DFO Atlantic Fisheries
Research Document 96/07

MPO Pêches de l'Atlantique
Document de recherche 96/07

Incorporating Ecosystem Information into the Fisheries Assessment Process: Can We Develop a Quantitative "Plankton Index"?

by

W. G. Harrison and D. D. Sameoto

Department of Fisheries and Oceans, Maritime Region
Ocean Sciences Branch, Bedford Institute of Oceanography
Box, 1006, Dartmouth, N.S. B2Y 4A2

Abstract

The incorporation of environmental data into the fisheries assessment process is now a priority within DFO. During the 1995 FOC meeting, plankton (both phytoplankton and zooplankton) data was added to the list of environmental properties for consideration. At that meeting, we identified both archived (e.g. CPR) and future (e.g. satellite ocean colour data) data sources that would be useful. The next step (and the subject of this paper) is to begin to explore more specifically if and how we can incorporate this information into the assessment process.

Our approach is to identify and exploit properties of the plankton which, based on established ecosystem principles, are most likely to reveal cause-effect relationships between prey (plankton) and predator (fish larvae). Our first cut at this is based on Cushing's "Match-mismatch Hypothesis" in which the timing, magnitude and duration of the phytoplankton seasonal cycle influences the survival of fish larvae and, in turn, recruitment and stock variability.

We have "parameterized" the phytoplankton growth cycles using two gaussian distributions (one for the spring and one for the fall bloom) which yield the relevant ecosystem properties of phase, magnitude and duration. Our test datasets are the CPR data from the NW Atlantic (1961-1994) and the 1979 CZCS ocean colour satellite data on primary production. The mathematical representation of the growth cycle and the resulting parameters are promising and, with regard to the CPR data, show some interesting changes in the relative magnitude and duration of the spring blooms between the early 60's and the present. A similar analysis is planned for the CPR zooplankton data.

It is anticipated that these plankton "parameters" alone may not be adequate in the assessment process. Therefore, we have speculated on a procedure in which we might "scale" or "rank" the parameters based on their observed environment range in order to come up with a quantitative "Plankton Index", analogous to the "Fire Hazard Index". This is presented more as a starting point for discussion than for implementation at this point.

Résumé

L'inclusion de données sur l'environnement dans le processus d'évaluation des pêches est maintenant une priorité au sein du MPO. Lors de la réunion du Comité des pêches de 1995, des données sur le plancton (phytoplancton et zooplancton) ont été ajoutées à la liste des propriétés de l'environnement à considérer. Nous avons, dans le cadre de cette réunion, identifié des sources de données archivées (p. ex., données d'enregistreur à plancton en continu) et de nouvelles sources de données (p. ex., données satellitaires sur la couleur de l'océan) qui pourraient être utiles. La prochaine étape, objet du présent article, est de commencer à explorer explicitement s'il est possible d'inclure cette information dans le processus d'évaluation et comment le faire.

Notre approche est d'identifier et d'exploiter les propriétés du plancton qui, selon des principes écosystémiques établis, sont le plus susceptibles de révéler des relations de cause à effet entre les proies (plancton) et les prédateurs (larves du poisson). Notre première tentative est basée sur l'hypothèse de l'appariement et du mésappariement de Cushing selon laquelle le moment, la durée et l'ampleur du cycle saisonnier du phytoplancton influe sur la survie des larves du poisson et, en retour, le recrutement et la variabilité des stocks.

Nous avons paramétrisé les cycles de croissance du phytoplancton en utilisant deux distributions gaussiennes (l'une pour l'efflorescence du printemps et l'autre pour l'efflorescence d'automne) qui donnent les propriétés écosystémiques pertinentes, soit la phase, l'ampleur et la durée. Les données d'enregistreur à plancton en continu recueillies dans l'Atlantique nord-ouest de 1961 à 1994 et les données satellitaires de balayeur couleur de zone côtière sur la production primaire recueillies en 1979 constituent notre base de données expérimentales. La représentation mathématique du cycle de croissance et les paramètres résultants sont prometteurs et, dans le cas des données d'enregistreur à plancton en continu, révèlent des changements intéressants dans l'ampleur et la durée relatives des efflorescences du printemps à partir du début des années 1960 jusqu'à aujourd'hui. Nous prévoyons effectuer une analyse semblable des données d'enregistreur en continu du zooplancton.

Nous prévoyons que, d'eux mêmes, ces paramètres du plancton ne seront peut-être pas adéquats au processus d'évaluation. Par conséquent, nous avons évalué une méthode pour «graduer» ou «classer» les paramètres d'après leur variation observée dans l'environnement afin d'obtenir un indice du plancton analogue à l'indice des risques latents d'incendie, que nous présentons comme point de départ des discussions plutôt que de sa mise en oeuvre.

I. Introduction

Among the recommendations made by the Fisheries Resources Conservation Council (FRCC) in 1994 regarding the DFO's Atlantic Science priorities, one which has prompted a significant redirection of effort and resources is the recommendation that the Department move more towards "... an ecosystem approach to fisheries management". In response to this, the Fisheries Oceanography Committee (FOC) has broadened its mandate in discussions of environmental variability and its linkages to fisheries issues. Environment now includes not only the physical/chemical properties of the ocean but also the biological components (i.e. the food-chain), specifically the plankton.

Although there has been considerable debate regarding the importance of the plankton food-chain in explaining variability in fish stocks (Cushing, 1990; Sinclair and Page, 1995), it is clear that the fisheries assessment process within DFO in the future will include an ecosystem component. The FOC has an important role in focusing discussion on how we can incorporate environmental information into the assessment process.

During the 1995 FOC meeting, we showed how ocean sciences activities might contribute to this process by providing information on the distribution, abundance and variability of the plankton using archival ship-based and satellite remote-sensing data. The next step (and the subject of this paper) is to begin to explore more specifically if and how we can incorporate this information into the assessment process.

II. Principles for developing a "Plankton Index"

Using established trophic-dynamics principles, it can be argued that the longer the food chain, i.e. the more trophic levels separating the plankton from the harvestable fisheries, the more difficult it is to equate the abundance and distribution of the latter to that of the former. There are examples in the literature, however, which show strong correlations between phytoplankton primary production and fish yields (Fig. 1) but these are only seen at the large-scale, i.e. global/annual mean values. At the regional/interannual scale, these correlations do not hold. This may result from the fact that the fisheries are not necessarily food resource-limited (Sinclair and Iles, 1989) or it may simply be that the link between the plankton ecosystem and fisheries is more subtle than can be explained by simple "bulk" energy relationships as shown in Fig. 1 (see also Iverson, 1990).

We take the view (Cushing, 1975; 1982; 1990) that the key lies in the annual growth cycles of prey and predator. While most harvestable finfish are at least three trophic levels separated from the plankton during adult stage (Pauley and Christensen, 1995), they are only one step removed during early larval growth and it is at this critical stage of the predator life cycle that the influence of the plankton (prey) may be manifest most strongly. This is the basis for the so-called "Match/Mismatch Hypothesis" (Fig. 2) where the survival of larval fish (and ultimately year-class strength) is dependent on

Nixon (1988)

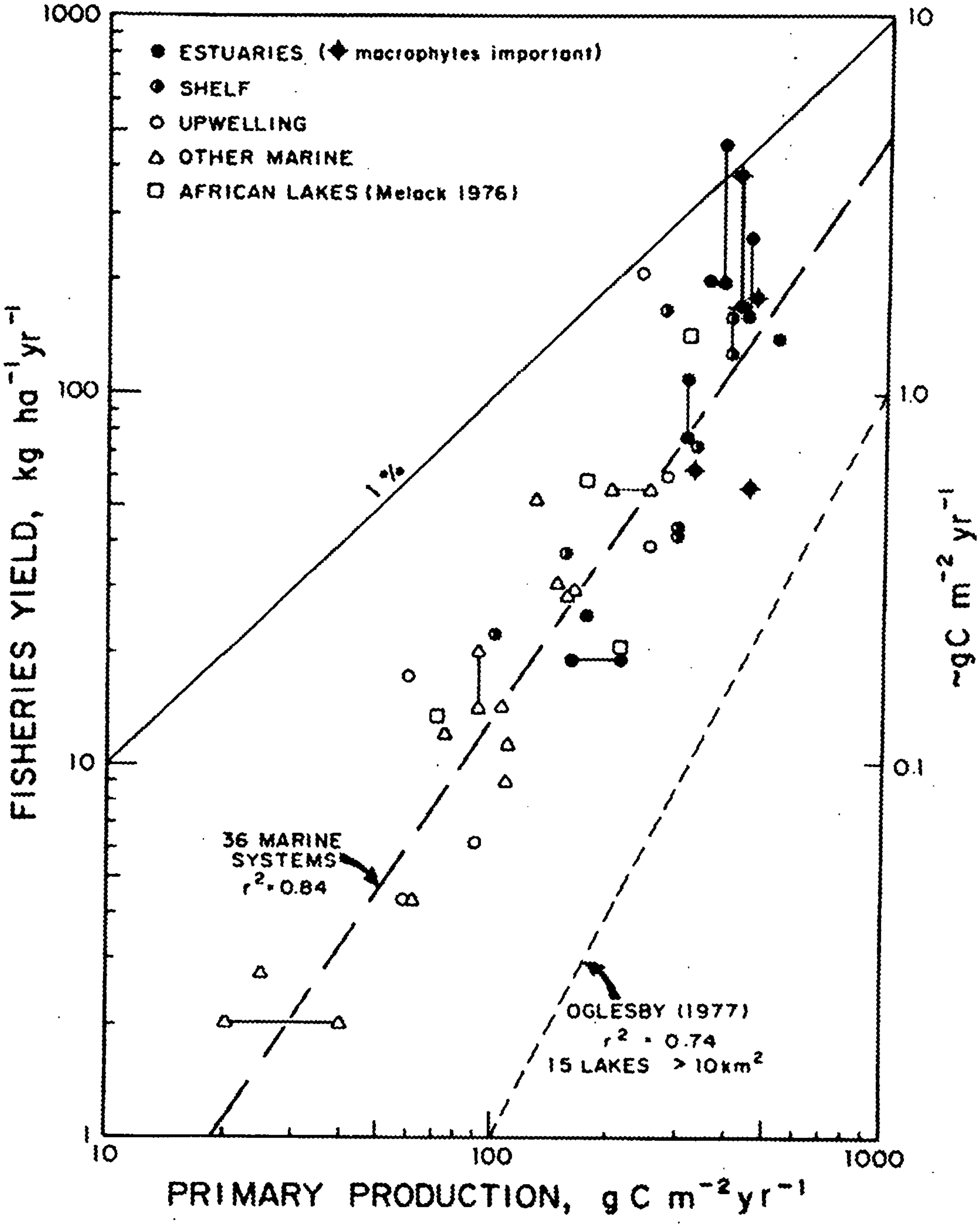

Fig. 1 - Fisheries yield (FY) per unit area as a function of primary production (PP) per unit area in a variety of marine and freshwater systems (Nixon, 1988).

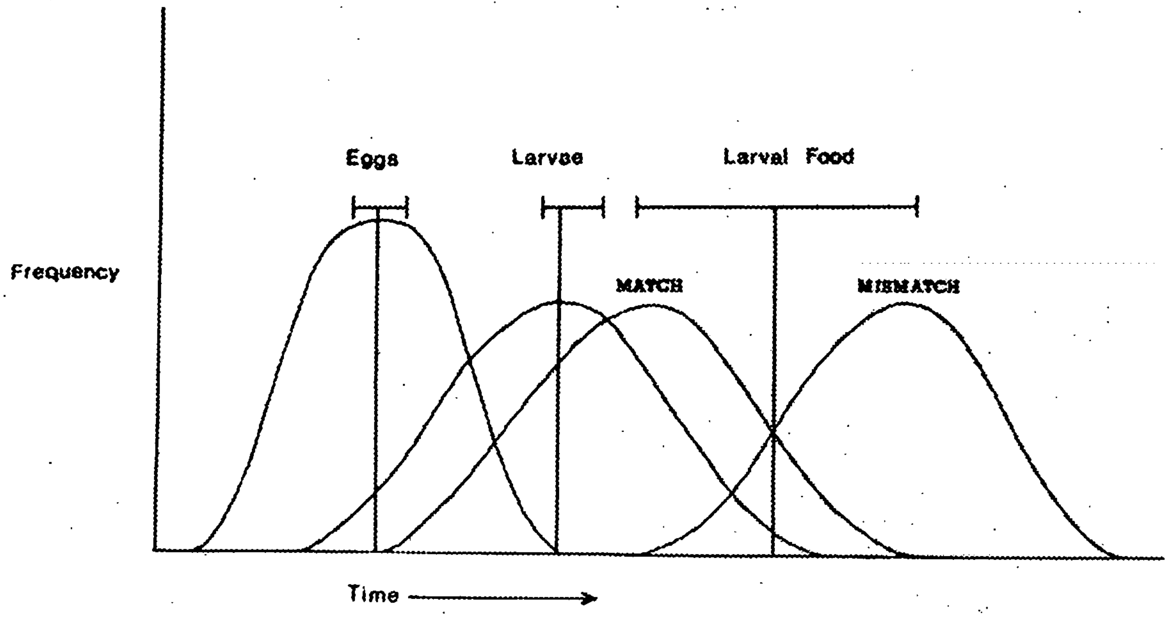

Fig. 2 - The match/mismatch hypothesis. The production of eggs, larvae and larval food are shown as distributions in time. The match or mismatch is represented by the overlap in time between the production of fish larvae and that of their food (Cushing, 1990).

the timing of larval hatching/first-feeding in relation to food (plankton) supply. To contribute meaningfully to fisheries issues, therefore, ocean scientists require temporally well-resolved data on the annual cycles of phytoplankton and zooplankton (distribution, magnitude and variability) to complement information on fish spawning locations and timing, larval distribution and abundance, etc. There exists currently within DFO a limited number of databases from sea-going operations which may provide this information but the nature, quality and extent of this data has not yet been fully evaluated. Additionally, satellite ocean-colour data, with its more comprehensive temporal and spatial coverage (Harrison and Platt, 1995), will be critical for development of the plankton indices we envisage.

III. Parameterizing the plankton growth cycle

Recent research on the partitioning of the global ocean into ecological provinces (Longhurst, 1996) has shown that the phytoplankton growth cycle of north temperate shelves is characterized by two seasonal peaks, one in spring and one in the fall, driven principally by light and nutrient cycles (Fig. 3). It is the nature of the timing, magnitude and duration of these growth peaks that are thought to be critical to the link with zooplankton (Colebrook, 1982) and, in turn, with the fisheries (Cushing, 1990). Our initial attempt to parameterize these critical properties is based on a simple mathematical description of the annual growth cycle using summed gaussian distributions; one curve representing the “spring bloom’ and one representing the “fall

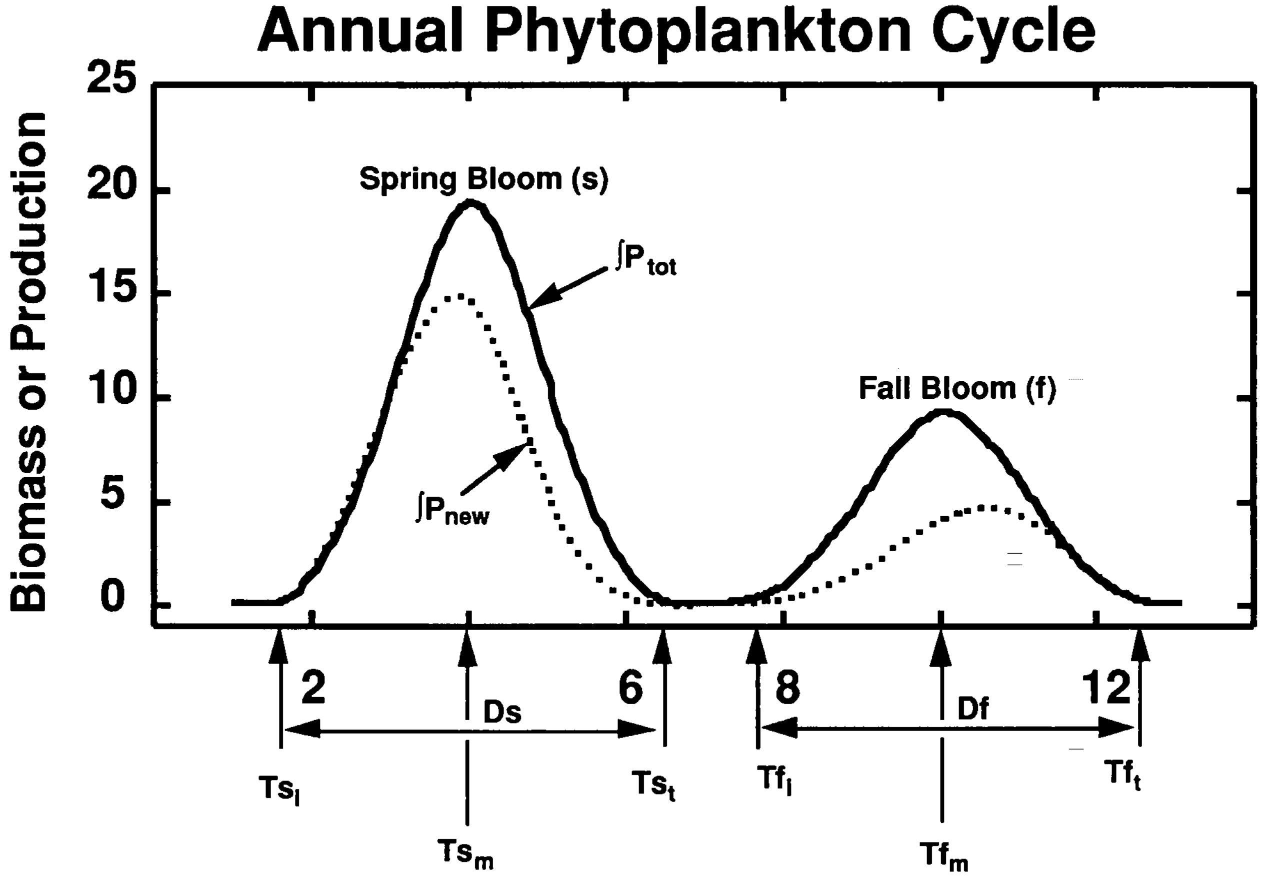

Fig. 3 - The "typical" annual phytoplankton growth cycle in north temperate shelf waters showing the spring and fall "blooms" and some important properties of the annual cycle: $\int P_{tot}$ and $\int P_{new}$ are the annual total and "new" (NO_3-based) primary production; Ts_i, Ts_m and Ts_t are the times of initiation, maximum development and termination of the spring bloom, respectively; Tf_i, Tf_m and Tf_t are the comparable times for the fall bloom; Ds and Df represent the duration of the spring and fall blooms, respectively.

bloom". This mathematical formulation is chosen because it describes the bloom sequence well and because three ecologically relevant parameters are derived: (1) the timing of the maximum, (2) the area under the curve and (3) the dispersion around the mean (i.e. bloom duration). Similar arguments can be used for parameterizing zooplankton data.

We have tested this procedure using the most extensive database presently available, i.e. the CPR data on "Greenness" for the NW Atlantic (Myers et al. 1994), and found it suitable (Fig. 4). Aside from differentiating the relative magnitudes of the spring and fall growth peaks, this procedure may also be useful in discriminating major functional groups (i.e. diatoms versus dinoflagellates) in the larger size categories sampled by the CPR (Fig. 5). A preliminary evaluation of phytoplankton "Greenness" parameters was made for the NW Atlantic between 1961 and 1994 for three regions (Grand Banks, Scotian Shelf, Gulf of Maine/Georges Bank). The magnitude of the spring and fall

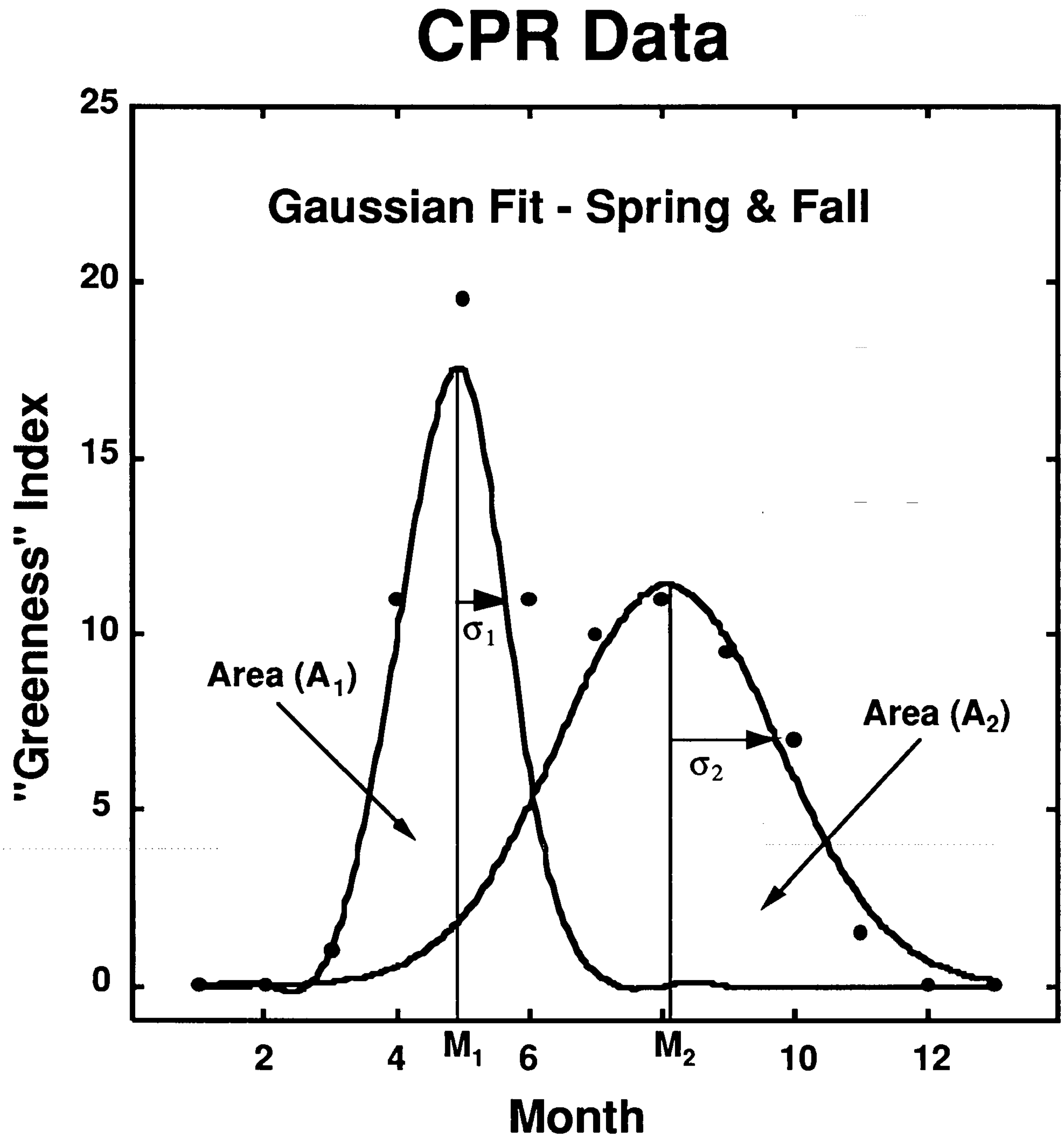

Fig. 4 - Gaussian fit to CPR data showing derived parameters: (A) area under the "greenness" curve, (M) time of "greenness" maximum and (s) dispersion around the mean i.e. analogous to the duration of the "bloom".

blooms (area under the curves) appeared to increase in all three regions in the 90's compared with earlier years (Fig. 6); this was primarily a manifestation of the 1992 and 1993 cycles (Fig. 7). [Note, however, that the comparisons between the 60's/70's and the 90's in the Gulf of Maine/Georges Bank region is complicated by the change in CPR tracks between those time periods.] By comparison, the ratios of the spring/fall

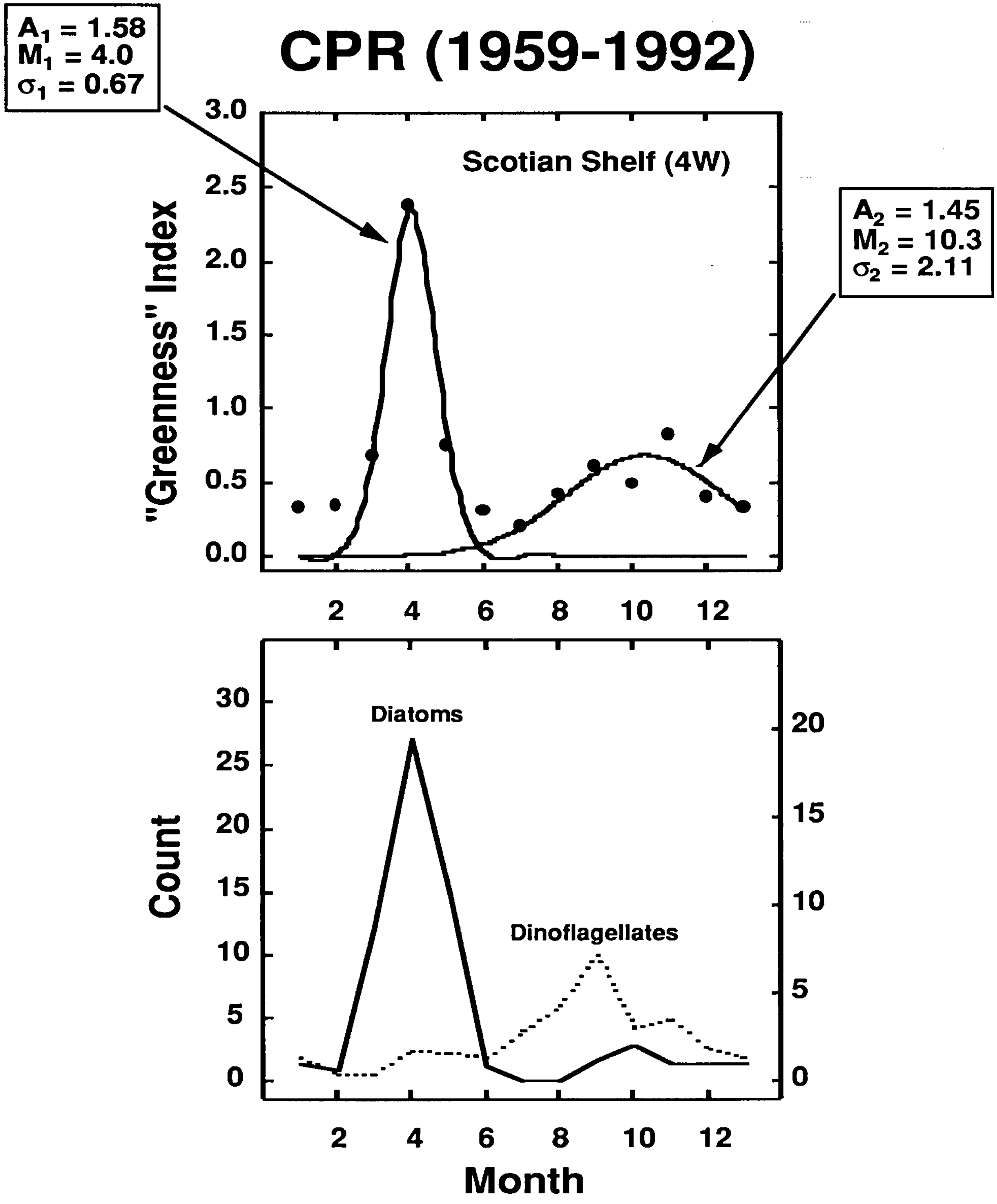

Fig. 5 - Gaussian fit of CPR data (monthly averages of years 1959-1992) from the Scotian Shelf (NAFO Area "4W"; Myers et al. 1994) showing spring and fall "greenness" blooms and calculated parameters (upper panel) and total diatom and dinoflagellate (Ceratia) counts for the same samples (bottom panel).

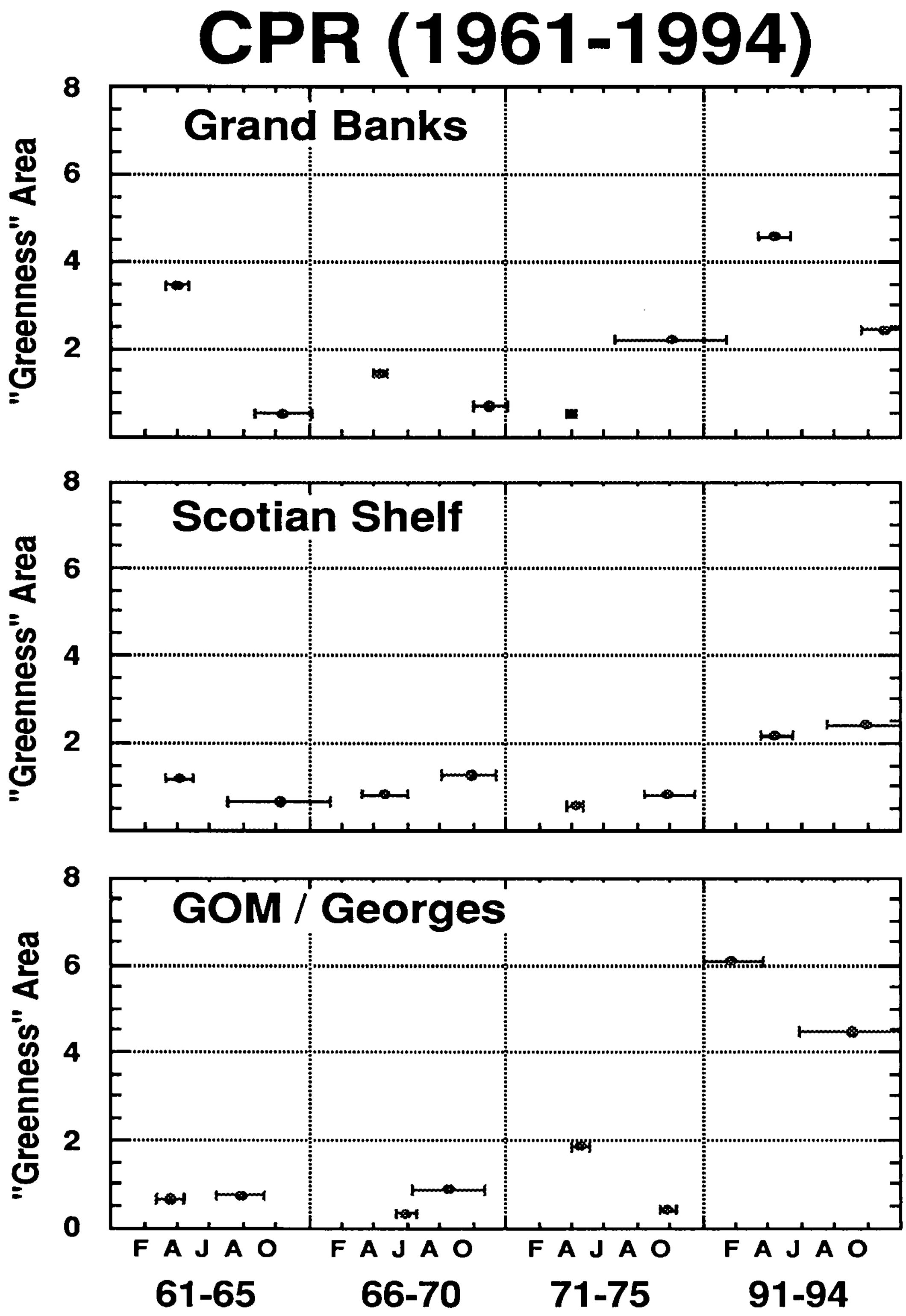

Fig. 6 - Variations in CPR "Greenness" parameters between 1961 and 1994: grouped by region (panels) and by years (see labels at bottom of figure). Ordinate = area under the curve (A), abscissa = timing of maxima (M), and horizontal bar = bloom durations (s).

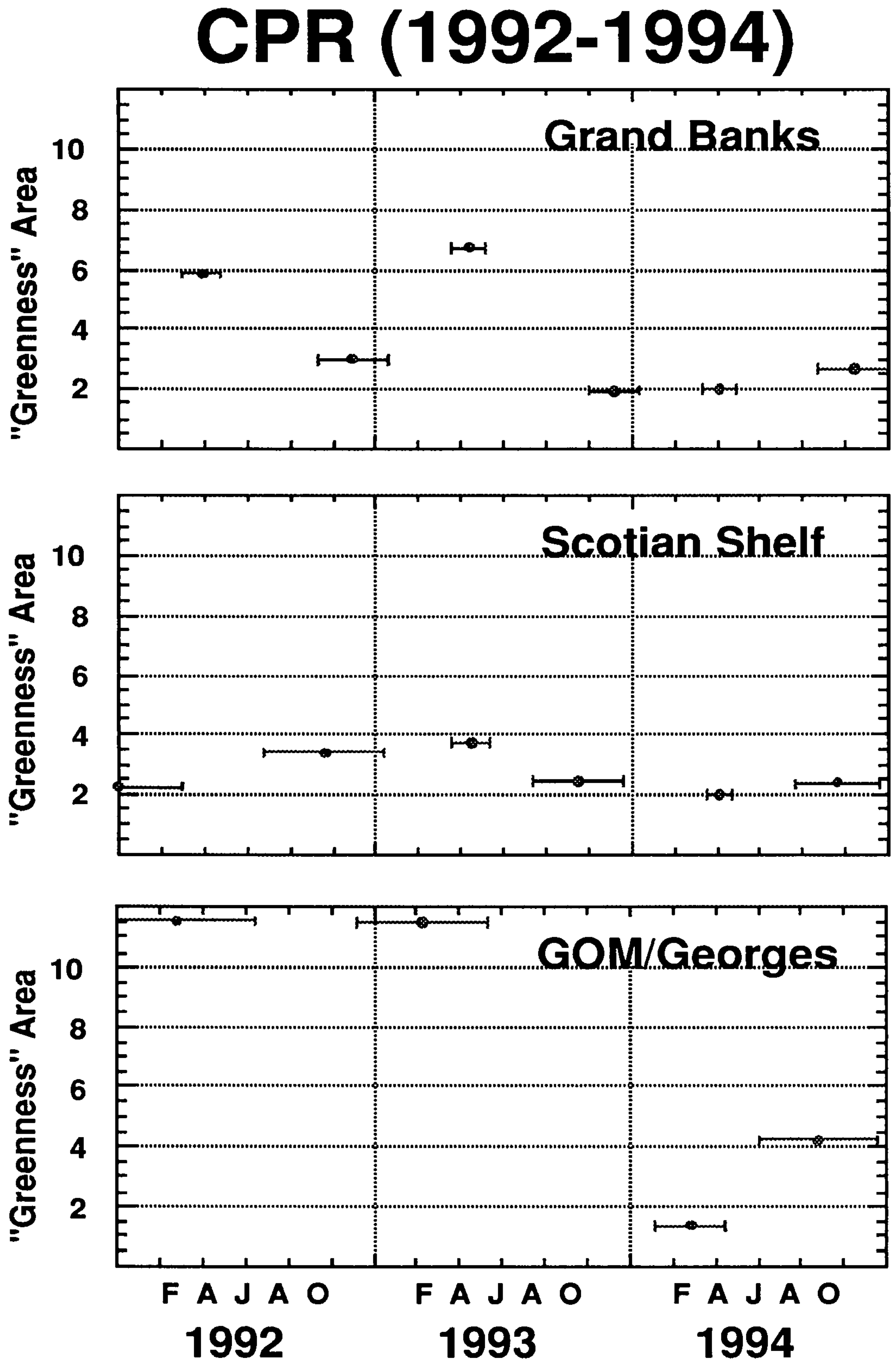

Fig. 7 - Variations in CPR "Greenness" parameters between 1992 and 1994. Symbols same as in Fig. 6.

peaks appeared to decline between 1961 and 1975 on the Grand Banks and Scotian Shelf but increased in the Gulf of Maine (Fig. 8); ratios recovered slightly in the 90's on the Grand Banks and Scotian Shelf but declined in the Gulf of Maine such that ratios in all three regions were similar. Timing of the spring maximum, on the other hand, varied little from 1961 to 1994 on the Grand Banks and Scotian Shelf but changed significantly in the Gulf of Maine. Duration of the spring maximum, in contrast, appeared to increase in all three regions in the 90's compared to earlier years.

In addition to the CPR data, we applied this parameterization procedure to the Coastal Zone Color Scanner (CZCS) satellite-derived primary production data from 1979 (Harrison and Platt, 1995). Results showed that the spring bloom dominated the annual production cycle on the Labrador and Newfoundland shelves but that the fall bloom dominated further south, on the Grand Banks, Scotian Shelf and Gulf of Maine (Fig. 9). No CPR data were collected during this period but results for the 70's on the Grand Banks and Scotian Shelf were consistent with the CZCS pattern, i.e. dominant fall peak. These results provide us with some sense of the scale of parameter variability to be expected but also lead us to some obvious questions: (1) what caused the apparent shift in the production cycle from spring to fall between the 60's and 70's, (2) do we see any similarities in the zooplankton cycles over that time period and (3) what, if any, were the consequences to the fisheries?

IV. How do we incorporate plankton "parameters" into the fisheries assessment process?

At present, it may be that the best we can realistically offer to the assessment process is information on the nature and scale of variability of certain properties of the plankton growth cycle, however, in the long term it may not (will not) be sufficient for us to simply provide an efficient and objective procedure for reducing the complexities of the plankton growth cycle to a few critical parameters. We are ultimately going to be asked by our fisheries colleagues and managers to *interpret* our findings of the "state of the plankton ecosystem" in the context of fish stock variability. How do we do this? Our ability to interpret this information depends on our level of understanding of how the system works - which is not very good. Until we reach that point of understanding, however, is there some way we can *quantify* the expected impact of the timing/magnitude/duration of the plankton cycle(s) on larval survival/recruitment/stock variability?

One way to accomplish this may be to develop a simple suite of criteria by which we can rank or score these parameters to yield an overall "Plankton Index" (Table 1), somewhat analogous to the Fire Hazard Index; a similar proposal was made at last year's FOC meeting to scale the "harshness" of the environment for the Gulf of St. Lawrence cod fishery. We can envisage a similar scoring procedure for environmental properties (Table 2) that have ecological significance (e.g. spring ice conditions, clouds, winds, stratification, etc.) and for zooplankton parameters (Table 3). These by nc means represent a complete listing of important ecological properties but are presented simply as a starting point for discussion.

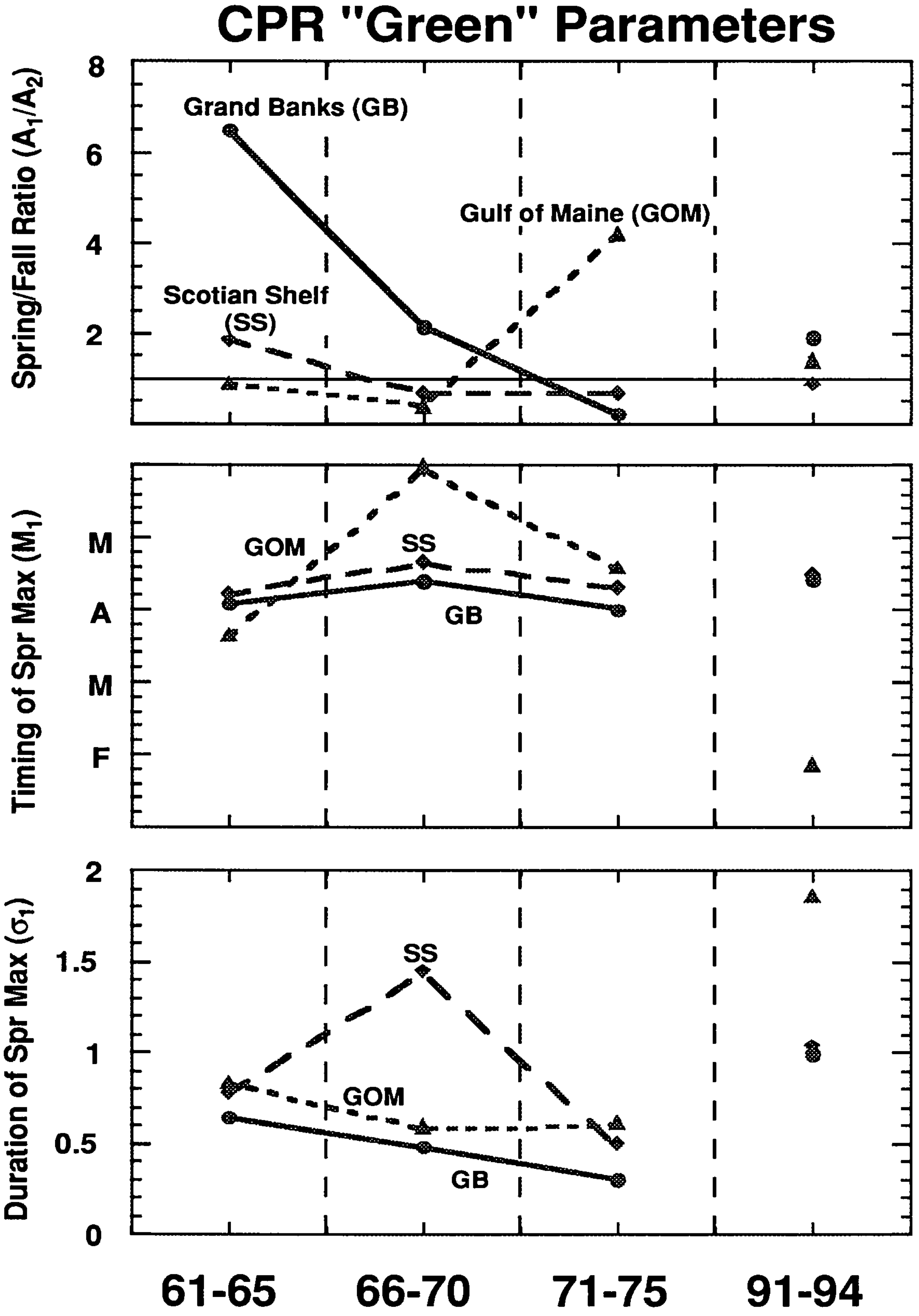

Fig. 8 - Variations in CPR “Greenness” parameters for spring: grouped by parameter (panels) and by years to facilitate regional comparisons.

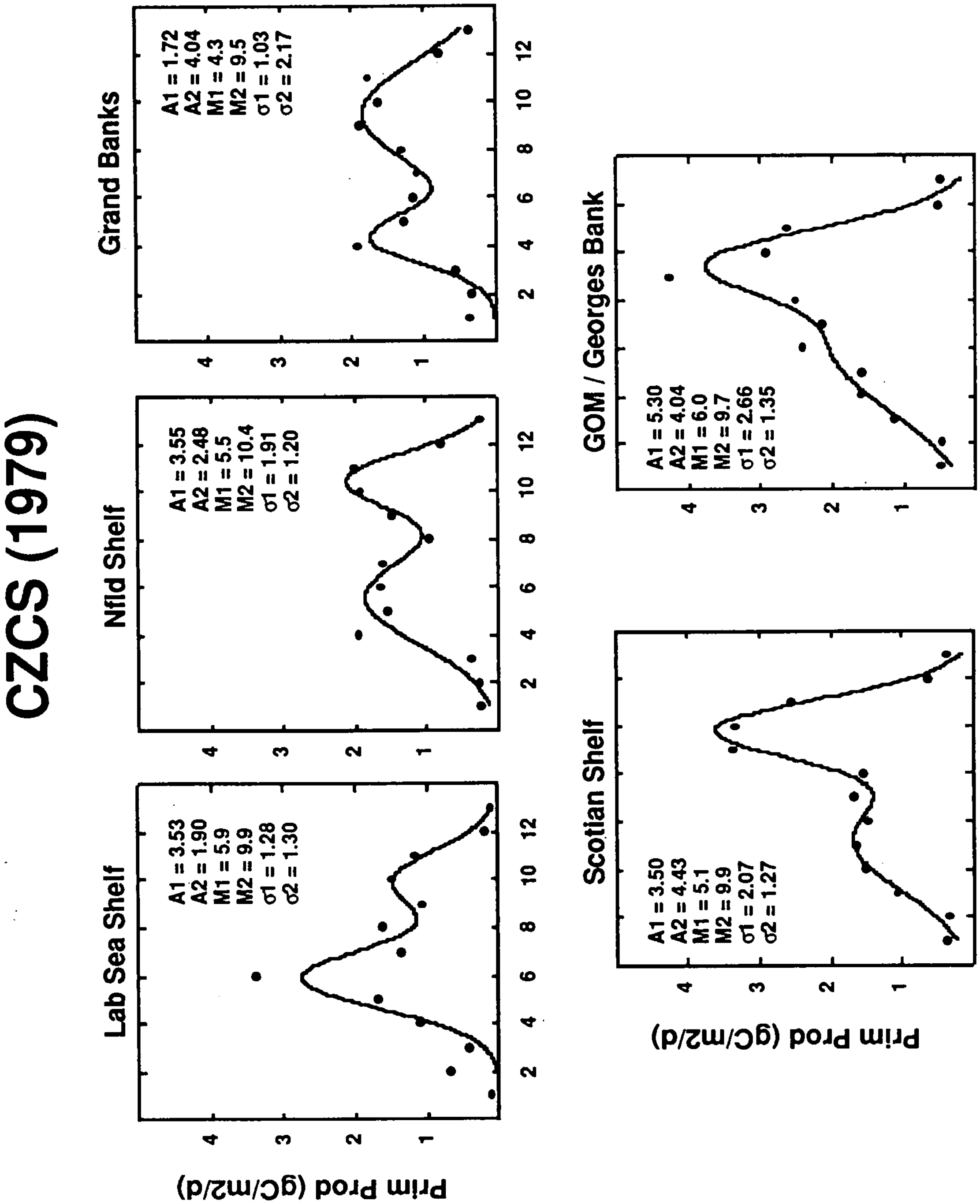

Fig. 9 - Gaussian fits and parameters for CZCS-derived primary production data, 1979: grouped by region.

The *utility* of this approach will not be fully realized until we have assembled and evaluated a more comprehensive set of data, however, its *value* lies in the concept that our success in establishing a link between the ecosystem and fisheries will be based on a good theoretical framework (hypothesis-testing) and not simply on empirical correlations.

Table 1. PHYTOPLANKTON INDICES:

I. Simplest Index:

Annual average biomass (CHL) or total annual primary production (APP) by region

II. Refined Indices:

Principle #1: Conditions necessary to MAXIMIZE exploitable fraction of primary production
Principle #2: Spring bloom component is key

A. Timing of biomass or productivity maximum (earlier is better):

Category:	≤MAR	APR	MAY	JUN	JUL
Score:	5	4	3	2	1

B. Magnitude of biomass or productivity maximum (larger is better):

Category:	Background	2X Bkgd	3X	4X	5X
Score:	1	2	3	4	5

C. Duration (longer is better):

Category:	≤ 2Wks	>2Wks	1mo	2mo	≥3mo
Score:	1	2	3	4	5

D. Fraction of APP (more is better):

Category:	≤10%	10-20%	20-30%	30-40%	>40%
Score:	1	2	3	4	5

E. Species (grazer preference):

Category:	Diatoms	D>F	D=F	D<F	Flagellates
Score:	5	4	3	2	1

F. Microbial Sink (ABP/APP ratio) where ABP = annual bacterial production:

Category:	≤20%	20-40%	40-60%	60-80%	>80%
Score:	5	4	3	2	1

Table 2. ENVIRONMENTAL INDICES (Phytoplankton):

Principle: Conditions (light & nutrients) to MAXIMIZE primary production
Light = ice/cloud cover
Nutrients = stratification

A. Ice cover - in March? (less is better):

Category:	Light	→	→	→	Heavy
Score:	5	4	3	2	1

B. Cloud cover - March to July? (less is better):

Category:	Light	→	→	→	Heavy
Score:	5	4	3	2	1

C. Strat. onset (earlier is better):

Category:	MAR	APR	MAY	JUN	JUL
Score:	5	4	3	2	1

D. Strat. intensity (moderate is better):

Category:	Low δs_t	→	→	→	High δs_t
Score:	1	2	5	4	3

E. Strat. duration (shorter is better):

Category:	≤ 1 mo.	2 mo.	3 mo.	4 mo.	≥5 mo.
Score:	5	4	3	2	1

F. Wind data:

LOW IN EARLY SPRING conducive to optimum light conditions for bloom
MODERATE IN SUMMER conducive to nutrient resupply

Table 3. ZOOPLANKTON INDICES:

I. Simplest Index:

Annual average abundance by region

II. Refined Indices:

A. Timing of maximum abundance:

Category:	≤MAR	APR/SEP	MAY	JUN/JUL	NOV
Score:	3	5	4	2	1

B. Duration:

Category:	≤1mo	2mo	3mo	4mo	5mo
Score:	1	2	3	4	5

C. Spring maximum/annual average:

Category:	1X	2X	3X	4X	5X
Score:	1	2	3	4	5

D. Dominant species:

Category:	Calanus	Pseudocal.	Pteropods	Gelatenous sp.
Score:	4	3	2	1

E. Calanus egg count in spring:

Category:	Low	Medium	High
Score:	1	2	3

F. Zoopl. max relative to fish spawning:

Category:	1mo before	During	1mo after
Score:	3	2	1

V. References

Colebrook, J.M. 1982. Continuous Plankton Records: seasonal variations in the distribution and abundance of plankton in the North Atlantic Ocean and the North Sea. J. Plankt. Res. 4: 435-462.

Cushing, D.H. 1975. Marine Ecology and Fisheries. Cambridge University Press, Cambridge, 278 pp.

Cushing, D.H. 1982. Climate and Fisheries. Academic Press, N.Y., 373 pp.

Cushing, D.H. 1990. Plankton production and year-class strength in fish populations: an update of the Match/Mismatch Hypothesis. Adv. Mar. Biol. 26: 249-293.

Harrison, W.G. and T. Platt. 1995. The state of the pelagic ecosystem: a synoptic assessment based on satellite remote-sensing. FOC Working paper 95/13.

Iverson, R.L. 1990. Control of marine fish production. Limnol. Oceanogr. 35: 1593-1604.

Longhurst, A. 1996. Seasonal cycles of pelagic production and consumption. Prog. Oceanogr. 36: 77-167.

Myers, R.A., N.J. Barrowman, G. Mertz, J. Gamble and H.G. Hunt. 1994. Analysis of Continuous Plankton Recorder data in the Northwest Atlantic 1959-1992. Can. Tech Rep. Fish. Aq. 1966: 1-246.

Nixon, S.W. 1988. Physical energy inputs and the comparative ecology of lake and marine ecosystems. Limnol. Oceanogr. 33: 1005-1025.

Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature 374: 255-257.

Sinclair, M. and F. Page. 1995. Cod fishery collapses and North Atlantic GLOBEC. U.S. GLOBEC News, No. 8.

Sinclair, M. and T.D. Iles. 1989. Population regulation and speciation in the oceans. J. Cons. Int. Explor. Mer. 45: 165-175.