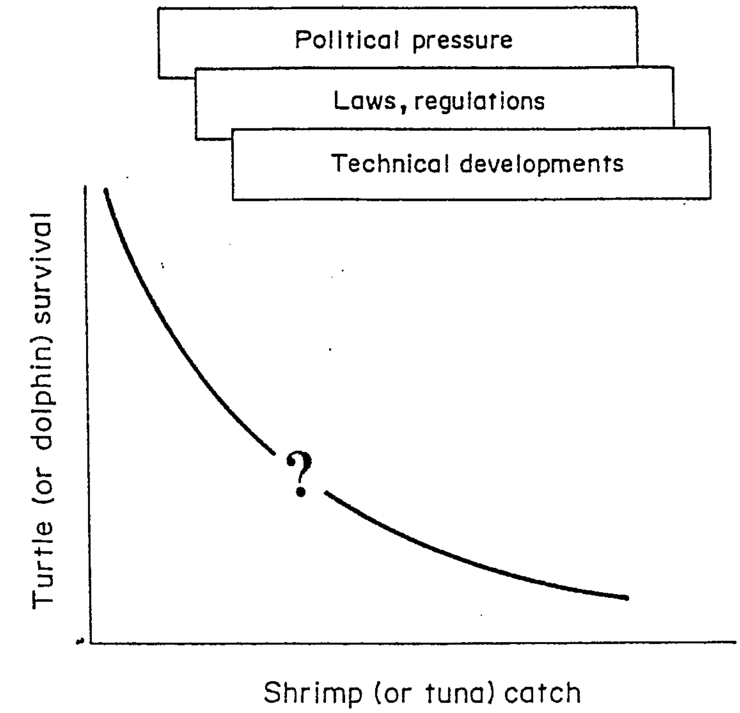

FIGURE 7.—Schematic illustration of two examples of the problems which fisheries scientists must address, when conservation issues are added to the usual task of optimizing fisheries—see Caillouet (1991) for shrimps and Ambrose (1992) for tuna.

presentation, he, in front of the outraged scientists said something like "how can I stand in front of British cod fishers and after 30 years of telling them to increase their mesh size, tell them that they now must *reduce* it, because your silly model says this would be good for herring? What was right then can't be wrong now, can it?"

Conclusion: The Need for a New Covenant

While this went on inside, another encounter was taking place just outside the meeting room: the regional representative of a conservationist group was denied entry, after he had formally applied a permission to join the meeting (the representative of that same organization from an important ICES member state had earlier walked in; she had assumed, quite correctly that she wouldn't be denied entry if she did not ask for it). Yet whether the conservationists were inside or outside that room, what matters is that they are now firmly in the picture, as is argued further below.

Given our awareness of strong predatory interactions between stocks of different species, and the competing but largely irreconcilable claims of different groups of fishers on different parts of the multispecies complex, meeting the need of "fishers" has become impossible without some mediation from outside the fishery sector. The price for this mediation is, however, that claims to the fisheries resources

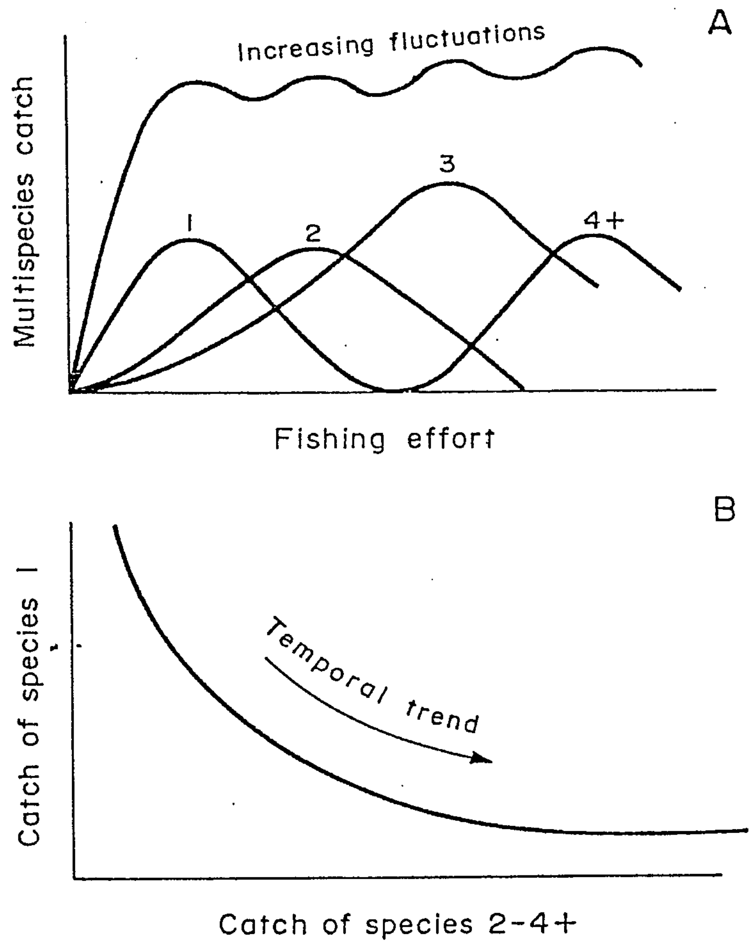

FIGURE 8.—Showing how the conventional view of how a multispecies resource is fished, i.e., through successive overexploitation of species along a gradient of preference and/or availability (1, 2 . . . etc., in A), can be reinterpreted as a choice between relatively large catches of the preferred species (1) *or* of species 1, 2 . . . etc. (in B).

from groups other than fishers will have to be accommodated as well. Furthermore, because it has become obvious that humans are now changing the global climate (Schneider and Londer 1984) and directly or indirectly, the composition of the entire biosphere (McKibben 1989), it has become rather untenable to view aquatic ecosystems solely as sources of income for the fishing industry.

Thus, at least in Western Europe and North America, a large segment of the voting public, perhaps even a majority, objects to the killing of sea mammals whether direct (as whaling) or indirect (through tuna purse seiners). Moreover, there is substantial pressure—and legislation in some countries—to maintain substantial populations of prey species for these sea mammals; the estimation of the required biomasses has indeed become a new task for fishery scientists.

Altogether, there is a questioning of the wisdom of the relationship between scientists and society—hence the need for a new "covenant" *sensu* Roy et al. (1991).

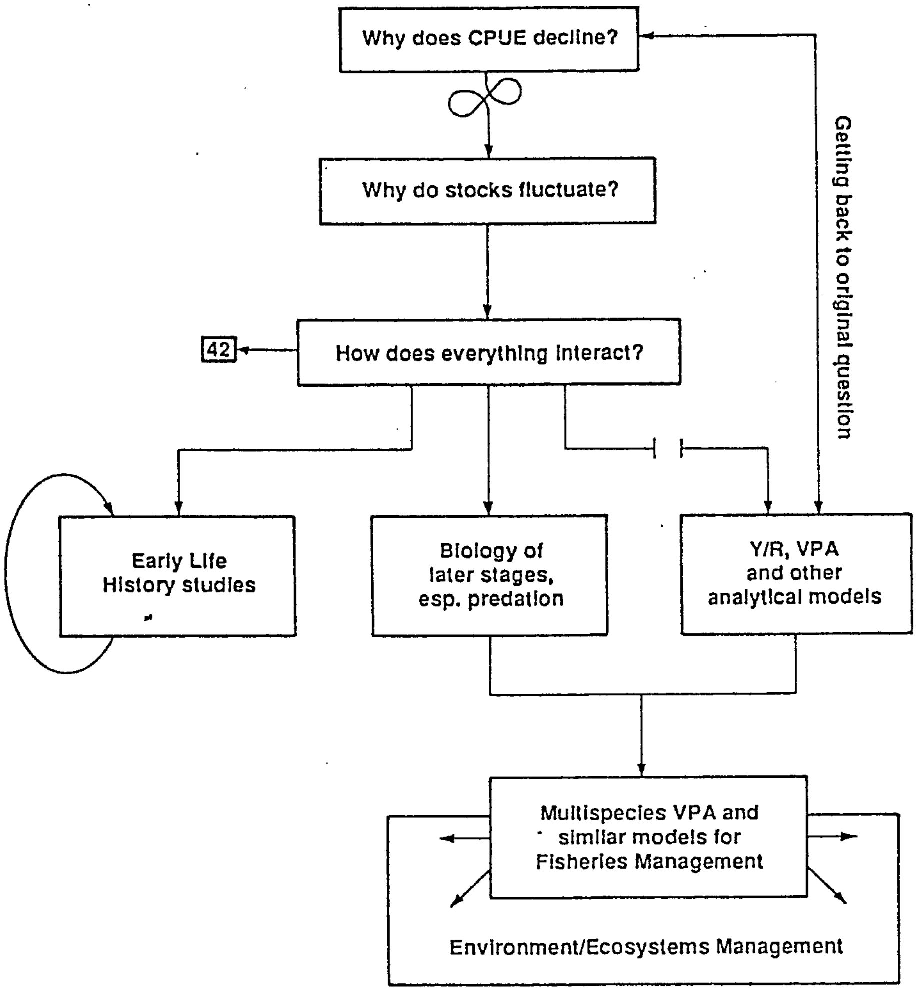

FIGURE 9.—Schematic representation of major trends in fisheries science, suggesting that it leads beyond fishery management, toward environmental/ecosystem management—if it leads anywhere.

Figure 9 recalls the case made so far, i.e.,

- that there is a line of research within fisheries science which, by combining the analytical methods of fish population dynamics and predation studies, has led through MSVPA to coherent descriptions of the impacts of different fleets on a multispecies complex;
- that the type of results generated by MSVPA do not straightforwardly lead to management advice for a given fleet or segment of the fishery industry;
- that MSVPA can contribute to resource system or ecosystem management to a much larger extent than the earlier stock assessment methods;
- that the clients and beneficiaries of fisheries scientists involved in multispecies modelling (MSVPA and others) need not only be fisheries managers, representing

the fishing industry, but "environmental managers" acting on behalf of beneficiaries such as the public at large (perhaps represented by environmental groups), and "future generations" to the extent that conservation of various species is involved.

Interestingly, even ICES has come to similar conclusions as documented in one of its recent Newsletters in which a "greening" of ICES is advocated, to compensate for the fact that "ICES has been primarily a fisheries-centered organization. Most of the participants in its various policy-making bodies, and contacts with other institutions are so-called 'fisheries' people. With the great change in marine perspective, many think this situation should be examined." and that "the continued absence from the ICES hierarchy of key administrators and scientists from non-fisheries ministries and institutes ... will lead to difficulties in fulfilling commitments on the environmental side ..." (Anonymous 1992b).

So we are getting there ...

Acknowledgements

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