Midlertidig rapport CALANUS:
EXPLOITATION OF ZOOPLANKTON AS BIO-RESOURCE FOR FISH FEED AND INDUSTRIAL RAW MATERIAL – A COMPLETE VALUE CHAIN EVALUATION

Background and identification of problem

There is a growing demand for marine bio-resources, and the salmon industry is already preparing for temporary limitations in resources for fish feed in the coming decade. It is in particular the availability of marine oils that has become scarce, in particular during El Nino events (Naylor et al. 2000). This is primarily an effect of a growing aquaculture industry world wide, but also the fact that traditional fisheries for industrial fish has an upper yield limitation (FAO-statistics, www.fao.org) and that a gradually increasing fractions of planktivore fish species like mackerel and herring are used for direct human consumption.

The fish feed companies have some identified countermeasures to meet this situation:

1. Increase use of lipids, and proteins, from agricultural origin.
2. Exploit raw materials from “new” marine sources
3. Use “single cell protein” with marine lipid composition

A “single cell protein” with marine lipid profile cheap enough to be raw material in fish feed may be a future challenge, but it is still not available. The industry is therefore left with the two first options. In a recent review Naylor et al. (2000) stated that “.. if the growing aquaculture industry is to sustain its contribution to world fish supplies, it must reduce wild fish input in feed and adopt more ecologically sound management practice”. This put restrictions on what type of “new” resources that could be exploited sustainably.

Marine fish require high amounts of essential ω3 fatty acids, and the tissues of marine animals are rich in such fatty acids. Warm-blooded terrestrial animals, on the other hand, have high requirements for ω6 fatty acids, and the agriculture food web is richer in ω6 fatty acids. ω3 fatty acids cannot be converted to ω6 fatty acids, and vice versa. Marine fish species like halibut and turbot do not efficiently synthesise long chain ω3 fatty acids based on shorter moieties, and their feed should most likely be based on lipids of marine origin. Some other fish species will, however, be more efficient in synthesising long-chain ω3 fatty acids based on shorter ω3 moieties, and salmonids are among the most flexible fishes in this regard. Even though salmon may accept a high fraction of agricultural lipids in their feed, it will always be an important objective to derive “new” marine sources of lipids and proteins, which are less dependent of the global climate than fish oils and meal.

There is an upper limit for “new” marine fish resources that can be harvested through traditional means. New concepts are searched for, and the MARICULT Research Programme (www.maricult.org) has the main objective to provide a basis for evaluation of potentials and environmental constraints for increased sustainable provision of food, raw material and energy from the ocean. The Programme has concluded that significantly higher quantities of bio-resources are available if we also harvest at the grazer or the plant levels of the food web (Olsen and co-workers, report in prep.). The marginal contribution of the marine food webs in human food supply (1-2% in 1997, www.fao.org) is due to the fact that humans act as first and secondary carnivores in the marine food web and as herbivore-omnivore in the agricultural. This implies that we feed some 2 trophic levels higher in the marine food web than in the typical agricultural food web, which suggest that only 1-4% of the total energy available will originate from marine primary production when the marine primary production is equal to the terrestrial. This is a rough, but nevertheless a very robust concept, already included in most ecological textbooks.

The implication of this general lesson is that we should harvest more grazing animals, or herbivore animals that feed primarily on algae (herbivore/omnivore). In fact, there are big resources of herbivore zooplankton in Norwegian waters. The average zooplankton biomass varies in the range 5-11 g dry weight per m^2 in the Norwegian Sea (1994-98) and between 8-13 g dry weight per m^2 in the Barents Sea (Ellertsen *et* al. 1999, Hassel 1999). The production of *Calanus* in the Norwegian and the Barents Sea has been estimated to 21 and 28 million tons dry weight per year, respectively (Aksnes and Tande 1996, Tande 1994), whereas the production of *C. finmarchicus* in the Nordic Seas is estimated to 74 mill tons wet weight (18 mill tons of dry weight) (Aksnes and Blindheim 1996). Exploitation of zooplankton resources is probably the fastest and most sustainable way to enhance marine harvest of bio-resources for fish feed and other industrial applications. Salmon feed mainly on krill, copepods, other large zooplankton, and on small fish in the sea. This makes zooplankton an interesting source for salmon feed, and fish feed in general. Harvesting at this tropic level in the food web also takes into considerations the concern expressed by Naylor et al. (2000) quoted above.

The present Strategic Programme addresses large scale harvesting of herbivore/omnivore zooplankton from a value chain perspective, including biological, technological, and social aspects. The groups focused on are **herbivore** copepods and krill species, and other herbivore zooplankton groups, which are abundant and exploitable based on their distribution in time and space and their biochemical composition. The fact that the zooplankton is food for important fish stocks brings up a strong management and political dimension, and the potential interaction with fisheries must therefore have a main focus in the research. It is, however, important to emphasise that 10% of the herbivore zooplankton production is of same order of magnitude as the total production of first order carnivores, including herring, caplin, and carnivore zooplankton. The potential of changing harvesting strategies is considerable, and the present programme will evaluate both potentials and constraints of this approach. The ultimate objective of the programme is:

Main objective:

> *To clarify possibilities, constraints, and consequences of large-scale application of marine zooplankton for fish feed and industrial raw material, with main emphasise on the identified critical factors*

The research strategy of the Programme is to put the main efforts into the most critical questions or constraints identified in the value chain for sustainable exploitation of zooplankton resources. The identified and selected potential constraints that will be focused are:

1. Are densities of herbivore copepods and krill, and other potential species, patchy enough in time and space to allow harvesting, and where are such patches found?
2. How will zooplankton-harvesting affect the food availability for important commercial planktivore fish stocks and how will it interact with fisheries?
3. Are the energy requirements for sustainable harvesting acceptable, and how should the 1st generation harvest gear be designed?
4. How is saltwater efficiently removed and how can the harvested resource be conserved?

5. Can crude zooplankton biomass, containing high levels of wax esters and chitin, be used as a bulk source for fish feed without removing chitin?
6. How can conserved zooplankton be further refined, i.e. how to separate protein, lipid, chitin, pigments and more?
7. How will a “new” resource that most likely is available through several months affect social conditions of fishery communities and the fishing fleet?

Project 1 Resource biology and model based evaluation of sustainable exploitation

Project leader: Jan Ove Evjemo, Trondhjem biological station, Dept. Biology (Jan.Ove.Evjemo@bio.ntnu.no)

Objectives:

- To examine environmental and biological implications and potential interactions with fishery of zooplankton exploitation by use of 3D ecosystem model.
- To compare biomass and species composition by classical methods, optical counters, and acoustic methods.
- To characterise biological and biochemical traits of zooplankton resources in selected high biomass locations.

Project 2 Concepts for harvesting technology of zooplankton

Project leader: Ludvig Karlsen, Dept. Marine System Design, (Ludvig.Karlsen@marin.ntnu.no)

Objectives:

- To establish a 1st generation selective and ecological friendly harvesting technology for zooplankton
- To examine thoroughly the relation between harvesting gear design and the catching efficiency.
- To establish a conceptual 2nd generation intelligent harvesting technology for zooplankton.

Project 3 Handling, salt water/salt removal and post harvest preservation of zooplankton.

Project leader: Ola M. Magnussen, Dept. Refrigeration and Air Conditioning (Ola.M.Magnussen@kkt.ntnu.no)

Objectives:

- To develop principles and equipment for loading of catch from gear to vessel, handling and methods to sort out fish, jellyfish and other by-catch from zooplankton.
- To establish and test methods for removal of saltwater, handling and transport of dry biomass.
- To establish knowledge and data on shelf life and biochemical/chemical changes post mortem dependent on temperature and storage condition.
- To develop principles, methods and equipment for short term (chilling) and long term (e.g., freezing, ensilage) preservation of the raw materials on vessel and catching site.
- To establish principle and methods for handling, storage onboard and unloading/storage to processing plant.

Project 4 Refinement of biomass for bulk and advanced industrial application

Project leader: Kjell Morten Vårum, Dept. Biotechnology, Kjell.Morten.Vaarum@biotech.ntnu.no

Objectives:

- To develop technology for production of a zooplankton powder from frozen raw material and agglomerated pellets with controlled sinking velocity in water.
- To produce stable zooplankton meal and oil products that may replace or be used as supplement to fishmeal and oil in feed for salmon and marine species of fish.
- Investigate the possibility to produce a coated “wet” fish feed from partly de-watered zooplankton.
- To establish methods for separation of chitin from proteins and lipids of pre-dried zooplankton biomass
- To evaluate the use of zooplankton biomass as raw material for isolation of chitin and other components like pigments and lipids. Chitin can be used for the production of chitosan, and glucosamine.

Project 5 Evaluation of zooplankton based products as basis and supplement to fish feed

Project leader: Elin Kjørsvik, Dept. Zoology, (Kjell.Morten.Vaarum@bio.ntnu.no)

Objectives:

- To test digestibility of chitin and wax esters in salmon and marine fish species.
- To run pilot scale production testing of zooplankton based feed for salmon and marine species
- To search for and to evaluate potential constraints caused by copepod parasites.

Project 6 Socio-economic effects of “new” resources and implications for the fleet structure.

Project leader: Oddmund Otterstad, Dept. of Sosiology and Political Science (Oddmund.Otterstad@svt.ntnu.no)

Objectives:

- To identify the likely general impacts stemming from the availability of a “new” and possibly abundant fishery resource on the present fisheries regime that is characterised by decades of a fish resource decline
- To examine in further detail the whole chain of current fish production processes in order to highlight the areas where the development of a new, possibly abundant fishery might induce radical changes
- To identify ways of advancing restructuration processes aimed at avoiding unnecessary conflicts within the fishing industry sector and between the fishing industry and other interest groups in society.

The following representatives formed the *Steering Committee* of the Programme:

Anders Endal (Co-ordinator), Ola Magnussen, Olav Smidsrød, Elin Kjørsvik, Jens M. Hovem, Yngvar Olsen, Olav Solem, Dag Slagstad, Olav Vadstein (secretary of committee from the start, Co-ordinator from 2003 onwards)

Table 1. Principal partners of Programme, key persons, and project participation

Partner	**Department**	**Participation, key representatives**	**Project participation, (responsible partner is underlined)**
1	Marine Systems Design (Coordinator)	Anders Endal, Ludvig Karlsen, Oddmund Otterstad	Projects 1, <u>2</u>, 3, <u>6</u>
2	Natural History/Trondhjem Biological Station	Yngvar Olsen, Olav Vadstein	Projects <u>1</u>, 2, 3, 4, 5
3	Biotechnology	Olav Smidsrød, Kjell Morten Vårum, Turid Rustad	Projects 3, <u>4</u>, 5
4	Refrigeration and Air Conditioning	Ola Magnussen, Ingvald Strømmen, Vidar Hardarson	Projects 2, <u>3</u>, 4, 5
5	Brattøra Research Centre (Zoology/Botany)	Elin Kjørsvik, Katja Hoehne Reitan, Trine Galloway, Jan Ove Evjemo	Projects 3, 4, <u>5</u>
6	Dep. Of telecommunications	Jens M. Hovem	Projects 1, 2
7	Industrial Economy and Technology Management	Olav Solem	Project 6
8	SINTEF Civil engineering	Dag Slagstad	Project 1

References

Aksnes, D. L. and Blindheim, J. 1996. Circulation patterns in the North Atlantic and possible impact on population dynamics of Calanus finmarchicus. Ophelia, 44, 7-28.

Annon 1999. Bærekraftig marin virksomhet. Strategisk plan for satsing på marin forskning, utvikling og undervisning ved NTNU/SINTEF.

Budzinski, E.; Bykowski, P.; Dutkiewicz, D. 1985. Possibilities of processing and marketing of products made from Antarctic krill, FAO Fish. Tech. Pap. 268. 46 p.

Cough C., Castells, N. and Funtowics, S. 1998. Integrated Assessment: an emerging methodology for complex issues. Environmental Modelling and Assessment, 3, p.19-29.

Engelen, G. 1998. Modulus: A Spatial Modelling Tool for Integrated Environmental Decision- Making. *Proceedings of the European Climate Science Conference*. Brussels: European Commission, DG12.

Ellertsen, B.; Rey, F. and Melle, W. 1999. Økosystemet i Norskehavet og på Kysten; Plankton og Næringssalter. Pp. 31-37 in: Fisken og Havet, Særnummer 2; Havets Miljø 1999, J. Aure (eds.). Institute of Marine Research.

Ellingsen, T.E. and Mohr, V. 1987. Biochemistry of the autolytic processes in Antarctic krill post mortem: autoproteolysis. Biochem. J. 246: 295-305.

Fahley, L. and Randall, R.M. (Eds). 1997. Learning from the future: Competitive Foresight Scenarios. John Wiley & Sons.

Hassel, A. 1999. Økosystemet i Barentshavet; Plankton. Pp. 18-20 in: Fisken og Havet, Særnummer 2; Havets Miljø 1999, J. Aure (eds.). Institute of Marine Research.

Janssen, R. 1992. Multiobjective Decision Support for Environmental Management, Kluwer Academic Publishers, Dordrecht.

Kaiser, M and Forsberg, E.-M. 1999. En verdivurdering av norske fiskerier mot 2020. Preliminary report. Proceedings, program seminar "Teknologiutvikling i fiskerisektoren", Norges Forskningsråd

Naylor, R.L., R.J. Goldburg, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folke, J. Lubchenco, H. Mooney and M. Troell. 2000. Effect of aquaculture on world fish supplies. Nature 405: 1017-1024.

Nicol, S. and Endo, Y. 1999a. Krill fisheries: Development, management and ecosystem implications. Aquatic Living Resources. Vol. 12(2): 105-120.

Nicol, S. and Endo, Y. 1999b. Krill Fisheries of the World, FAO Fish. Techn. Pap. 367, FAO, Rome. 100 p.

Slagstad, D., Tande, K. and Wassmann, P. 1999. Modelled carbon fluxes as validated by field data on the North Norwegian shelf during the productive period 1994. Sarsia 84, 303-317.

Slagstad, D., K. Tande, W. Melle, B. Ellertsen and F. Carlotti (in prep.). Regional dynamics of Calanus in the Norwegian Sea in response to ocean climate in 1997.

Tande, K. 1994. Dyreplankton. Pp. 118-136 in: Økosystem Barentshavet. E. Sakshaug, A. Bjørge, B. Gulliksen, H. Loeng, F. Mehlum (eds.). Universitetsforlaget AS.

Van der Most, H. 1998. Thematische Oriëntatie op Projectdefinitie in een Interactieve Context (TOPIC). Final report, Land Water Environment Information Technology Programme, Foundation LWI, Gouda, The Netherlands, 35p.

Vårum, K.M., Holme, H.K., Izume, M., Stokke, B.T. & Smidsrød, O. 1996. Determination of enzymatic hydrolysis specificity of partially *N*-acetylated chitosans. Biochim. Biophys. Acta 1291: 5-15.