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IMAGE ANALYSIS AT THE INSTITUTE OF MARINE RESEARCH, NORWAY

by

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ABSTRACT

Computer-aided analysis of images is a technology gaining importance and utilization in marine science. Whereas analyses by eye are often tedious, slow and inaccurate, state-of-the-art image analysis is rapid, accurate, permits operator intervention and produces data in the form of tables as well as graphic presentations.

In addition to image-analytic expertise on otoliths at the institute's biological station at Flødevigen, the Institute of Marine Research in Bergen has developed an image-analysis system called Zeus to aid scientists in routine and specialized investigations. In its simplest form the system consists of a Zeus computer, a Macintosh computer, a high-resolution monitor and high-resolution black-and-white camera. Zeus is user-friendly, can be run in the laboratory or in the field and can analyze images from video tapes, still photographs, computer pictures, directly from a camera or from digitized images stored on diskette.

Zeus has been applied for objects ranging in size from bacteria to ice floes. Research includes investigations on autotrophic as well as heterotrophic plankton, fish otoliths and swimming behavior, bioturbation in sediments, seal sizing from aerial photography and even distribution of drift ice. Development of applications continues.

The purpose of this paper is to provide a brief description of the image-analysis system developed at IMR, an overview of some of the major projects using Zeus, key findings and references for additional reading.

HISTORY OF "NICFAR"

Supported by The Royal Norwegian Council for Scientific and Industrial Research (NTNF), Dr. Kenneth W. Estep began development of an image-analysis system at the Institute of Marine Research (IMR) in Bergen. This promising start was recognized and awarded by the Norwegian Fisheries Research Council (NFFR), and consequently the project, Norwegian Image-Analysis Centre for Fisheries and Aquatic Research (NICFAR), was established in 1989. From 1989 to late 1990 Estep further assembled the computing and video hardware and developed the programs for Zeus, as the image-analysis system is called. In early 1990 Dr. Thomas T. Noji joined the institute and worked intensively with Estep in developing applications for marine research using Zeus. In the latter part of 1990 Noji and Dr. Ferren MacIntyre, co-programmer of the Zeus software, continued research on the development and application of Zeus in fisheries and marine research. These two scientists decided to emphasize the refinement of systems applications rather than systems development. Naturally modifications were still made on the system software but primarily in accordance with specific applications requirements.

The development of Zeus is now considered to be complete, although minor modifications according to users' needs are still possible. Further development of applications using Zeus at IMR continues. Emphasis is given not only to utilizing Zeus for new research activities but also for improving and accelerating ongoing routine analyses.

WHAT IS IMAGE ANALYSIS?

Image analysis has come to be identified with state-of-art computer technology, high resolution cameras, expensive video equipment and complicated applied empirical modeling understood by only the very few (Fig. 1). This is unfortunate, as the uninitiated laymen and scientists are often too alarmed by this corrupt picture to employ image analysis in their work. Indeed the method can be manifested in such a high-technology art for the expert, however in its simplest form we may consider image analysis to be nothing more than the measurement of some optical property, e.g. length, of an object on a television screen. This is usually handled by a computer. Thus an image-analysis system consists of a camera, a monitor and a computer. It may be used to measure the length of a kitchen table or model the 3-dimensional swimming speeds and behavior of juvenile salmon.

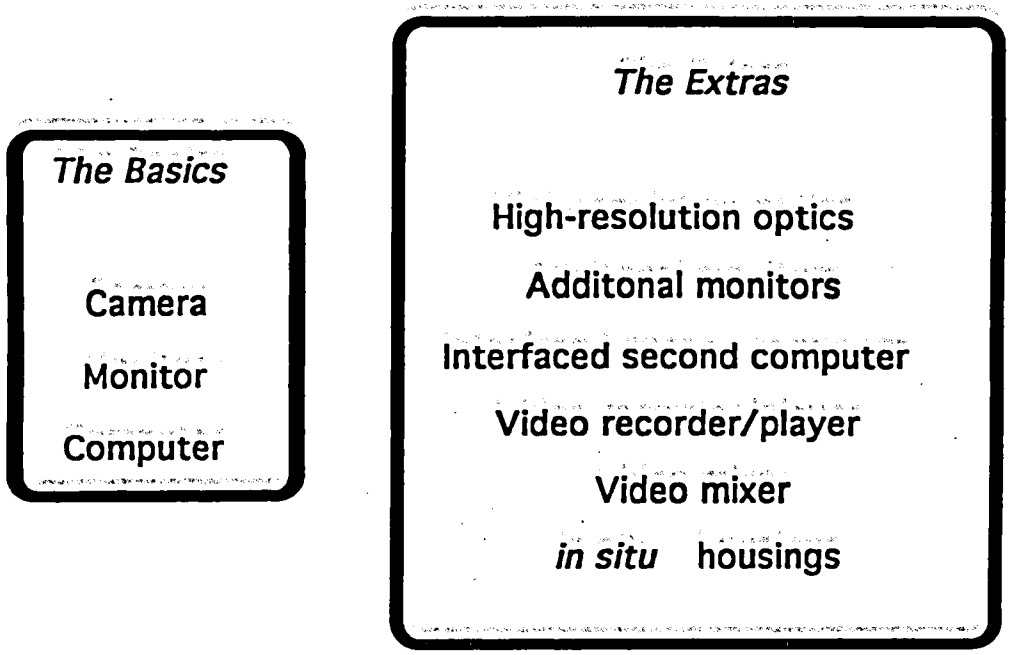

Figure 1. Image analysis - basic and additional equipment.

WHAT IS ZEUS?

A complete description of the Zeus image-analysis system and its operation is provided in the Zeus User's Manual (Estep *et al.* 1993) . Only a cursory description of the set-up and functionality of the system is provided here. The Zeus image-analysis system consists of a Zeus computer, a Macintosh computer, a high-resolution monitor and high-resolution black-and-white camera (Fig. 2). The camera, monitor and Macintosh computer can be exchanged for other compatible equipment. The usage of a digital VHS video cassette recorder and digital mixer often facilitates analyses.

The source of the images to be analyzed can be recorded on video tapes or live. Recorded video may, for example, be made via microscopy, underwater photography, aerial photography, etc.. Live images are direct from the camera and often facilitated using optical instruments such as filters and lenses for magnification.

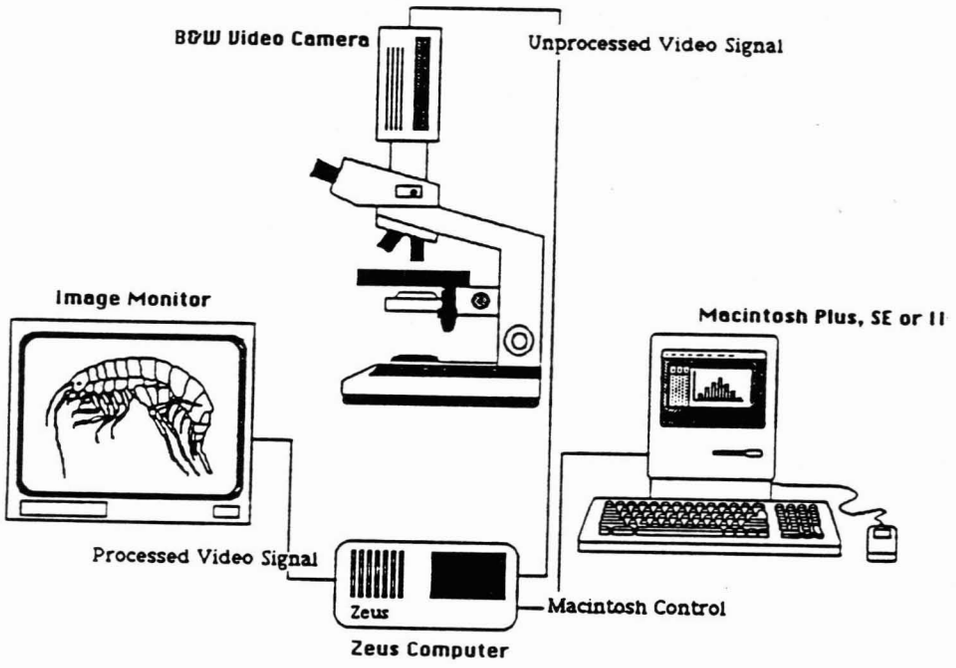

Figure 2. The Zeus image-analysis system consisting of a Zeus and Macintosh computer, a high-resolution camera (mounted here on light microscope) and high-resolution color monitor.

Analyses of objects on the monitor commence with the selection of the objects for analysis according to the gray-level intensity of the objects or manually by hand. This is followed by digitization of the image, which entails the counting of pixels which compose the image. The software of Zeus can measure the pixel array of an object to calculate a variety of parameters such as length, width, fiber length, circumference, and surface area. Zeus then can calculate parameters derived from such basic measurements; these include aspect ratio and holes in the objects. In addition, Zeus can measure nonlinear parameters such as the intensity of an object which has been used to analyze shape, e.g. of otolith rings. All findings can be viewed as graphic representations or

can be exported as data to be processed by other software programs. An additional feature of Zeus is the capability to modify and store the viewed objects as computer images, which can be retrieved using Zeus as well as commercial software. Modification of the objects, e.g. tracing outlines, shading and contrast control, can be made using Zeus and is an important aid in improving images to achieve optimal image analysis.

ZEUS VERSUS MANUAL METHODS

There are four main criteria for comparing manual measurements with image analysis: accuracy, precision, speed and capability. The accuracy of image analysis depends upon the optics, image enhancement and proper calibration. The purpose of optics and enhancement is to improve clarity and resolution; these can improve the accuracy compared with unaided measurements by eye. If calibration is correct, then accuracy of the image analyzer is better than that of the unaided eye. In addition, automation of the measurements minimizes subjectivity during data collection. Precision for both manual and automated measurements can be good. However, as the tedium and difficulty of a task increase, precision of manual measurements tends to decrease, whereas precision of automated ones remains unaffected. The speed of analysis is a strongly differentiating factor of comparison. The time needed to manually measure data usually is much longer than that by image analysis. If this is not the case, then image analysis may be the wrong method for routine analyses. For some analyses the capability of image analysis is no more than by manual methods. This is especially true if the measurement is simple, such as for length, and time is not a factor; this is rarely true. However, the human eye cannot perceive many fine differences in optical properties of an object as well as an image analyzer can. Thus measuring by eye the fluorescence intensity of phytoplankton cells or the speed of an erratically swimming fish larva is primitive and of low resolution compared with the capabilities of an image analyzer.

IMAGE ANALYSIS AND MARINE RESEARCH

Automated image analysis has been increasingly applied in marine science due to its accuracy, speed, precision, capability and provision for operator intervention and rapid data modification. The technique has been used to obtain data on bacterioplankton (Bjørnsen 1986), picoplankton (Sieracki *et al.* 1985, Estep *et al.* 1986), nanoplankton (Gorsky *et al.* 1989, Estep and MacIntyre 1989), zooplankton (Rolke and Lenz 1984, Arts and Evans 1991), zooplankton fecal material (T. Noji *et al.* 1991a), suspended (T. Noji unpubl. data) and sedimenting particles (Costello *et al.* 1989) as well as benthic bioturbation (C. Noji *et al.* in prep.). More recently image analysis of aerial photography and video of seals on ice has been used for counting and sizing purposes (Estep *et al.* accepted). Notably, the collection of recorded images for analysis has assumed state-of-the-art character employing e.g. long-term deep-sea moorings fitted with still-photographic cameras (Lampitt *et al.*

1993) as well as *in situ* video recorders mounted on towed vehicles and providing real-time images (e.g. Welsch *et al.* 1991). Summarily, it can be stated that with the development of computer technology and the pressure to process samples rapidly and to conduct complicated analyses no longer easily managed by manual methods, the importance of image analysis in marine research is growing and progressively becoming more sophisticated.

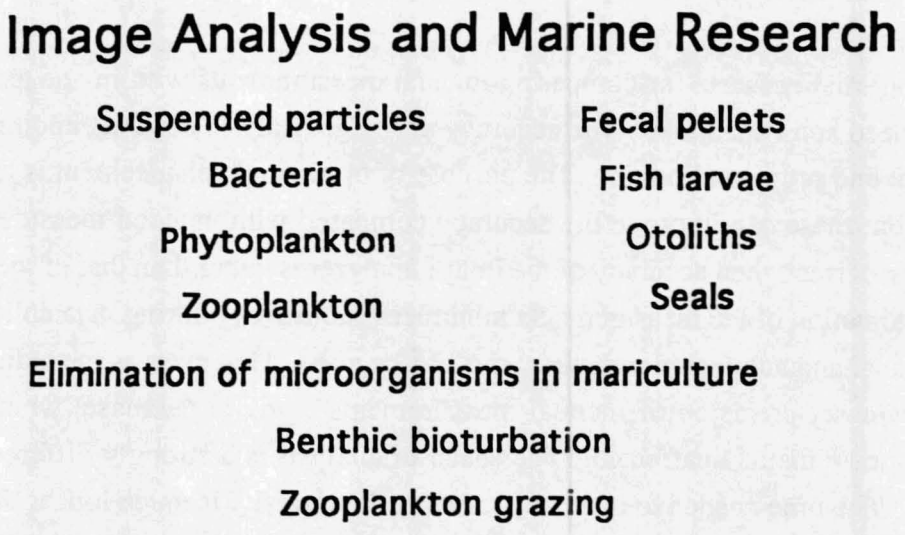

Figure 3. Some of the topics investigated using image analysis at The Institute of Marine Research.

GOALS OF NICFAR

NICFAR was established to develop a user-friendly image-analysis system to be applied to marine research. The system had to be flexible in the sense that it must be compatible with a variety of image sources and portable for usage outside of the laboratory, e.g. shipboard. Further, it had to meet the needs of the researcher and quickly display results in a simple but informative fashion. These prerequisites were fulfilled during the gradual development of the system.

A further major goal of NICFAR was to develop applications of the Zeus system. The investigations, in which Zeus was tested and employed to gather data, encompassed the following themes:

Plankton and benthos research

1. The numeration and sizing of planktonic organisms and development of techniques for routine analysis

2. Numeration and sizing of suspended particles from natural sea water
3. Sedimentation velocities of pteropods, other plankton and aggregates
4. Orientation of swimming krill in relation to a surface echo sounder
5. Identification of crustaceans in the gut contents of krill
6. Numeration of benthic bacteria and measuring bioturbation in sediments

Fisheries

1. Sizing and identification of otoliths
2. 3-dimensional motion of fish larvae
3. 2-dimensional swimming of fish larvae

Marine mammals

1. Numeration and sizing of seals from aerial photography
2. Correlating seal abundance with ice conditions

Other

1. Completion of the computerized taxonomic key - *Linnaeus Protist* - for autotrophic and heterotrophic protists in Norwegian waters

CHIEF INVESTIGATIONS - RESULTS AND DISCUSSION

The investigative work performed with Zeus has been satisfactory, and results from the various investigations have largely been presented in the form of publications, reports and presentations at scientific forums. A brief summary of some of the methods developed and results from chief investigations is provided here. Minor studies are not presented. Since, it is only possible to describe the findings here in a very general fashion, the reader is referred to publications cited in the text for more details.

Planktological and benthological investigations

Subject: Protistan associations on copepod fecal pellets
Chief investigator: T.T. Noji

The Zeus image-analysis system was used to record video of various monocultures and mixed

cultures of protists with copepod fecal pellets. Grazing of bacteria on the pellets and the influence of protists on pellet degradation were documented.

Relevant presentation:

Protistan associations with fecal pellets - T.T. Noji and K.W. Estep, poster/video, presented at ICES statutory meeting from 4 to 10 October 1990, Copenhagen.

Subject: Grazing by zooplankton on *Phaeocystis*
Chief investigator: K.W. Estep

During a cruise with the R.V. "G.O. Sars", experiments were conducted to measure the grazing selectivity of copepods on the colony-building phytoplankton genus, *Phaeocystis,* in different physiological states. Results using the image analyzer on samples of live natural plankton indicated that *Phaeocystis* is consumed when its colonies are in poor physiological state. Fresh healthy colonies were not ingested.

Relevant publication:

Predation by copepods upon natural populations of *Phaeocystis pouchetii* as a function of the physiological state of the prey - K.W. Estep, J.C. Nejstgaard, H.R. Skjoldal and F. Rey, 1990, *Marine Ecology Progress Series* 67:235-249

Relevant presentation:

The unpalatability of *Phaeocystis* and its effect upon predation by Arctic copepods - K.W. Estep, presented at the Norwegian Marine Scientists Meeting, 1989, Bergen, Norway

Subject: Biology of the toxic alga, *Chrysochromulina*
Chief investigator: K.W. Estep

Using Zeus to study live cultures of the toxic alga, *Chrysochromulina,* video tapes of live algae were recorded, and a theory explaining the biological features of this genus was postulated.

Relevant publication:

Taxonomy, life cycle, distribution, and dasmotrophy of *Chrysochromulina*: a theory accounting for scales, haptonema, muciferous bodies, and toxicity - K.W. Estep and F. MacIntyre, 1989, *Marine Ecology Progress Series* 57:11-21

Subject: Destruction of harmful algae in mariculture using a sonic-cavitation technique
Chief investigator: M. Garras

Sonification methods were applied to destroy protists normally found to contaminate tanks used for the mariculture of fish. The Zeus system analyzed the efficiency of various strengths of sonification

for destruction of the algae.

Relevant publication:

Acoustic cavitation - its effects on microorganisms - M. Garras, 1993, Cand.scient. thesis, University of Bergen, 54 pp.

Subject: Stomach-content analysis of copepod mandibles
Chief investigator: K. Karlsson

The contents of the krill gut were investigated. In particular, using the light microscope and mounted color camera, the remains of copepods found in the krill guts were recorded on video tape. These video recordings as well as live images direct from the camera were image-analyzed to determine the dimensions of the copepod remains. The data are being used for identification of the ingested copepods. The method is good for estimating the importance of predation by krill in the ocean.

Relevant publication:

Stomach-content analysis of copepod mandibles. A method to quantify predation rate of planktonic predators - K. Karlson and U. Båmstedt, in preparation.

Subject: Orientation of swimming krill with respect to surface acoustic recorders
Chief investigator: T. Knutsen

In order to interpret acoustic data on swarms of swimming krill, it was necessary to measure the orientation of the organisms in relation to the acoustic sensors. This was done by analyzing video tapes using Zeus. Findings indicated that the image-analysis system was a good tool for such measurements. The collected data are presently being interpreted.

Subject: Benthic bacteria
Chief investigator: C.I.-M. Noji

The fluorescence microscope and light-sensitive Dage camera were employed to count stained bacteria in sediment samples. These data are being used to estimate benthic bacterial biomass at sites along the Norwegian coast. The findings are part of a larger data set including biomass and activity parameters for benthic communities off Norway.

Subject: Benthic bioturbation
Chief investigator: C.I.-M. Noji

The researcher used the fluorescence technique of tracing luminophores as they were transported down into sediments via biological processes - bioturbation. The sediment cores were taken from Ramfjorden, near Tromsø, as part of a study on benthic-pelagic coupling in the fjord conducted in winter 1989. Findings showed that bioturbation can be a significant process in the mixing of sediments in this fjord.

Relevant publication:

Benthic-pelagic coupling during fall in a northern Norwegian fjord. Benthic activity - C.I.-M. Noji, T.T. Noji and K.-G. Barthel, in preparation

Pelagic-benthic coupling during the onset of winter in a northern Norwegian fjord. Carbon flow and fate of suspended particulate matter - T.T. Noji, C.I.-M. Noji and K.-G. Barthel, 1993, *Marine Ecology Progress Series* 93:89-99

Relevant presentation:

Benthic Activity in a Northern Norwegian Fjord in Late Autumn - C.I.-M. Noji, T.T. Noji and K.-G. Barthel, poster at ICES statutory meeting from 4 to 10 October 1990, Copenhagen

Subject: Endophytes on macroalgae
Chief investigators: T.T. Noji, K.W. Estep, T.E. Lein

The endophytic coverage of blades of the macrophyte, *Laminaria hyperborea,* was measured using Zeus. This was conducted employing overhead transparencies on which blade outlines and endophytes were transcribed. A calibration of the accuracy of the method was also conducted. Findings showed that the Zeus system was more accurate than routine measurements by eye and much faster.

Relevant publication:

Automated image-analysis of sori and an unidentified endophyte on the kelp *Laminaria hyperborea* (Gunnerus) Fosslie - T.T. Noji, K.W. Estep, T.E. Lein, R. Palerud, K. Sjøtun, S.M. Wakili, 1991, Havforskningsinstituttet Rapport *HSMM* 2:1-18

Subject: Grazing on fecal pellets
Chief investigator: T.T. Noji

Grazing by copepods on copepod fecal pellets was investigated at a PROMARE workshop, *The role of zooplankton defecation and grazing in pelagic carbon and nitrogen cycles,* near Bergen in 1988. Findings showed that not only do copepods feed on fecal pellets, but they can fragment the pellets to small particles, which are presumably more easily recycled in the water column. The important process of coprochaly - the loosening of the fecal content and accompanying reduction in specific density - was discovered during this investigation.

Relevant publications:

(1) Image analysis of faecal material grazed upon by three species of copepds: evidence for coprorhexy, coprophagy and coprochaly - T.T. Noji, K.W. Estep, F. MacIntyre and F. Norrbin, 1991, *Journal of the Marine Biological Association of the United Kingdon*, 71:465-480

(2) The influence of zooplankton on sedimentation in the Norwegian Sea - T.T. Noji, 1989, *Sonderforschungsbereich 313 Bericht* 17:1-183

(3) The influence of macrozooplankton on vertical particulate flux - T.T. Noji, 1991, *Sarsia* 76:1-9

(4) Macrozooplanktonic influence on vertical particulate flux - T.T. Noji, 1991, In Wassmann P., Lindahl O. and Heiskanen A.-S. (eds.). *Sediment trap studies in the Nordic countries*. Nurmi Print Oy, Nurmijärvi, pp. 94-116

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(1) Macrozooplankton-mediated influences on benthic-pelagic interactions - T.T. Noji, invited speaker at American Society of Limnology and Oceanography (ASLO) conference in Halifax, Canada, 10-13 June 1991

(2) Same title as nr. 4, - T.T. Noji, at "2. Nordiska symposiet: Sedimenteringsmätningar i marinekologisk forskning och monitering", Kristineberg's Marine Biological Station, Fiskebäckskil, Sweden, 21-25 November 1990,

(3) Zooplankton-mediated fluxes - T.T. Noji, at Symposium on zooplankton fecal pellets, Norwegian College of Fishery Science, Tromsø, 9 December 1992.

Subject: Biology of *Phaeocystis*
Chief investigators: T.T. Noji, K.W. Estep

The inverted microscope and color camera were used to record video of the marine alga, *Phaeocystis*, in several phases of its poorly understood life cycle. The image analyzer was used to size and shape these cells and colonies. In addition, experiments on the formation of colonies by *Phaeocystis* on artificial and natural substrates were conducted. Zeus proved to be an effective means to conduct these measurements and information on the life cycle of this algal species was collected. This work was conducted in the workshop entitled The Trophic Fate of *Phaeocystis*, held in Tromsø from 10 to 31 May, 1992.

Fisheries research

Subject: Swimming of salmon larvae in relation to light
Chief investigator: R. Nortvedt

Video of salmon larvae under varying conditions of light was recorded using two synchronized cameras and was analyzed with the image analyzer. This was an ambitious project, as the analyses

consider two sources and are essentially 3-dimensional. A technique was developed for recording and processing data to calculate 3-dimensional swimming speeds of the larvae. The data helped to establish relationships between light intensity and swimming speed of salmon larvae.

Relevant publication:

The combined influence of hatching substrate and light intensity on swimming velocity, yolk absorption, mortality and growth of Atlantic salmon alevins - R. Nortvedt, K.W. Estep, T. Hansen, F. MacIntyre and T.T. Noji, submitted to *Journal of fish Biology*

Relevant presentation:

Same title - R. Nortvedt, at the symposium for "The cultivation of Atlantic salmon", Bergen, 17-20 August 1992.

Subject: Swimming of cod larvae
Chief investigators: P. Solemdal, A. Nissling

Image analyses were made of swimming cod larvae in relation to variations in salinity. A method was developed to track swimming larvae from live and recorded video and calculate the swimming speeds. The data are being used not only to relate swimming to salinity but also to assess the implications for feeding, growth and predator avoidance.

Relevant publication:

Survival, activity and feeding ability of Baltic cod (*Gadus morhua*) yolk sac larvae in different salinities - A. Nissling, P. Solemdal, M. Svensson and L. Westin, submitted to *Marine Ecology Progress Series*.

Subject: Identification and age determination of otoliths
Chief investigator: K. Nedreaas

The image-analysis system is being used to analyze the shapes of otoliths and otolith rings. In its early phases this investigation was instrumental in developing the densitometric functions of the image analyzer; these functions permit the collection of data which can be used for analyzing the shape of objects, e.g. otolith rings. Otolith shapes and ring patterns can be useful in species and age determination of the fish.

Relevant publications:

(1) Datateknologi henter fram informasjon i øyresteinar og fiskeskjel - K. Nedreaas, NFFR-prosjekt Rapportsammendrag nr. 7 1992

(2) Sluttrapport NFFR-prosjekt 701.311 Bildeanalyse for automatisering av alderslesing - K. Nedreaas

(3) Genetic studies and age-determination of Northeast Atlantic redfish (genus Sebastes - K. Nedreaas, Dr. Scient. Thesis, University of Bergen, 1990

(4) Computer image analysis of otoliths. Image enhancement and presentation - K.W. Estep, K. Nedreaas and F. MacIntyre, in preparation

Relevant presentation:

Computer image enhancement and presentation of otoliths - K. Nedreaas, symposium on Fish otolith research and application, Hilton Head, S. Carolina, USA, 23-27 January 1993

Other research

Subject: Computer taxonomy of protists in Norwegian waters
Chief investigators: K.W. Estep, F. Rey

Under the auspices and with the technical assistance of NICFAR, the computer taxonomy program, known as "Linnaeus", was created in cooperation with a large number of taxonomic scientists in Norway and other European as well as North American countries. The initial example program, which contained only 50 species of marine zooplankton common in Norwegian waters, was developed to contain over 500 species of protists. Linnaeus now comprises over 50 megabytes of information, collating and presenting a wide range of information, including a line drawing of each species, high-resolution pictures from various sources, e.g. light and scanning electron microscopy, information on blooms, toxicity, distribution, literature references and authorities. It also contains a great deal of ancillary information on methods of collection, culturing, preparation and examination of plankton samples. Species may be identified by clicking on pictures on the screen and the program obviates the need to consult widely scattered and difficult-to-find literature. UNESCO subsidized its production and distribution in CD format.

Relevant publications:

1) The cost of user-friendly programming, MacImage as example - F. MacIntyre and K.W. Estep, submitted to *Journal of Forth Applications Research*

2) Linnaeus: Interactive taxonomy using the Macintosh Computer and HyperCard - K.W. Estep, A. Hassel, L. Omli and F. MacIntyre, 1989, *Bioscience* 39:635-638

(3) Counting, sizing and identification of algae using image analysis - K.W. Estep and F. MacIntyre, 1989, *Sarsia* 79:12-29

(4) Creating and using taxonomic keys with HyperCard - K.W. Estep, 1989, *Fisken og Havet* No. 1, 36 p.

(5) *Deus creavit; Linneaus disposuit:* an international effort to create a catalogue and expert system for the identification of protistan species - K.W. Estep, F. Rey, K. Bjøklund, T. Dale, B.R. Heimdal, A.J.W. van Herteum, D. Hill, D. Hodell, E.E. Syvertsen, K. Tangen and J. Throndsen, 1992, *Sarsia* 77:275-285

Relevant presentations:

(1) Computer Image Analysis in Marine Biological Research - K.W. Estep, at the "Environmental Influences on Marine Biological Resources Symposium", 1989, Murmansk, USSR

(2) Zeus the all seeing - Image analysis with a Macintosh, an IBM and two kinds of forth - F. MacIntyre, presented at the Rochester Forth confer4ence on automated instruments, 18-22 June 1991, Rochester, New York, USA

(3) Linnaeus protist - A computer taxonomy program - K.W. Estep, presented at ICES statutory meeting from 4 to 10 October 1990, Copenhagen

Other relevant material:

Linnaeus protist and the Linnaeus toolkit, a CD ROM module and handbook for identification of the protists and selected zooplankton of the N.E. Atlantic - K.W. Estep and F. Rey, 1991

Subject: Analysis of sea-floor topography from sea charts
Chief investigator: T.T. Noji

Zeus was employed to analyze sea charts of Ramfjorden (near Trmsø) to estimate the distribution of sediments within selected depth ranges. The data were used to assess the importance of resuspension of shallow sediments for rates of sedimentation and redeposition in deeper parts of the fjord. This information was used to interpret findings from this fjord on the flow of carbon with respect to benthic-pelagic coupling.

Relevant publication:

Pelagic-benthic coupling during the onset of winter in a northern Norwegian fjord. Carbon flow and fate of suspended particulate matter - T.T. Noji, C.I.-M. Noji and K.-G. Barthel, *Marine Ecology Progress Series* 93: 89-99

Subject: Numeration and sizing of seals on ice floes
Chief investigator: T. Øritsland

Using video tape and still photographs obtained from aircraft, seals on ice floes were counted and measured for length. Further, the relation between seal abundance and ice-floe traits, e.g. average size and density of individual floes, was analyzed. Findings showed that Zeus could usually distinguish between adults and pups from aerial photography.

Relevant publication:

Seal abundance and habitat conditions assessed from aerial photography and video analysis - K.W. Estep, F. MacIntyre, T.T. Noji, B. Stensholt and T. Øritsland, *ICES Journal of Marine Science* accepted

GENERAL CONCLUSIONS AND FUTURE RESEARCH

The project, Norwegian Image-Analysis Centre for Fisheries and Aquatic Research (NICFAR), has shown much success in terms of developing a suitable image-analysis system, Zeus, for marine and other research. Zeus is user-friendly, has a variety of simple and sophisticated applications for most research needs and good graphic presentations of data. The considerable number of important studies, which have been conducted with the aid of Zeus and NICFAR, testifies to this conclusion.

It is anticipated that Zeus shall be in continual use in the years to come. Modifications to the program in accordance with special needs of the scientist are still possible, and thus Zeus should evolve as new applications are tested and used in routine and specialized research.

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Estep, K.W., 1989. Creating and using taxonomic keys with HyperCard - *Fisken og Havet* 1989(1), 36 p.

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Nortvedt, R., K.W. Estep, T. Hansen, F. MacIntyre and T.T. Noji, submitted. The combined influence of hatching substrate and light intensity on swimming velocity, yolk absorption, mortality and growth of Atlantic salmon alevins - *Journal of Fish Biology*

Appendix 2. Relevant presentations

Estep, K.W.. Computer Image Analysis in Marine Biological Research - at the "Environmental Influences on Marine Biological Resources Symposium", 1989, Murmansk, USSR

Estep, K.W.. Linnaeus protist - A computer taxonomy program - at ICES statutory meeting from 4 to 10 October 1990, Copenhagen

Estep, K.W.. The unpalatability of *Phaeocystis* and its effect upon predation by Arctic copepods - presented at the Norwegian Marine Scientists Meeting, 1989, Bergen, Norway

MacIntyre, T.. Zeus the all seeing - Image analysis with a Macintosh, an IBM and two kinds of forth - at the Rochester Forth confer4ence on automated instruments, 18-22 June 1991, Rochester, New York, USA

Nedreaas, K.. Computer image enhancement and presentation of otoliths - symposium on Fish otolith research and application, Hilton Head, S. Carolina, USA, 23-27 January 1993.

Noji , C.I.-M., T.T. Noji and K.-G. Barthel. Benthic Activity in a Northern Norwegian Fjord in Late Autumn - a poster at ICES statutory meeting from 4 to 10 October 1990, Copenhagen

Noji, T.T.. Macrozooplanktonic influence on vertical particulate flux - at "2. Nordiska symposiet: Sedimenteringsmätningar i marinekologisk forskning och monitering", Kristinebergs Marinbiologiska Station, Fiskebäckskil, Sverige, 21-25 November 1990,

Noji, T.T.. Macrozooplankton-mediated influences on benthic-pelagic interactions - at American Society of Limnology and Oceanography (ASLO) conference in Halifax, Canada, 10-13 June 1991

Noji, T.T.. Zooplankton-mediated fluxes - at Symposium on zooplankton fecal pellets. Norges Fiskerhøgskole, Tromsø, 9 December 1992.

Noji, T.T. and K.W. Estep. Protistan associations with fecal pellets - poster/video, presented at ICES statutory meeting from 4 to 10 October 1990, Copenhagen.

Nortvedt, R., K.W. Estep, T. Hansen, F. MacIntyre and T.T. Noji. The combined influence of hatching substrate and light intensity on swimming velocity, yolk absorption, mortality and growth of Atlantic salmon alevins - at the symposium for "The cultivation of Atlantic salmon", Bergen, 17-20 August 1992.