Summing Up – Symposium on Reproductive and Recruitment Processes of Exploited Marine Fish Stocks

Keith Brander
Danish Institute for Fisheries Research, Technical University of Denmark,
Charlottenlund Castle, DK-2920 Charlottenlund, Denmark

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It is not possible to do justice to a Symposium with over 50 papers and nearly 100 posters in a short summing up, but the sheer numbers tell their own story about the vitality of this area of science and level of interest which the topic generated. My impressions are of course coloured by personal interests and my choice of papers for comment is in no way intended to reflect on the quality of other papers. In fact my only comment on the general excellence of the oral presentations and the posters is that they contained too much information. With posters in particular, many authors try to write a paper on a board, instead of showcasing the main findings and tempting the chattering crowds to find out more, as they mingle past at the end of a long day.

The task of summing up was made much easier by the wonderful introductory talk by Ed Houde, which set the scene, both historically and in terms of scientific development, as he reminded us of Johann Hjort's seminal publications on the causes of recruitment variability. Hjort's "critical period" hypothesis provided the framework for research programmes on egg and larval survival throughout the 20th century, but Ed noted that "… single-minded research on the Critical Period hypothesis gave way to realization that recruitment variability was the outcome of complex trophodynamic and physical processes acting over many temporal and spatial scales and throughout pre-recruit life". It is only in the last two decades that the scope of research has widened to look at other periods in the life history, when compensatory processes may also be occurring, notably those governing maturation, fecundity and spawning. I have structured my summary around this and other perceptive insights from Ed's talk.

Variability in recruitment results in variability in catch from year-to-year, which is a problem for fishermen, for the processing industry and for fisheries managers. It is commonplace to read how large the interannual variability in recruitment can be and how difficult it is to determine the causes. However for an ecologist, the astonishing feature of recruitment variability is how small it is, given that fish produce thousands or millions of eggs each and that survival is extremely unlikely and uncertain. Among the pelagic and demersal stocks assessed in the NE Atlantic the smallest year-class is generally within a factor of 10 of the biggest. It is not infrequent for interannual recruitment variability to be less than the variability of the spawning biomass of the stock (Brander, 2003). How is the variability damped out? What are the compensatory mechanisms? Density dependence is necessary for populations to remain within feasible bounds (Reddingius, 1971) but as Ed told us "A little density dependence, especially in the relatively long juvenile stage, can regulate recruitment". Density dependence should not be invoked without good evidence in relation to processes like adult growth, however appealing it is to biologists or convenient for modellers trying to keep their models stable.

Fisheries assessment and management, at least in the North Atlantic, has focussed on year-to-year tracking of stock biomass in order to set annual catch limits. Questions about the role of recruitment were therefore also principally directed at annual prediction and the understanding of processes needed in order to do this. The biological book-keeping was done using sequential population analysis which gives estimates of both annual recruitment and spawning stock biomass (SSB). The latter is assumed to represent spawning output of the stock, but as many of the papers in this symposium show, fecundity, maturity, spawning frequency and egg quality, are not constant. The relevance of the symposium is therefore obvious, since strategies for sustainable management, using precautionary reference levels of SSB and fishing mortality, are based on the relationship between SSB and recruitment. We need to move on to a longer term view which includes a wider range of information about the biological state of fish, their environment and their interaction with the rest of the marine ecosystem. Ed once more: "'Solving the recruitment problem' is no longer the holy grail of fishery science. Appreciating recruitment variability, explaining probable causes, considering implications for management, and understanding it in the context of broader variability in marine ecosystems are worthy goals."

How can we use the kinds of new knowledge presented in this symposium to improve our management of fisheries and marine ecosystems? I have borrowed the symposium logo (Fig. 1) to represent a stock-recruit relationship and to suggest three headings under which many of the symposium contributions can be grouped:

1. Contributions which improve the dependent variable, which is the SSB in most stock-recruit relationships (Table 1). SSB is supposed to represent the annual reproductive output (*i.e.* number of viable eggs which are released), but many of the contributions showed that it can be greatly improved.
2. Contributions which show effects of environmental and biological factors on survival from viable egg to recruitment (Table 2). Potentially valuable information is lost if annual variability in survival is treated purely as noise. Environmental and biological factors can be included, when they are well established by field and experimental studies. This will be particularly valuable in relation to medium and long-term management strategies when we expect trends in the systematic effects (*e.g.* due to climate change).
3. Contributions which reconsider the form, credibility and fit of the functions which are used to represent the relationships between spawners and recruits and the management implications of different models (Table 3).

Will the contributions to this Symposium help to improve our management of fisheries for sustainable yields and "ecosystem health"? The answer has to be a tentative "yes, but…"; acknowledging that successful management requires more than science and that effective action to limit fishing mortality and maintain stock biomass must be based on acceptable, well designed instruments. One of the excuses which is used to delay the implementation of actions to limit fishing is that the science is uncertain. Scientists may unwittingly encourage such procrastination, by statements such as: "To achieve sustainable management of the ecological resources of the oceans it is a fundamental requirement to be able to both understand and predict the behaviour of the marine ecosystem". We cannot delay action until we can "both understand and predict the behaviour of marine ecosystems". A different view of the control of complex, poorly understood systems is that "We do not need to understand the things we cannot control. We do not need to understand precisely the things we can control".

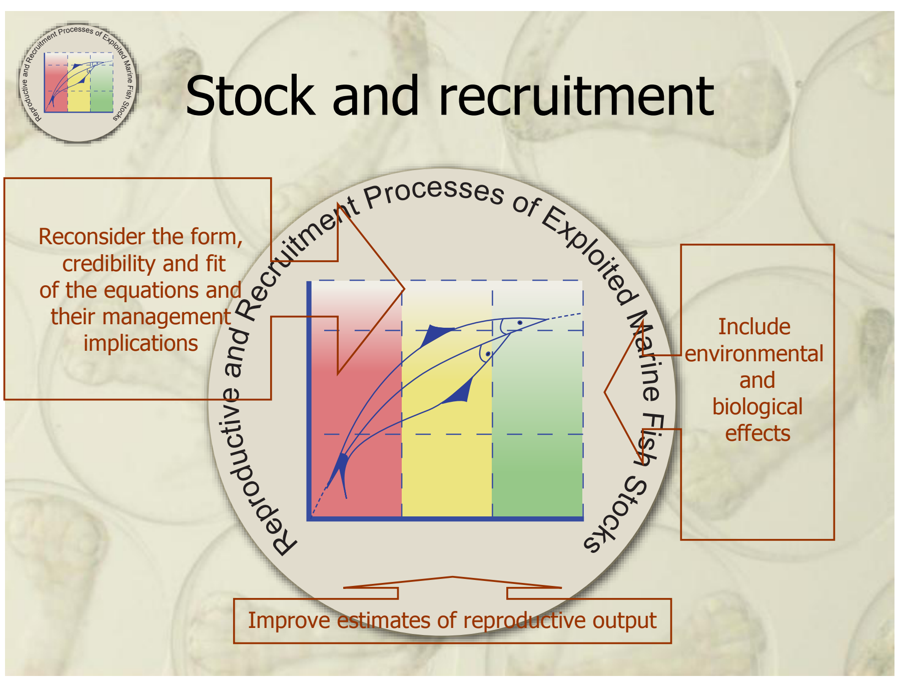

Fig. 1. The logo for the Symposium represents a general stock-recruit relationship on which three block arrows have been superimposed, to represent ways in which contributions to the Symposium may be used to improve such relationships.

The precautionary approach, which is now enshrined in declarations and frameworks for sustainable management, requires action while our ability to "understand and predict" is being improved. The balance of proof argument has shifted, but we have not yet worked through the methods and consequences of incorporating new knowledge such as this Symposium provides. I suggest that three criteria should be satisfied in cases where it is proposed that new information be applied (*e.g*. a method for improved estimation of annual reproductive output):

1. The effect of adding new information should be significant.
2. The processes (*e.g*. change in age/size of maturity) should be reasonably well understood in order to enhance credibility and as a basis for prediction.
3. New information must be available on time and at acceptable cost.

I want to go on to consider some of the scientific issues which this Symposium raised concerning changes in maturity and the trends and causes. This is an active and interesting area of debate, which has quite profound consequences for monitoring, modelling and management. Changes in age and size at maturity (generally decreasing) were observed in a number of studies and were in some cases attributed to fisheries-induced evolution (FIE)(Table 4). Some of the views expressed in Symposium abstracts were:

> "a long-term trend towards earlier maturation has frequently been observed in exploited fish stocks. ...resiliency to high rates of fishing mortality is partly due to earlier maturation leading to higher values of cohort-specific r. This conclusion runs counter to the widely held view that earlier maturation has deleterious effects on stock dynamics." Marshall, T. (1–1)
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> "A decreasing trend in age and size at maturity in Flemish Cap cod has been well documented..." Saborido-Rey, F.R. *et al.* (1–3)
>
> "conclusive evidence for evolutionary changes can never be obtain through probabilistic maturation reaction norms (PMRN), but both the magnitude of changes and their uniform direction strongly suggest that fisheries-induced evolution is widespread..." Heino, M. (1–4)
>
> "these changes (in FIE) alter the reproductive and recruitment processes of stocks, diminish the quality and quantity of fishery yields, and take substantial time to reverse - if such reversal is feasible at all... " Dunlop, E.S. *et al.* (1–7)

It is difficult to see how the extra, selective mortality which fishing is imposing can avoid causing some adaptive change, but the speed and even direction of change is difficult to measure and to separate from other factors. These are current areas of disagreement and controversy, but the wealth of new information which is being published should help to resolve the issues. The questions to be asked include:

Are the claims concerning rapid adaptive change justified?
- Are other explanations possible (geographic variability, bioenergetic changes, growth during early life)?
- Is there evidence of rapid reversal of trends in maturation?

What are the consequences of change in age and size at maturity?
- Increase in resilience?
- Decrease in quantity and quality of yield?
- What is the utility (desirable/undesirable)?

Let me end with a plea for improved routine monitoring of the biological characteristics of reproduction and recruitment, which have been the subject of this Symposium (fecundity, maturity, condition, *etc*.). It may be that in following Hjort and focussing our scientific attention on the "critical period" in early life, we neglected the study and routine monitoring of other parts of the reproductive cycle of commercial fish species. This tendency is perhaps reinforced by the use of yield models, which consigned reproduction and recruitment to one or two rudimentary stock-recruit relationships. ("Historical fishery models have sometimes restricted data acquisition to the requirements for a particular mode of book-keeping"). The time has come to implement the collection and application of a richer suite of biological and environmental information in managing marine ecosystems and fisheries.

TABLE 1. Symposium contributions which can help to improve estimates of reproductive output.

What did we learn?	Who from? (oral/poster number)
Critical time window in early vitellogenesis for skipped spawning. HSI <4% makes skipped spawning more likely.	Skjæraasen, J.E. *et al.* (2–7)
NSS herring don't skip as expected.	Kennedy, J. *et al.* (2–6)
Large females produce large eggs with high survival	Venturelli, P.A. *et al.* (2–12)
Age structure is an important variable in reproductive performance	Parker, S.J. *et al.* (2–13)
Lethal malformations due to age/stage of spawning females	Korsbrekke, K. *et al.* (4–4)
Effects of spawner age on larval viability and management consequences of mis-specified reference points	Spencer, P.D. and Lucero, Y. (4–7)

TABLE 2. Symposium contributions which show environmental and biological effects.

What did we learn?	Who from?
Spawning biomass of Baltic is the most important (but not only) factor in explaining recruitment	Cardinale, M. *et al.* (3–8)
Environmental effects on E. Baltic cod recruitment and consequences	Köster, F. *et al.* (4–2)
Anchovy egg production related to plankton production in California, Humboldt, Benguela, Bay of Biscay and Mediterranean	Somarakis, S. *et al.* (4–8)
Life history models can be used to explore environmental effects	O'Brien, L. *et al.* (4–10)
NAO effects on NW African hake recruitment	Meiners, C. *et al.* (P4–8)

TABLE 3. Symposium contributions which explore models and management implications.

What did we learn?	Who from?
Reproductive biology, productivity, resilience and management advice	Morgan, M.J. (4–1)
Need to revise reference points when environment affects productivity	Köster, F. *et al.* (4–2)
Carrying capacity, productivity and robust management	Simmonds, J. *et al.* (4–9)
Process- observation- and model –uncertainty; effects on risk of falling below reference points	Myrseth, J. *et al.* (4–11)

TABLE 4. Evidence both for and against fisheries-induced evolution as the cause of observed change in size and age of maturation was presented.

What did we learn?	Who from?
Using energy allocation and individual growth trajectories to study FIE. Evidence of time trends, possibly due to energy intake	Mollet, F.M. *et al.* (1–2)
Accounting for other factors in PMRN *e.g.* bioenergetic condition. Rate of change (11 000 darwins) same for length or liver condition.	MacAdam, B.J. and Marshall, C.T. (1–5)
Growth during the early life may explain variation in PMRN. Change in PMRN could not be related to fishing mortality for the cod stock in the Kattegat	Svedäng, H. *et al.* (1–6)

References

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