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A Pilot Study of Stratification Variability on Georges Bank and Its Effect on Larval Fish Survival

by The Stratification Group

The physical environment on the southern flank of Georges Bank during spring is characterized by the development of density and thermal stratification. This stratification has been shown to have a significant influence on the feeding and survival of larval cod and haddock (Buckley and Lough 1987). The timing and intensity of stratification are likely to be affected by the climate change anticipated in the NW Atlantic.

The development of stratification is controlled by a balance between solar insolation, which warms and reduces the density of the surface layer, and mixing induced by tidal currents and surface wind stress. On the deeper portions of Georges Bank stratification begins to develop in the spring, while in the shallow central region strong tidal currents keep the water column well-mixed year-round (Garrett, Keeley and Greenberg 1978). Spawning of cod and haddock stocks on Georges Bank occurs in late winter and spring on the northeastern part of the Bank. The developing eggs and larvae are carried south and west in the mean flow along the southern flank of the Bank as the seasonal stratification begins to develop (Fig. 1).

In the well-mixed region cod and haddock larvae have been observed to grow more slowly and to be in poorer

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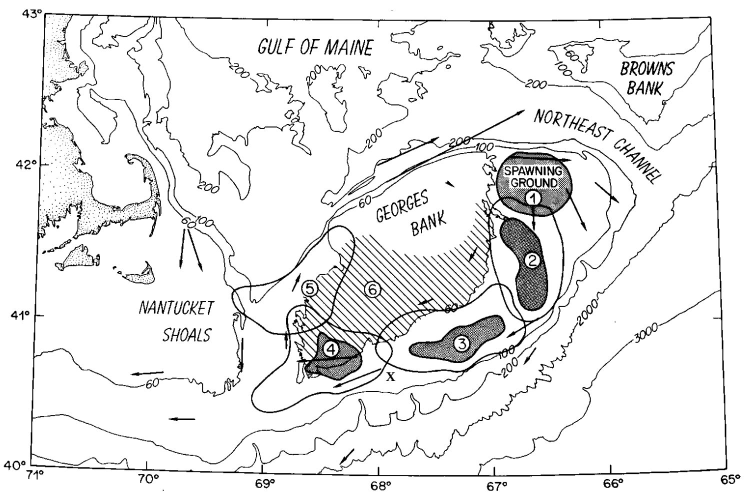

Figure 1. Georges Bank. Arrows indicate the mean circulation around the Bank. Numbered areas indicate the characteristic location of the early life stages of cod and haddock, from spawning (1), to early and late stage larvae (2,3,4), to demersal juveniles (5) and young-of-the-year fish (6) in the fall. The moored site of the May 1992 study is at the 'X'.

SCOPEX, a Multidisciplinary Study of Right Whale - Ecosystem Interactions

by The SCOPEX Group

The right whale, *Eubalaena glacialis*, is an endangered species with only a few hundred individuals remaining in the northwestern Atlantic. For at least the past ten years, a large proportion of the population of these zooplankton-feeding baleen whales has been present for about two months during spring in a small area just north of the Great South Channel (GSC) in the southern Gulf of Maine (GOM)(Fig. 1, page 3). SCOPEX, the **S**outh **C**hannel **O**cean **P**roductivity **Ex**periment, was a multidisciplinary program to investigate springtime aggregations of right whales in the southern GOM, the interactions between these whales and their main prey, the copepod *Calanus finmarchicus*, and physical processes influencing these biological interactions. This program

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Stratification—(Cont. from page 1)

physiological condition, as measured by an RNA/DNA ratio, than larvae at a stratified site on the southern flank of the bank (see Fig. 4 and 5 in Buckley and Lough 1987). The difference in condition is believed to be due to a reduced concentration and vertically more homogeneous distribution of prey at the well-mixed site in comparison to the stratified site. The sensitivity of the larvae to temporal variability in stratification, such as that caused by wind events, is not known, but is hypothesized to be important. In other areas the dissipation of biological structure by wind events has been shown to be detrimental to larval fish feeding and growth (Lasker 1978; Peterson and Bradford 1987).

Stratification also can have negative implications for the feeding of larvae and zooplankton. Recent theoretical and observational studies hypothesize that certain levels of turbulence enhances encounter rate between predators and prey, and promotes growth of the predator (e.g. Rothschild and Osborn 1988; Sunby and Fossom 1990; Davis et al. 1991).

Models of climate change suggest that the NW Atlantic in the future may be characterized by warmer temperatures, increased precipitation and river runoff (Manabe and Stouffer 1980), and reduced wind stress (Manabe and Wetherald 1980). These factors may result in changes in the characteristic development of stratification on Georges Bank. For example, at warmer temperatures the nonlinearity in the equation of state of seawater would result in more buoyancy per unit of heat input to the surface water. Even subtle changes in relationship between buoyancy and heat input might have significant effects on the timing and character of the stratification process and on the availability of food organisms to larval fish.

A simple, one-dimensional model of stratification (which includes wind stress, tidal mixing, surface heating, and uses canonical parameter values

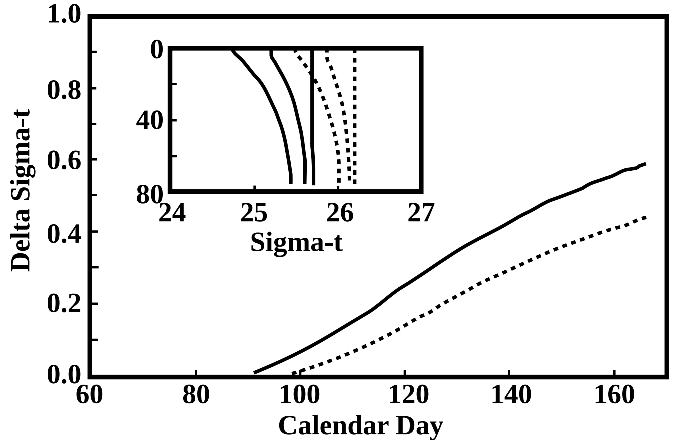

Figure 2. Results of a model of the seasonal development of stratification (density difference between the surface and 40 m) on Georges Bank for winter water temperatures of 8˚C (solid line) and 4˚C (dashed line). The inset shows the vertical distribution of density (sigma-t) in March (rightmost), April, and May (leftmost) for the two cases.

from the literature) suggests that an increase in the winter water temperature from 4˚ C to 8˚ C would result in an earlier and stronger development of stratification during the spring (Fig. 2). Though preliminary, this result suggests that climate induced changes in stratification would be of a magnitude known to be important to the growth and survival of larval fish. It also suggests that the linkage between stratification and larval survival is an important area of study for U.S. GLOBEC.

A study of stratification variability on Georges Bank and its effect on larval fish survival is being supported by the NOAA Climate and Global Change, Marine Ecosystems Response Program (this MER project has since been merged into U.S. GLOBEC). The objectives of this study are two-fold: (1) to relate spatial and temporal variability in stratification to change in the food availability, growth and survival of larval cod and haddock on Georges Bank; and (2) with this understanding, to evaluate the potential effects of climate change on larval survival. As a first step, cruises were done in May 1992 and are planned for May 1993 to test and intercalibrate biological sampling systems, biochemical techniques and sampling strategies.

Sampling Systems

For this pilot study, observations of the micro-scale distributions of larvae and their prey are critically important. To obtain these observations, a series of sampling systems designed to observe and/or collect larvae and their prey on small vertical and horizontal length scales are being utilized (see box, page 10). The MOCNESS and plankton pump provide quantitative abundance estimates and samples for biochemical analysis. The BIOSPAR, TAPS and the two towed acoustic systems provide bioacoustical profiles of the water column. The VPR provides fine-scale visual observations of the plankton. The combination of acoustic, optic and net sampling systems provides information on the abundances of organisms ranging in size from 10 µm to cm's, and provides considerable overlap between systems that will permit intercomparisons.

Biochemical methods will be used to determine recent growth and physiological condition of fish larvae in relation to water column conditions and prey density. In addition, the recent daily increments in otolith growth will be analyzed to compare with recent physiological condition and water column structure.

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SCOPEX—(Cont. from page 1)

was carried out between 1988 and 1991 with field sampling during late spring in 1988 and 1989. Support for a pilot study in 1986 was provided by ONR with ship time provided by NMFS/ NOAA. The main study described below was supported by NSF and the Minerals Management Service.

The basic hypothesis being investigated was that the whales concentrated in this limited area each spring because of dense concentrations of their copepod food. Three (not mutually exclusive) sub-hypotheses concerning causes of possible copepod aggregations in the GSC were developed as follows:

- The advection hypothesis states that the interaction between water flow (including currents, eddies, and vertical stratification of flow) and the behavior of copepods (especially their vertical migration and depth preferences) passively concentrates the copepods.

- The second hypothesis was that the high copepod abundances were due to high primary production in the region, i.e., a simple food chain response.

- The third hypothesis was that species-specific social behavior, such as swarming, creates the copepod aggregations.

Physical oceanographic surveys in late April 1988 and early June 1989 indicated substantial differences in the extent of a freshwater plume which occurs east of Cape Cod in spring. This plume is derived from spring river runoff into the western and northern GOM. In April 1988, the surface plume was just beginning to form along the outer coast of Cape Cod, while six weeks later, in 1989, the plume was fresher and extended further eastward towards Georges Bank. The difference in the amount of freshening between the two surveys was primarily due to the later sampling and increased river runoff in 1989. The offshore spreading of the low-salinity plume was driven by the deep circulation and upwelling favorable winds. Hydrographic data and satellite SST images showed relatively permanent continuous fronts along the eastern flank of Nantucket Shoals, across the northern shallower region of the GSC, and along the northern flank of Georges Bank.

Satellite-tracked drifters were deployed to determine flow patterns in the GSC region (Fig. 2). Near-surface (5m) flow in the western GSC was southward out of the GOM along paths of nearly constant bathymetry. In the central GSC, especially near and east of 69°W, near-surface water flowed east and then northeast along the northern flank of Georges Bank, passing north of the 20 m crests of Cultivator Bank. Subsurface (50 m) flow was generally slower than the near-surface currents, and often opposite in direction. The 50 m circulation in the GSC was generally southeastward west of 69°W and northeastward east of 69°W. The mean Lagrangian time scale was 57 ± 24 days for near-surface cyclonic recirculation in the Wilkinson Basin and 48 ± 8 days for anticyclonic recirculation

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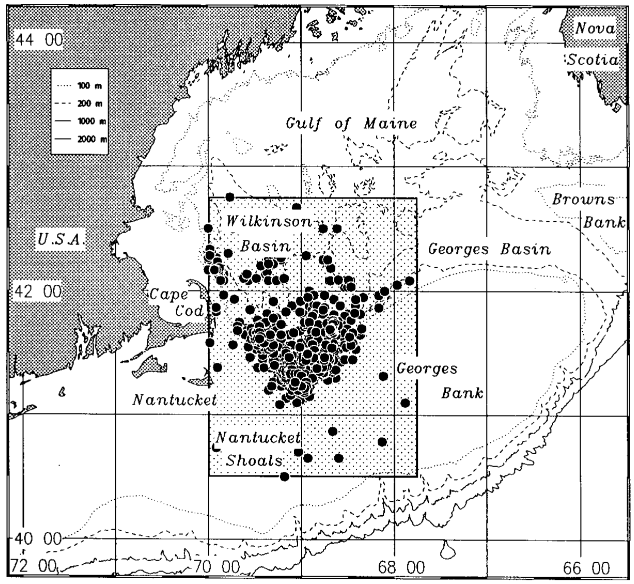

Figure 1. The SCOPEX study area (shaded) in the Great South Channel region of the southern Gulf of Maine, showing right whale sightings within the study area for 1975-1989 (R. D. Kinney, H. E. Winn and M. C. Macaulay, "Cetaceans in the Great South Channel, 1979-1989: right whale (Eubalaena glacialis)", Cont. Shelf Res., submitted).

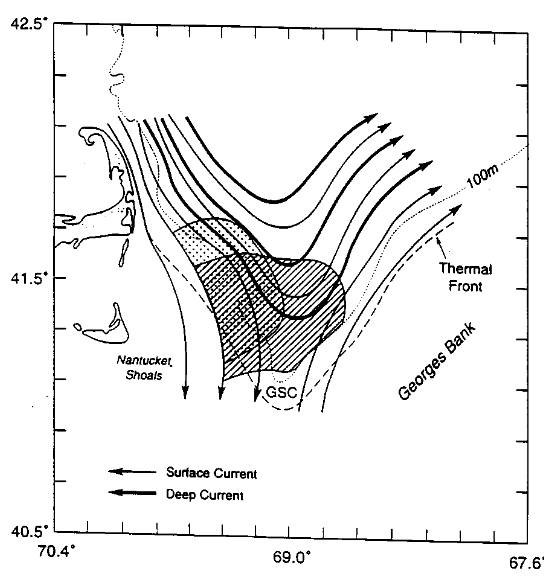

Figure 2. Conceptual schematic of upper and lower layer circulation in the northern GSC during late spring. Solid lines are near surface currents, heavy solid lines are deep currents associated with Maine Intermediate Water (MIW), and dashed lines are the locations of the tidal mixing thermal fronts. Shaded areas with dots and lines are the convergence zones for April 1988 and June 1989 surveys, respectively. (C. Chen, R. C. Beardsley and R. Limeburner, "Variability of water properties and currents in late spring in the northern Great South Channel", Cont. Shelf Res., submitted).

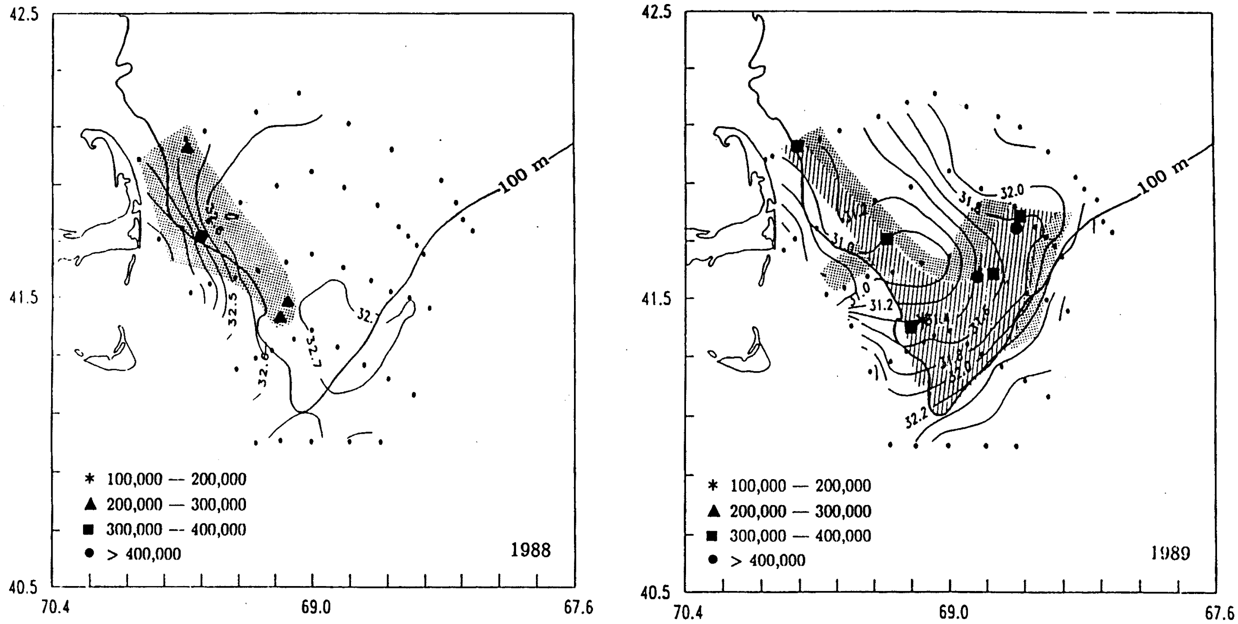

Figure 3. Distributions of _Calanus_ *and surface (2m) salinity in 1988 (left) and 1989 (right) relative to the 100 m isobath. Water column abundances (number* m^{-2}*) of total* _Calanus_ *(C_3 and older stages) are shown as shaded areas, with symbols showing locations of peak abundances. Dotted shading represents* _Calanus_ *abundances from 100,000-200,000* m^{-2}*; line shading represents abundances from 200,000-300,000* m^{-2}*. Small dots show the hydrographic locations used to contour salinity. (K. F. Wishner, J. R. Shoenherr, R. Beardsley and C. Chen, "Spatial and temporal variability of copepod abundance and popualtion structure in a springtime right whale feeding area in the northern Great South Channel region of the western Gulf of Maine", Cont. Shelf Res., submitted).*

SCOPEX—(Cont. from page 3)

over Georges Bank.

Seasonal hydrographic changes also have a major effect on the biological processes in the southern GOM. The spring phytoplankton bloom begins in February and early March in shallow areas of the western GOM and extends into deeper areas as spring progresses. In early May 1988, some regions of the study area still had high concentrations of large diatoms, while in other areas the spring bloom had terminated. By late May and early June of 1989, the spring bloom had ended and the dominant phytoplankton were small (<7 µm). In the well-mixed shallower areas on Nantucket Shoals, in the shallow portion of the northern GSC, and over Georges Bank, phytoplankton concentrations were somewhat higher. However, these are outside the areas frequented by right whales where the dense aggregations of *Calanus finmarchicus* occur.

Calanus finmarchicus dominated the zooplankton of the GSC in both years. They were aggregated in patches which were acoustically detectable (200 kHz). The locations of highest *Calanus* abundances differed in the two years, as did the locations of feeding whales. Younger life stages of *Calanus* were most abundant in the northwestern part of the study region each year, whereas older stages of *Calanus* tended to be found in the eastern part of the study area, particularly near the front of the freshwater plume, where a large-scale convergence was present (Fig. 3). These stage-distribution and abundance patterns result from the advection of maturing copepods by the regional circulation.

Maximum *Calanus* abundances and biomass of older stages were significantly higher in 1989 than in 1988, both in the region as a whole and at locations where whales were feeding. This difference might reflect the later sampling in 1989 rather than a real interannual difference in *Calanus* abundance. High concentrations of younger *Calanus* stages in the northwestern part of the study region in 1988 suggest that they are advected into the region from the north.

Calanus populations in both years were actively growing (and not diapausing), as evidenced by the temporal progession of life stages during the several week cruises. Stage durations estimated from plankton collections indicated development rates in 1988 that were similar to maximal rates observed in the laboratory, whereas development rates in 1989 were greatly reduced. These results were consistent with observations of intermediate to high and very low *in situ* feeding rates in 1988 and 1989, respectively.

Calanus diel vertical migration patterns differed between years. Both strongly migrating and non-migrating populations were present in 1988. In 1989, there was little migration, with dense aggregations being found at the surface both day and night. Reasons for these differences in vertical migration are not clear; there was no obvious relation between migration behavior and stage of development,

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SCOPEX—(Cont. from page 4)

food abundance, or feeding rates. The possibility that predation intensity is responsible for these behavioral differences is being explored using acoustical data collected during the study.

Within the broad-scale distributions described above, there was considerable small-scale horizontal and vertical variability in *Calanus* abundance. This was most apparent in 1989 when the non-migrating population was observed at the surface. Abundance varied by up to 1000X in horizontal tows spanning about 0.5 - 1.5 km. Maximum concentration from the MOCNESS tows in 1989 was 30,800 m^{-3}. However, a number of visibly red surface patches were observed in 1989 at scales too small to be sampled effectively with a MOCNESS; one of these sampled with a bucket yielded a concentration of 331,000 m^{-3}.

Whales were observed feeding in the regions with older (larger) *Calanus*. In 1988, whales were found primarily in the western side of the study area, while in 1989 most of them were seen on the eastern side. Whale diving patterns differed, and appeared to be directed by the distribution of the copepods, in the two years. In 1988, when the copepods spent the day near the bottom, right whale dives were much longer in the day. Conversely, whale daytime dives in 1989, when the copepods stayed near the surface, were both shorter and shallower. Tagging studies indicate that the whales were diving only to 5-20 m where copepods were most abundant.

The SCOPEX study has improved our understanding of this area where *Calanus finmarchicus*, a preferred food of the right whales, is concentrated during late spring. The higher regional concentration of *Calanus* may be related to recruitment processes occurring earlier in the spring in coastal waters in the western GOM, which is outside the SCOPEX study area. Earlier, upstream recruitment may lead to the development of large populations of later-stage *Calanus* as the waters are advected into the GSC. Furthermore, the low salinity surface plume with its associated fronts and convergences creates considerable small-scale patchiness of *Calanus* within the study area. It is the presence of these-small scale patches with very high concentrations of older stages of *Calanus* in them which offers a favorable feeding habitat for the right whales.

As a footnote, the high concentrations of *Calanus* observed in this region in 1988 and 1989, as well as during the pilot study in 1986, did not occur in 1991 and 1992. In both of these years whales either did not stay long in the region or were absent. This interannual variability is especially pertinent to U.S. GLOBEC studies of *Calanus* in the NW Atlantic; drifter information from the SCOPEX study demonstrates a close link between the southern GOM and Georges Bank populations of *C. finmarchicus.*

The SCOPEX group: R. Beardsley and R. Limeburner (Woods Hole Oceanographic Institution); P. Cornillon, A. Durbin, E. Durbin, R. Kenney, H. Winn, and K. Wishner (University of Rhode Island); M. Macaulay (University of Washington). ΔΔΔ

Stratification—(Cont. from page 2)

May 1992 Pilot Study

A two-vessel study was conducted in May 1992 to test and intercompare physical and biological collection and observation systems in a variety of water column conditions. A site was selected on the southern flank (80 m depth) where stratification was undergoing seasonal development and where a preliminary survey indicated a concentration of gadid larvae was located. A second site was selected in the nearby (25 km distance) well-mixed part of the bank (49 m depth). A mooring with current meters and temperature/conductivity recorders was deployed at the stratified site to measure water column conditions during the experiment. BIOSPAR also was moored at the stratified site, about

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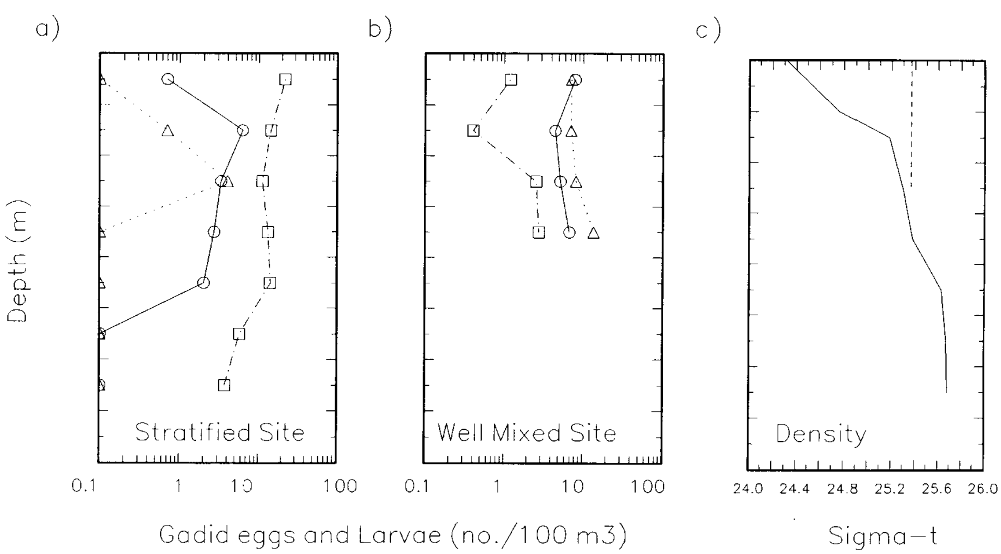

Figure 3. Vertical distribution of haddock larvae (circles), cod larvae (triangles) and gadid eggs (squares) at (a) the stratified and (b) well-mixed sites; (c) water column density profiles at the stratified (solid) and well-mixed (dotted) sites.

(Editors Note: This issue of U.S. GLOBEC NEWS introduces Technology Forum, which will be a regular feature of the newsletter, and which we hope will stimulate thought and discussion on diverse oceanographic technology issues. We welcome contributions on technological issues relative to ocean science, but particularly to U.S. GLOBEC.)

The Video Plankton Recorder

by Cabell Davis and Scott Gallager

The VPR is a video-microscope system used for imaging plankton and other particulate matter in the size range from a few micrometers to several centimeters. It consists of four video cameras (with magnifying optics) synchronized at 60 fields per second (fps) to a red-filtered 80 W xenon strobe (pulse duration = 1 microsecond). The current lens on each camera can be adjusted to provide a field of view between 5 mm and 10 cm. Use of higher magnification lenses is currently being explored for viewing protozoans (<1 μm resolution). The four cameras are set for concentric viewing fields so that a range of up to four magnifications can be viewed simultaneously, allowing a wide size range of plankton to be sampled. Depth of field is adjusted by the lens aperture setting, and the volume sampled in each video field ranges from about 1 ml to 1 liter, depending on lens settings. The cameras have been configured for stereoscopic viewing as well.

The red light beam from the strobe is expanded to 10 cm, collimated, and aimed obliquely to provide dark-field illumination. Strobe to camera distance is 1.0 m with the viewing area at 0.5 m. Video data are telemetered to the surface via fiber optic cable and stored, together with time code overlay, using broadcast quality video tape recorders.

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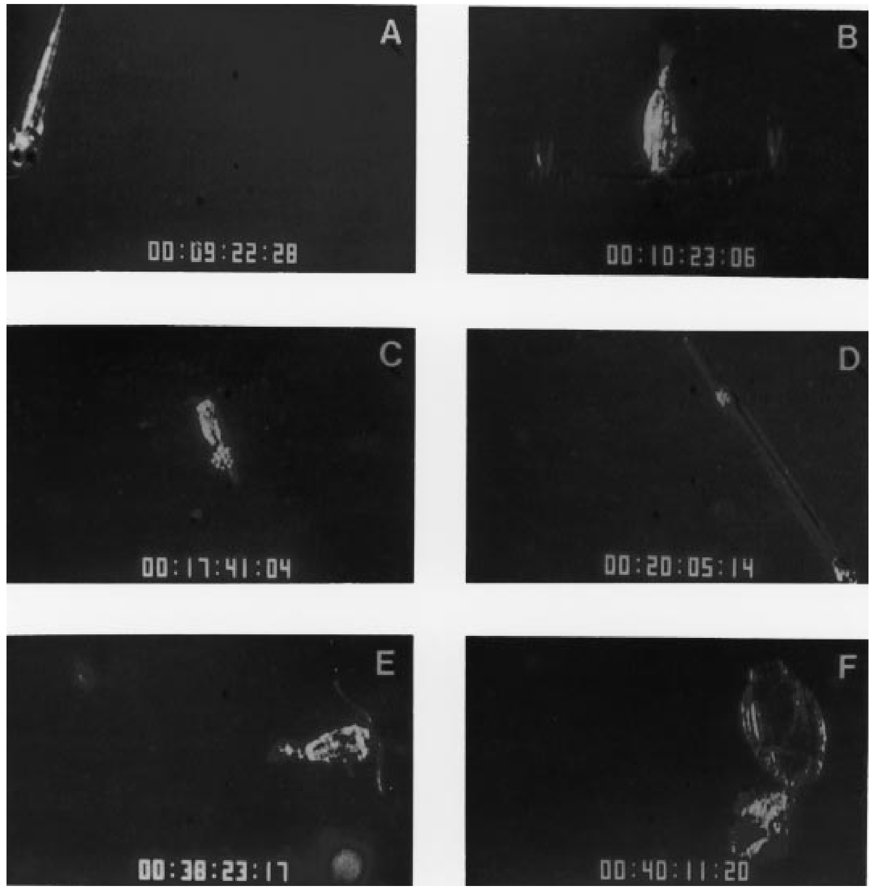

VPR Images of Plankton. (A) Larval fish; (B) Calanus; (C) Pseudocalanus adult female with attached eggs; (D) Sagitta, a chaetognath; (E) Centropages typicus; (f) Doliolum nationalis.

Moored Optical Plankton Counter — Long-Term Monitoring of Zooplankton and Temperature in Scotian Shelf Waters

by Alex W. Herman

The Scotian Shelf contains several deep basins (Emerald and La Have) which aggregate and harbor zooplankton during fall and winter months. As a result of a sampling program starting in 1984 using Batfish/BIONESS/acoustics (Herman et al. 1991; Sameoto and Herman 1990), we have found that these copepod populations (mainly *Calanus*) exhibit certain annual characteristics. That is, they represent a large component (≈50%) of the shelf *Calanus* populations from the previous growth season. They also contain the dominant populations that will seed the surface waters at the end of winter, thereby commencing the reproduction and production cycle on the Scotian Shelf. These surface populations then dominate the central Shelf waters and banks. The basins contain warm slope water (9-12˚C) and are marked by weak circulation near the bottom thus enabling the copepod populations to reside there. The Emerald and La Have Basins, therefore, are focal/observational points for determining the state of the copepod populations on the Scotian Shelf.

Mounting observational evidence indicates that temperature is a key factor in controlling zooplankton production and that we should be monitoring the Emerald/La Have Basins over decadal periods. If long-term global climate change occurs, will we see its effects in Nova Scotian shelf

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OPC—(Cont. from page 6)

water temperatures and zooplankton populations? Two independent observations indicate that temperature effects produce an impact on zooplankton populations. First, during the late 1960's, shelf water temperature decreased as a result of an influx of the Labrador Current. Temperature of the slope water residing in the Emerald Basin decreased by 5˚C. Intensive zooplankton sampling indicated that species composition and migrational behaviour changed during this period. Second, temperature effects on basin zooplankton populations are currently being observed on decadal time scales. Since 1984 our studies of the Scotian Shelf and Emerald/La Have Basins indicate that basin temperatures have decreased from 11.5˚C in 1984 to 9.2˚C in 1991. These changes were accompanied by a simultaneous decrease in basin zooplankton populations by a factor of 4-5.

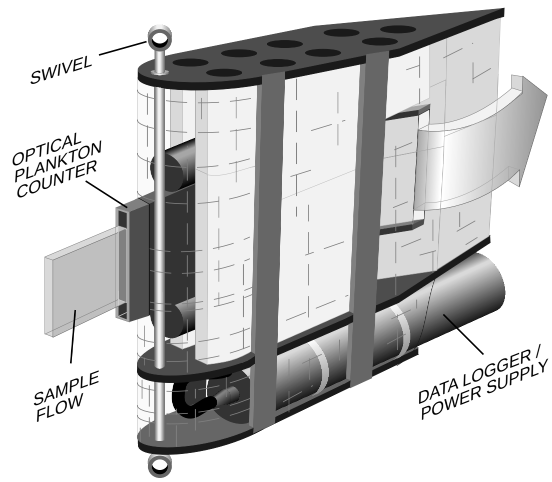

Figure 1. Design of the moored optical plankton recorder showing the vertical orientation, foil for alignment in the flow, and data logger and power supply unit.

The Moored Optical Plankton Counter

A pilot mooring program was initiated in September 1991 to monitor zooplankton populations and temperature continuously in Emerald Basin. The central sensor of the mooring is a redesigned optical plankton counter (OPC; Herman 1992; Herman 1988) which is mounted inside a foil (Fig. 1). The foil aligns itself in the tidal flow and samples zooplankton via a protruding tunnel. A data logger/power supply mounted below the OPC controls its operations. An on-board computer contains a 'look-up' table of peak tidal flows (predicted flows based on experimental data) and 'wakes up' twice a day sampling zooplankton for a period of ≈1 hr. Temperature and current are monitored via two recording current meters mounted above and below the OPC foil.

Figure 2 shows data collected during a test deployment in Emerald Basin in September 1991. The moored OPC sampled 30 minutes every hour for 24 hours. Current meters situated 5 m below and 15 m above the foil yielded flow and direction, temperature and salinity information. The data show that zooplankton counts for *Calanus* copepodite stages IV & V increased with current speed. Reliable zooplankton count data can be obtained only at speeds of >7 cm s^{-1} which represents a detection limit for the OPC. Hence, the OPC must sample during periods of peak tidal flow (which in Emerald Basin ranges between 10-20 cm s^{-1}). Measurement of flow speed is required to estimate volume of seawater processed through the tunnel.

Subsequent to this trial deployment, the moored OPC has been deployed and has functioned reliably in Emerald Basin since September 1991. It is intended to project the program as far into the future as resources will permit.

Sampling Strategy

It is clear that a single depth

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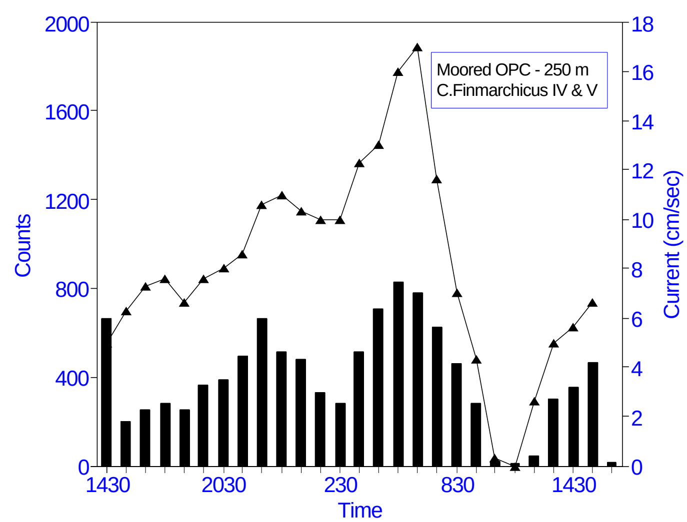

Figure 2. Data collected during a 24 hour test deployment of the moored OPC in Emerald Basin in September 1991. Data were collected at 30 minute intervals. Histogram bars indicate counts of <u>Calanus finmarchicus</u> copepodite stages IV and V grouped. Line and triangles are current speed.

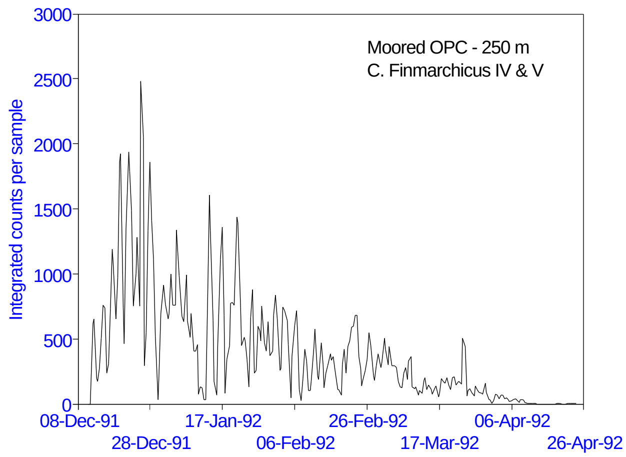

Figure 3. Uncorrected counts (i.e., not normalized by volume) of the size group corresponding to Calanus finmarchicus copepodites IV and V for the period December 1991 to April 1992 in Emerald Basin.

OPC—(Cont. from page 7)

mooring is insufficient to provide a full and complete picture of zooplankton populations. On the positive side, a single mooring situated deep in the Emerald Basin can provide considerable information that would not be otherwise available in, say, surface layers. The Emerald Basin, as is the case with most shelf basins, represents a stable and quiescent environment for zooplankton. Intrusions into basins from external sources occur slowly and rarely displace zooplankton. Intrusions consist of denser water which cause upward displacement of existing basin water at an extremely slow rate (≈0.1 mm sec^{-1}). Emerald Basin copepod stocks are dominated by *Calanus finmarchicus* stages IV & V (90% of copepod populations present while within the Scotian Shelf basins; 60% of the entire shelf biomass during winter). Therefore they are easily monitored by the OPC. Their migration into the surface layers in winter can be monitored as can the buildup of basin populations during spring and summer. Generation cycles (growth and development) can also be monitored by optical measurement of size distributions. The basin zooplankton layers are generally homogeneous; the layer is approx. 40 m in vertical thickness and spatial variability (horizontal) of concentration (no. m^{-3}) is only a factor of 2X as determined from Batfish sampling. As a result, basin environments are easily sampled and quite respesentative of shelf zooplankton over the long-term. At present our sampling scheme has been extended to 2 depths: one at the center of the copepod layer at 240 m depth; and one just above the layer at 210 m depth. The OPC at the latter depth provides information on upward and downward flux out of and into the deep layer.

Optical Fouling

At depths below 200 m in the Emerald Basin, fouling of the optical windows is not as serious as in the upper layers. During the fall and winter of 1991-92, the moored OPC provided continuous data of high quality and had no fouling problems. However, the spring bloom in April and subsequent “fallout or raining” of material at depth caused immediate and intense fouling of the OPC windows rendering the data unusable. Growth in the upper layers during spring and summer and subsequent fallout limited our sampling periods. Our highest quality data has been obtained for the overwintering, nonproductive period. Various solutions to the fouling problem are being tested for the summer sampling periods.

Preliminary Data

The overwinter period from December 1991 to April 1992 was sampled successfully with a moored OPC deployed at 240 m depth in the Emerald Basin. Our current thought regarding the surface migration of basin populations has been that these animals migrate to the surface nearly instantaneously by responding to some cue. The winter period has always been undersampled by our ships-of-opportunity net-sampling cruises and the migration period has never been adequately resolved. Figure 3 shows a record of raw counts per second (not normalized to volume sampled) of the size group corresponding to *Calanus finmarchicus* Stages IV-V. The record shows that the counts decrease rapidly, particularly during the months of Febuary-March, dwindling to nil in April. This decrease indicates that the return migration to the surface is a more gradual process than previously believed. Moreover, return of the deep-dwelling populations to the surface is completed just prior to the spring surface bloom.

Future Direction

Due to its large size, it is difficult to deploy enough moored OPC samplers to achieve good spatial resolution of zooplankton abundance in Scotian Shelf Waters. We are currently developing a laser-based OPC that is more compact, requires only a single pressure case, and is capable of measuring zooplankton abundances and sizes in static conditions without flow. The completed development of a laser-based OPC would enable deployment of a larger number of sensors per mooring, which would significantly improve vertical resolution of zooplankton abundance estimates. *(Alex Herman is an oceanographer at the Bedford Institute of Oceanography.)*

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VPR—(Cont. from page 6)

Abundance is calculated from the video by counting number per field and dividing by the field volume. Full description of the VPR design is given in Davis et al. (1992a,b). (To minimize potential avoidance problems, the gauze recorder box shown in Davis et al. (1992a) has not been incorporated into the VPR, so that the 1.0 m space between cameras and strobe is free of obstructions).

The VPR can be deployed in towed configuration for mapping plankton distributions, or in a fixed position for viewing plankton swimming behaviors in two or three dimensions. The system has been used in both configurations, and deployment on moorings and ROVs has been proposed.

During towing of the VPR, fluid flow is orthogonal to the camera-strobe axis. The VPR has been towed at speeds of 0.5-3 m s^{-1} in shelf and oceanic waters near Woods Hole providing data on abundance of planktonic taxa over a continuum of scales from micrometers to kilometers (Davis et al. 1992b). Extensive transects (100 km, 14 h deployments at 2 m s^{-1}) have been made across Georges Bank while "towyoing" the instrument between the surface and bottom. Reconfiguring the tow body for towing at speeds up to 5 m s^{-1} has been proposed. The VPR is currently rated to 300 m, and pressure casings rated to 2000 m are under construction.

In situ observations of zooplankton swimming behaviors have been made at the WHOI dock and the data are currently being analyzed. In addition, the VPR will be deployed on the ROV JASON for two-camera observations of plankton distributions and swimming behaviors in mid-water and near bottom in the vicinity of hydrothermal vent sites (Guaymas Basin, March 1993).

The VPR was designed to minimize disturbance of the sampled volume in order to reduce possible disruption of the imaged particles or detection and avoidance of the sampler by the plankton. Frontal area is much smaller than that of a comparably sized plankton net, and the imaged volume is located along the forward (upstream) edge of the instrument. Red light was used since zooplankton are known to be phototactic but are least sensitive to long wavelengths of light. The large amount of open space between cameras and strobe (1.0 m) minimizes flow disturbance near the viewing area as determined by dye and avoidance studies in a tow tank (C. Davis and L. Haury, unpublished data). *In situ* observations made in lower magnification cameras revealed that organisms' trajectories, body orientation, and shape remained constant during transit through these windows, indicating lack of flow distortion or escape response.

The VPR was designed to minimize disturbance of the sampled volume in order to reduce possible disruption of the imaged particles or detection and avoidance of the sampler by the plankton.

Examples of planktonic organisms imaged with the VPR are shown in Figure 1. Pattern recognition algorithms are being developed for automated analysis of the VPR images. We presently use an Imaging Technologies Inc. model 151 Image Processor that does real-time (60 fps) frame grabbing, convolutions, edge detection, and outputs the edge coordinates to a host computer. This procedure follows that described by Berman et al. (1990). New image processing algorithms are being developed in collaboration with pattern recognition experts as part of a two-year ONR contract (1/1/93-12/31/94). The goal is to develop a procedure for accurate automated analysis of zooplankton size and taxonomic composition (first to major taxa and ultimately to genus level). Once accurate algorithms are developed, appropriate hardware for real-time analysis will be configured. The automated system then can be used at-sea to provide real-time acquisition of these data. A moored system also has been proposed which will transmit processed images to shore via satellite.

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Stratification—(Cont. from page 5)

500 m from the physical oceanographic mooring. A LORAN-C drifting buoy with drogue at 15 m depth was deployed at the stratified site and constituted a third, southwestward drifting site during the cruise.

The two vessels conducted short (4 km) transects at the different sites on a rotating basis. During a transect the various sampling systems were deployed and, when appropriate, tow-yo'ed to provide information on the distribution of larvae and their prey on small space scales (e.g., VPR, TAPS, CTD). Joint transects by both vessels were done to allow comparisons between systems. These short transects provided repeated simultaneous measurements by different systems under different stratification conditions.

In the second portion of the study, sampling on five 1.5 km x 1.5 km grids was conducted at the different sites. The grid surveys were conducted both individually and jointly by the vessels. The grid sampling attempted to provide a three-dimensional picture of the fine-scale distribution of larvae, their prey, and the hydrographic structure. A grid consisted of six transects spaced about 300 m apart. In joint operations, one vessel followed the other and offset laterally by about 150 m, so that the result was 12 transect lines about 150 m apart.

Results

A broad concentration of gadid larvae was located on the southern side flank of Georges Bank, extending from the shoals (<60 m) to the 90 m isobath and centered near 68°W. Haddock eggs and recently hatched larvae (4-5 mm standard length [SL]) were most abundant at the deeper, stratified site, whereas cod larvae were most abundant at the shoal, well-mixed site. Larvae at the well-mixed site were a few weeks older (5-8 mm SL) (Fig. 3). At the stratified site, larvae were concentrated

(Cont. on page 11)

Biological Sampling Systems

MOCNESS (Lough): Two Multiple Open/Closing Net and Environmental Sampling Systems are being used. A 1 m^2 system, with 333 µm mesh nets, is the primary tool for determining the vertical distribution of cod and haddock larvae and collecting specimens for chemical analyses. A 1/4 m^2 system with 64 µm mesh nets provides depth stratified collections of the larval prey organisms.

Plankton Pump (Green and Incze): A plankton pump equipped with 20 µm mesh collects discrete depth samples of organisms down to the smallest copepod life stages. Analysis of these samples will provide taxonomic and life history stage composition of the larval prey field.

BIOSPAR (Wiebe): BIOSPAR (BIOacoustic Sensing Platform And Relay), is an autonomous dual-beam biological echo sounder system and satellite and radio communications systems mounted in a spar buoy. BIOSPAR carries two down-looking transducers, one operating at 420 kHz and the other operating at 120 kHz. Profiles of acoustic backscattering are obtained in 1 m depth intervals in the upper 100 m.

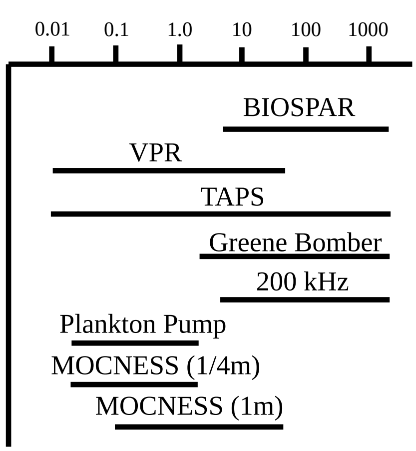
Greene Bomber (Wiebe and Greene): A towed, dual-beam acoustic system operating at 420 kHz and 1 MHz provides continuous profiles of the water column for zooplankton with a size range of 1.5 mm to 100 mm.

Video Plankton Recorder (Davis): A Video Plankton Recorder (VPR), under development with NSF funds, measures the distribution of larval fish prey taxa on scales from microns to kilometers. The VPR allows real time, high-resolution (< 10 µm), video observations of planktonic organisms (and other particulate matter). The field of view of the optics allows organisms from 100 µm to > 1 cm to be identified to major taxa (i.e., nauplii, copepodite, chaetognaths, etc.).

TAPS (Green and Berman): The Tracor Acoustic Profiling System developed by V. Holliday of Tracor Inc. uses a four transducer array operating at frequencies 265 kHz, 420 kHz, 1.1 MHz, and 3 MHz. The transducer array is designed to provide information on the distribution of individual organisms ranging in size from individual copepods to nauplii at distances of 2-3 m.

Towed 120 & 200 KHz System (Green and Berman): A towed body with 120 kHz and 200 kHz dual-beam transducers provides synoptic horizontal mapping of macrozooplankton concentrations (Macaulay et al. 1990). The system can efficiently provide the broadscale context in which the localized observations from the other systems occur. ΔΔΔ

Sampling Systems Target Size Ranges (mm)



Stratification—(Cont. from page 10)

within the broad region of the pycnocline between 10 and 30 m. At the well-mixed site, larvae were distributed throughout the water column, with the older, larger cod larvae increasing in abundance toward the bottom.

The 1-m MOCNESS collected larvae for gut content, biochemical and otolith analysis. RNA, DNA and protein content have been analyzed for 244 larvae. The otoliths from these same larvae will be analyzed for daily increment width for estimating larval growth. The prey field for the larvae will be determined from gut contents and compared with suitable prey in the water column estimated from the 1/4-m MOCNESS and plankton pump samples, and from the results of the video and acoustic systems.

Calanus finmarchicus were sorted from the MOCNESS collections at the stratified and the well-mixed study sites for genetic analysis by Ann Bucklin (University of New Hampshire). The genetic similarity of the Georges Bank, Wilkinson Basin (Gulf of Maine) and Gulf of St. Lawrence populations confirms that the Gulf of Maine and Gulf of St. Lawrence are source regions for recruitment of *C. finmarchicus* to Georges Bank.

Initial data processing indicates that the various acoustic and video sensing systems all functioned well. Sufficient data were collected to intercompare the systems, but those comparisons have not yet been completed. The VPR provided near-real time insights into the plankton taxonomic composition in the water column. *Calanus* remained largely within the top 10 m of the water column both day and night. Preliminary abundance estimates indicate surface swarms at densities as high as 20,000-50,000 m^{-3}. High densities of larvaceans and pteropods were also observed. Densities of the latter were as high as 10^6 m^{-3} and comprised a dense scattering layer observed with the towed acoustic instruments.

The 120 kHz acoustics on BIOSPAR provided volume backscattering in 1 m depth intervals throughout the water column for the seven day mooring period. In addition to storing the data internally, the data were transmitted via VHF radio telemetry to the vessel, and, in reduced form, were transmitted daily to shore via ARGOS satellite. In general, BIOSPAR observed a significant diel cycle which consisted of a layer of high volume backscattering residing at mid-depths (~40 m) during the day and moving up into the surface layer at dusk (Fig. 4). Large transient targets appeared occasionally in both the BIOSPAR and the 420 kHz towed acoustic ("Greene Bomber") data. These targets occurred from mid-depth to just above the bottom and may have been schools of herring or other larger fish.

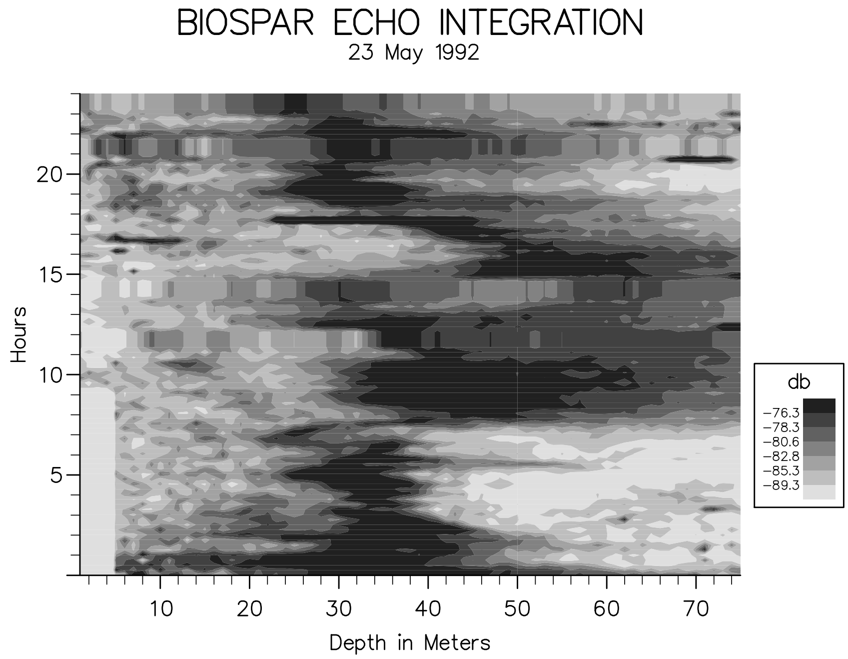


Figure 4. BIOSPAR volume backscattering for 23 May 1992.

The towed 420 kHz acoustic system had roughly an order of magnitude greater backscatter than the BIOSPAR 120 kHz system, probably because of the different abundance of targets visible by the different frequencies (120 kHz has a minimum detectable size of ~10 mm; 420 kHz has minimum detectable size of ~4 mm). Preliminary analysis of the differences in the vertical distribution of acoustic backscatter by the two instruments suggests that the differences are real and reflect the difference in vertical distribution of the organisms detectable by the two frequencies.

Identifying the three-dimensional relationships between the biology and the physical structure on a fine spatial scale was an important objective of this study. To maintain the correct spatial relationship of the sampled water columns during the four hours needed to complete the grid required compensating for the net translation of the water by the tidal currents. To accomplish this, six parallel transects spaced 300 m apart were sampled relative to a drifting buoy drogued at about 15 m. This simple technique worked quite well. While the drifter moved about 4 km and the vessel track relative to the earth extended over about a 6 km area, the pattern of sampling, relative to the water (i.e., drifter) formed the desired, well-defined grid. The method assumes that the horizontal current shear on the scale of the grid is small,

(Cont. on page 12)

Stratification—(Cont. from page 11)

which is probably a reasonable assumption. The vertical current shear, however, is a problem. The moored current measurements indicate about a 3 to 2 ratio in the displacements expected at 15 and 45 m. With the surface moving about 4 km, the deeper part of the water column would have moved only about 2.5 km—so that the surface and deeper water columns would have been shifted about one grid scale relative to each other during the grid sampling. This problem can be minimized by placing the drogue at the depth where the biological and physical structure of interest is located. Compensation for vertical shear translation of sampled water parcels can also be done using moored or shipboard current measurements to calculate relative locations in a fixed-time reference frame.

The analysis of the data from the various sampling systems is continuing. The data sets will be used for both system intercomparisons and for analysis of the relationships between the larval fish (both abundance and physiological condition), their prey field and the physical structure of the water column. It is hoped that these results will provide a foundation for more intensive studies during the U.S. GLOBEC Northwest Atlantic Program.

The Stratification Group includes: R. Beardsley (Woods Hole Oceanographic Institution, WHOI), M. Berman (National Marine Fisheries Service, NMFS), L. Buckley (NMFS), C. Davis (WHOI), A. Epstein (WHOI), J. Green (NMFS), L. Incze (Bigelow Laboratory of Ocean Sciences), G. Lough (NMFS), J. Manning (NMFS), D. Mountain (NMFS), P. Wiebe (WHOI).

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Bioacoustical Oceanography Workshop

A five week workshop on bioacoustical oceanography will be held at Friday Harbor Laboratories from July 19 to August 21, 1993. The workshop will attempt to give participants an extensive overview of the field of bioacoustics including review of the principles of sound propagation in the ocean and the basics of acoustic signal processing. Participants will be introduced to the theory and practical aspects of multiple-frequency, split-beam, dual-beam, acoustic doppler, and acoustic imaging techniques. The first two weeks will focus on lectures, seminars, and demonstrations (many by invited acoustical experts). The final three weeks will be devoted to experiments, data analysis and reporting. The intended audience for this workshop includes graduate students, postdoctoral associates and research scientists at the beginning of their careers. Course instructors are Charles Greene (Cornell), Peter Wiebe (Woods Hole Oceanographic Institution, WHOI) and Tim Stanton (WHOI). Further information about the workshop can be obtained from Dr. Charles Greene, Director, Ocean Resources & Ecosystems Program, Corson Hall, Cornell University, Ithaca, NY 14853. ΔΔΔ

U.S. GLOBEC

GLOBAL OCEAN ECOSYSTEMS DYNAMICS

U.S. GLOBEC NEWS

U.S. GLOBEC NEWS is published by the U.S. GLOBEC Scientific Coordinating Office, Division of Environmental Studies, University of California, Davis, California 95616-8576, telephone (916) 752-2332, FAX (916) 752-3350. Correspondence may be directed to Hal Batchelder at the above address. Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the meeting calendar should contain dates, location, contact person and telephone number. To subscribe to U.S. GLOBEC NEWS, or to change your mailing address, please call Sharon Lynch at (916) 752-4163, or send a message to Omnet address T.POWELL or H.BATCHELDER or Internet address hpbatchelder@ucdavis.edu, or write to the address above.

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Janet Perkins

GLOBEC/ICES Working Group on Cod and Climate Change

by Keith Brander

The working group on Cod and Climate Change was established at the 1992 ICES Statutory meeting to carry forward the work begun by the ICES study group. It will meet for the first time in June 1993 in Lowestoft, U.K. under the chairmanship of Dr. K. Brander. Terms of reference for the meeting are as follows:

- review planning and progress of Cod and Climate research;
- review previous study group reports and ongoing regional programs to identify common elements which may serve as unifying themes and enhance comparisons between areas;
- review recent advances in models of global and Atlantic climate variability, consider how these models may be used as boundary conditions for regional models, and plan a specialized workshop on the subject if necessary;
- explore ways of incorporating numerical population models of key species within spatially resolved ecosystem models, in which other species are represented by a relatively small number of aggregated functional groups;
- consider additional opportunities for regional studies and, if appropriate, initiate planning;
- make recommendations, with terms of reference, for future meetings of the working group and/or more specialized workshops, to advance the goals of the Cod and Climate Change program.

Expertise in many fields will be needed to tackle this wide-ranging and ambitious agenda, but the scope is limited to some extent because the investigation is applied to a single species—cod. Previous reports of the ICES study group (notably ICES C.M. 1991/G:78) provide useful summaries of discussions on the application of physical models. Five questions framed by Ken Brink on the application of physical models in the Cod and Climate context are as follows:

- How sophisticated do the models have to be?
- Is the database adequate for intialization, model driving and evaluation?
- What gaps are there in physics and biology process knowledge?
- Is the cod population predictable? Is it chaotic?
- What phenomena need to be resolved by the models?

It is my impression that we can answer a number of these questions and will, I hope, be able to make progress at the meeting in identifying and specifying fruitful areas for modelling and field or experimental investigation. Scientists wishing to participate in the June 1993 working group meeting should contact Dr. K. Brander, Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT, UK (Omnet: MAFF.LOWESTOFT - Attn. Keith Brander). ΔΔΔ

ICES Symposium on Zooplankton Production Set for August 1994

A symposium will take place on August 15-18, 1994 in Plymouth, U.K. on "Zooplankton Production: Measurement and Role in Global Ecosystems and Biogeochemical Cycles". The directions set forth at this meeting will be valuable in guiding future activities of the international GLOBEC and GOOS (Global Ocean Observing Systems) programs. Topics of discussion will include:

- Coupling of zooplankton population dynamics and ocean physics to control the magnitude of secondary production, interannual variability of living marine resources, magnitude and fate of primary production, and biogeochemical cycles.

- New technologies for rapid at-sea zooplankton population characterization, including production indices.

- Coupled models of physical and biological dynamics.

Co-convenors of the planning committee are Mike Reeve, Washington, DC, and Hein Rune Skjoldal, Bergen, Norway. For further details contact the local organizers: Roger Harris (Omnet: PML.UK), Plymouth Marine Laboratory, or John Gamble (Omnet: J.GAMBLE.CPR), Sir Alister Hardy Foundation for Ocean Science. The address for both is Prospect Place, Plymouth PL1 3DH, U.K. (Phone: +44 752 222772; Fax +44 752 670637).

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1993

20-22 May: International Symposium on Environmental Information Management and Analysis: Ecosystem to Global Scales, Albuquerque, NM. Contact: EIM Symposium Information Office, Department of Biology, University of New Mexico, Albuquerque, NM 87131-1091 (Internet: eim@sevilleta.unm.edu; Phone: 505-277-1913; FAX 505-277-5355).

2-3 June: U.S. GLOBEC Scientific Steering Committee meeting, Washington, DC. Contact: H. Batchelder, Division of Environmental Studies, University of California, Davis, CA. (Omnet: H.BATCHELDER or T.POWELL; Phone: 916-752-4163; FAX 916-752-3350).

June: GLOBEC/ICES Working Group on Cod and Climate Change, Lowestoft, U.K. Contact: K. Brander, Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory, Lowestoft, Suffolk NR33 0HT, U.K. (Omnet: MAFF.LOWESTOFT; Phone: 0502-562244; FAX 0502-513865).

14-18 June: Gordon Research Conference on Coastal Ocean Circulation, Plymouth, NH. Contact: M. Bowman, State University of New York, Stony Brook, NY. (Internet: mbowman@ccmail.sunysb.edu; Phone: 516-632-8669; FAX 516-632-8820).

14-18 July: Workshop on Researcher-Seabird Interactions, St. Paul, MN. Contact: W. Fraser, Polar Oceans Research Group, 830 Hunt Farm Rd., Long Lake, MN. (Omnet: W.FRASER; Phone: 612-473-3881; FAX 612-476-8527).

16-20 August: Gordon Research Conference on Predictive Theory in Biological Oceanography and its Evaluation, New London, NH. Contact: P. Jumars, School of Oceanography, University of Washington, Seattle, WA. (Omnet: P.JUMARS; Internet: jumars@ocean.washington.edu; Phone: 206-543-7615; FAX 206-685-3354).

22-24 September: Marine Technology Society meeting on Technology Requirements in the Nineties., Long Beach, CA. Contact: MTS '93 (Phone: 703-631-6200; FAX 703-818-9177).

7-8 October: U.S. GLOBEC Scientific Steering Committee meeting, Woods Hole, MA. Contact: H. Batchelder, Division of Environmental Studies, University of California, Davis, CA. (Omnet: H.BATCHELDER or T.POWELL; Phone: 916-752-4163; FAX 916-752-3350).

21-23 October: Eastern Pacific Oceanic Conference Annual Meeting (EPOC), Fallen Leaf Lake, CA. Contact: G. Lagerloef (Omnet: G.LAGERLOEF; Internet: lagerloef@frazil.nw.saic.com).

25-30 October: Second Annual Meeting of the North Pacific Marine Science Organization (PICES), Seattle, WA. Contact: PICES Secretariat, Institute of Ocean Sciences, P.O. Box 6000, Sidney, BC, Canada V8L 4B2 (Omnet: PICES.SEC;Phone: 604-363-6366; FAX 604-363-6827).

1994

15-18 August: ICES Symposium on Zooplankton Production: Measurement and Role in Global Ecosystems and Biogeochemical Cycles, Plymouth, U.K. Contacts: R. P. Harris, Plymouth Marine Laboratory, or J. C. Gamble, Sir Alister Hardy Foundation for Ocean Science, Prospect Place, Plymouth PL1 3DH, UK (Omnet: PML.UK or J.GAMBLE.CPR; Phone: + 44 752 222772; FAX +44 752 670637).

NSF and NOAA Agree to Joint Management of U.S. GLOBEC

by William Peterson

One year ago, the U.S. GLOBEC program became an interagency endeavor through signing of a formal agreement between NSF assistant director for Geosciences, Robert Corell, and NOAA assistant administrator for Fisheries, William Fox. Terms of that agreement are summarized in this article.

U.S. GLOBEC is organized around two major foci, the Scientific Steering Committee (SSC) and the Interagency Program Coordination Office (IPCO). The SSC, responsible for developing the scientific rationale for the program, is comprised of members from both the NSF and NOAA communities. IPCO manages day-to-day matters and direction of the program by coordinating field activities, arranging logistical support and ensuring adherence to U.S. GLOBEC data management policies. IPCO is headed by a program manager (Bill Peterson). Overall direction of U.S. GLOBEC via the IPCO is provided by two co-directors: Mike Sissenwine, senior scientist for Fisheries of NOAA, and Phil Taylor, program manager of biological oceanography of NSF. The co-directors will receive recommendations from an advisory council which will consist of members of each NOAA Line Office and the NOAA Chief Scientist Office, and representatives from the NSF Advisory Commit-

(Cont. on page 15)

Joint Agreement—(Cont. from page 14)

tees for Ocean Sciences and Polar Programs. The council will be established later this spring.

Research support for U.S. GLOBEC is provided by the National Science Foundation, NOAA/Office of Global Programs and NOAA/National Marine Fisheries Service.

The Interagency Program Coordination Office and the Program Manager

Presently, the IPCO and program manager are located at Fisheries Headquarters: NOAA/NMFS, F/RE3, 1335 East-West Highway, Silver Spring, MD 20910. The location may be changed if NOAA and NSF agree that a change is beneficial to U.S. GLOBEC. The host organization provides facilities support. The manager is responsible for:

(1) Management of U.S. GLOBEC planning and research activities.
(2) Interagency coordination, including that with non-sponsoring agencies.
(3) Coordination with the Scientific Steering Committee.
(4) Coordination with other relevant and appropriate scientific programs.
(5) Preparation of joint NOAA/NSF solicitations for proposals for U.S. GLOBEC activities; organization and supervision of the relevancy, priority and merit review of research proposals; coordination and direction of award funding; and adherence to all agency procurement and review regulations.
(6) Coordination of implementation teams for large multi-disciplinary, multi-investigation projects.
(7) Intergovernmental coordination in International GLOBEC activities.

Status

An RFP for research on Georges Bank/Northwest Atlantic was issued last summer with a proposal deadline of September 15, 1992. An implementation plan review panel convened on December 17, and the proposal review panel convened on December 18-19. Decisions on Georges Bank/Northwest Atlantic funding were delayed due to budgetary uncertainties caused in part by the change in administration. The precise amount of the FY 1993 budget for U.S. GLOBEC was dependent upon a number variables and even at this writing, is still not completely known! Money from the NOAA side was released in early April 1993, but the NSF appropriation is tied to President Clinton's Economic Stimulus Package which, at the time of this writing, is held up by a filibuster in the Senate.

Decisions have been made on all awards; however, not all PI's know the size of their awards because we do not have a final budget yet. The next newsletter will contain a summary of projects which we have initiated.

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SCOR WG93
Pelagic Biogeography

by A.C. Pierrot-Bults and D.B. Olson

A SCOR working group (SCOR WG93) created in 1990 is reviewing our understanding of pelagic biogeography. Specifically, the working group is formulated to:

1) Review recent developments in biogeographic theory and their application to ocean pelagic biogeography;

2) Recommend new approaches to future studies on pelagic biogeography emphasizing the mechanisms that result in observed patterns and the interactions of organisms and their physical-chemical-biological environment;

3) Examine the possibilities of advancing pelagic biogeography using (a) more adequate sampling techniques and (b) futher interpretation of available data and existing plankton and nekton collections.;

4) Prepare a manual of existing collections;

5) Hold appropriate workshops, followed by a second international conference on pelagic biogeography in cooperation with other interested organisations; and

6) Identify the significance of biogeographic patterns and their changes with respect to other aspects of oceanography.

The general chair for SCOR WG93 is A. C. Pierrot-Bults of the Institute for Taxonomic Zoology at the University of Amsterdam. The working group held its first meeting at the University of Amsterdam in November 1990. Following a review of the terms of reference and the recommendations of the International Conference on Pelagic Biogeography (see UNESCO technical papers in marine science #49, 1986) the meeting continued with a set of technical briefings. These included discussions of theory and methods of pelagic biogeography, of distribution patterns in both the paleorecord and in the present ocean, and of the various problems in pelagic biogeographical research. A manual of existing plankton collections, a set of white papers on various issues in pelagic biogeography, and future meetings were discussed. Several white papers are now available with several others in preparation. A second meeting was held in Kiel in September 1992 in coordination with the international meeting on paleoceanography. Another meeting is planned for the fall of 1993. Current plans call for an international conference in early summer 1995 similar to the one held in 1985. ΔΔΔ

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