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An approach to improve the sustainability of aquaculture in East Aegean River Basin District (The FISHFARMING project)

IRIS - 2016/031

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Preface

The project « FISHFARMING » is a part of the programme « BG02 Integrated marine and inland water management », **BG02.01: More integrated management of marine and water resources.**

Performance of investigative monitoring program for assessment of pressure and impact of fish farming activities on surface water bodies and actualization of program of measures in the RBMP of East Aegean River Basin District.

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Stavanger, 16. March 2016

Thorleifur Agustsson,
Project Manager

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Summary

This report describes the IRIS contribution as a partner of the FISHFARMING Project funded by the BG02 "Integrated Marine and Inland Water Management" Program under the Financial Mechanism of the European Economic Area (eea grants).

The contribution emphasizes suggested measures to improve the present culture of sturgeon, trout and carps in freshwater reservoirs and brooks in the East Aegean River Basin in order to obtain a more sustainable production. Introductorily, a survey of freshwater pond and cage based fish farming and employed models for ecological carrying capacity of the water body is critically reviewed. Waste load and pathways, and the significance of proper control of the dissolved oxygen (DO), in fish cages are discussed in a subsequent brief overview.

Due to a reported poor feed utilization, the waste load from the fish farms in the river basin seems improperly high. At a feed conversion rate (FCR) as high as 2.5 in sturgeon cages, the estimated phosphorus load is about 22 g TP/kg produced biomass. Attempts to adjust the feeding concurrently with the appetite rhythm of the fish stock and thus reduce feed loss should be introduced. Surveillance of the fish's behaviour using underwater cameras has demonstrated improved feed utilization. Another vital factor is sufficient DO control avoiding sub-optimal levels, especially during warm periods. Introduction of cost-efficient aeration by diffusers at 2 – 4 m depth in cages is an obvious measure to control DO, improve the fish's welfare and not least, contribute to reduced waste load.

Unlike in ponds, mechanical removal of solids in cage farms is rather demanding and the efficiency might vary. Such systems are still not well established, but collection of settling solids in funnels attached to the bottom of the cages with subsequent pumping of sludge to the surface may recover up to 50% of the waste phosphorus. Usage of semi-closed cages is a more predictable technology for solid removal. However, such systems require higher investment costs than open cages.

By combining the mentioned measures, improved feed control and removal of produced feed loss and faecal waste solids, the present load of solids, organic matter and phosphorus could be reduced to about the half.

As briefly illustrated in the report, rather simple systems to avoid bird attacks and to collect dead fish in cages are available.

Regarding carrying capacity the same problem arises as the situation in Bulgarian lakes and rivers do not correspond to the situation in the sea. However, the same logic applies to both situations, which is to gather information on the lakes and rivers for better understanding of the natural status and the basis for estimation of carrying capacity.

In Norway, the MOM surveillance method was developed to estimate effects of the fish farm on the benthos directly under the fish cages or in a close vicinity of the cages (MOM B) and in the near and far environment (MOM C). MOM C is requested by the authorities when and if MOM B reveals a negative effect. Even though this method was developed for marine recipients (fjords in Norway), similar principles can be applied for Bulgarian reservoirs.

1 Introduction

The EU's marine and freshwater ecosystems are currently underutilized: the potential for aquaculture growth is significant. Development of a sustainable and efficient aquaculture sector will come from implementation of an ecosystem approach to aquaculture development (FAO, 2010), consistent with the WFD and MSFD to ensure that the environment is protected, whilst at the same time ensuring growth targets can be achieved.

Most European freshwater culture is carried out in ponds: evaluating *ecological carrying capacity* of these systems requires knowledge of the hydrological balance, together with habitat and natural resources—freshwater aquaculture systems show significant environmental diversity, while being separated and fragmented (Olson *et al.* 2001, Spalding *et al.* 2007). The estimation of *ecological carrying capacity* for **inland aquaculture ponds** should be analysed at the watershed scale (Beard *et al.* 2011) and determined as maximum water use and maximum nutrient loading, an approach which agrees well with the requirements of the WFD.

In **lakes or reservoirs**, carrying capacity for finfish cage culture is often evaluated by assessment of total phosphorus at the whole water body scale through various models (Johansson & Nordvarg, 2001) — this is inappropriate for dealing with local benthic effects, and *a remote sensing approach at the ecosystem scale is of very limited use.*

For all types of extractive aquaculture, within the limits of ecological carrying capacity, environmental services provided by aquaculture can make a positive contribution to environmental targets under the WFD and MSFD. In identifying the 'environmental services' provided by aquaculture the broad definition of the Millennium Ecosystem Assessment (MEA 2005) is usually interpreted as goods (harvestable biomass) and environmental services (e.g. water purification, climate regulation, erosion control, habitat provision - Barbier *et al.* 2011).

In Natura 2000 areas, as well as WFD regulations on watershed-level nutrient and pollutant output, regulations of the Habitats Directive and the Birds Directive are relevant for farming operations and must be taken into account (EC, 2012).

Uneaten food, fecal and excretory losses to the environment can be estimated using data on feed quantities and quality, feed conversion ratio (FCR), digestibility and fecal composition (Beveridge, 1996). There is a close connection between the feed utilization (FCR) and load level. The estimated load of organic matter (BOD), nitrogen (TN) and phosphorous in salmonid cages is approximately halved assuming a FCR of 1.5 compared to at a FCR of 1.0. Thus, proper feeding control based on the fish stock's appetite is vital in order to minimize the load of feed derived components.

Most mass budgets in floating cages are based on on-growing of salmon and trout (Braaten, 2007). In a salmon cage, supplied compound, feed more than 50% of the supplied nutrients, nitrogen and phosphorus, will affect the environment (Figure 1). The main part of feed nitrogen (protein) not incorporated in the fish biomass, will enter the water column as dissolved ammonium/ammonia (TAN) excreted from the fish, while the dominating part of excess phosphorus is solid based originating from fecal solids and feed loss.

Dissolved nitrogen from cages will be diluted in the surrounding water column while the smaller part incorporated in solids tends to settle beneath and around the cages. As the major fraction of unutilized phosphorus is solid based, as much as half of the totally supplied quantity may end up in the sediments.

According to Figure 1, some 25-35% of oxygen consuming organic matter in feed is waste and may potentially accumulate as sediments on the sea or lake bed at the farm site. The degree of settling below the cages will depend on site conditions, such as current velocity, depth and topography (Beveridge, 1996). In general, sediment accumulation from fish cages is more of a problem in lakes compared to along the coast and in fjords due to reduced current velocity and depth.

The estimated waste volume per ton of produced salmon or trout assuming a feed conversion ratio of 1.15 (kg feed per kg produced fish) is (Figure 1):

41 kg N, 28 kg dissolved + 13 kg solid based
8 kg P, 1-2 kg dissolved + 6 kg solid based
480 kg as BOD (O_2), 120 kg dissolved – 360 kg solid based

To remove waste solids from cages requires installing of collecting devices beneath the cages, such as funnel shaped fine-meshed nets for collection and recycling of lost feed pellets (Beveridge, 1996). Screens for removal of solids in effluent water from fish ponds or tanks are commonly employed (e.g. Cripps & Bergheim, 2000). Usage of sedimentation ponds and/or wetlands for a more complete treatment of wastes from land based farms have demonstrated efficient retention of particles and soluble nutrients (Sindilariu, 2007).

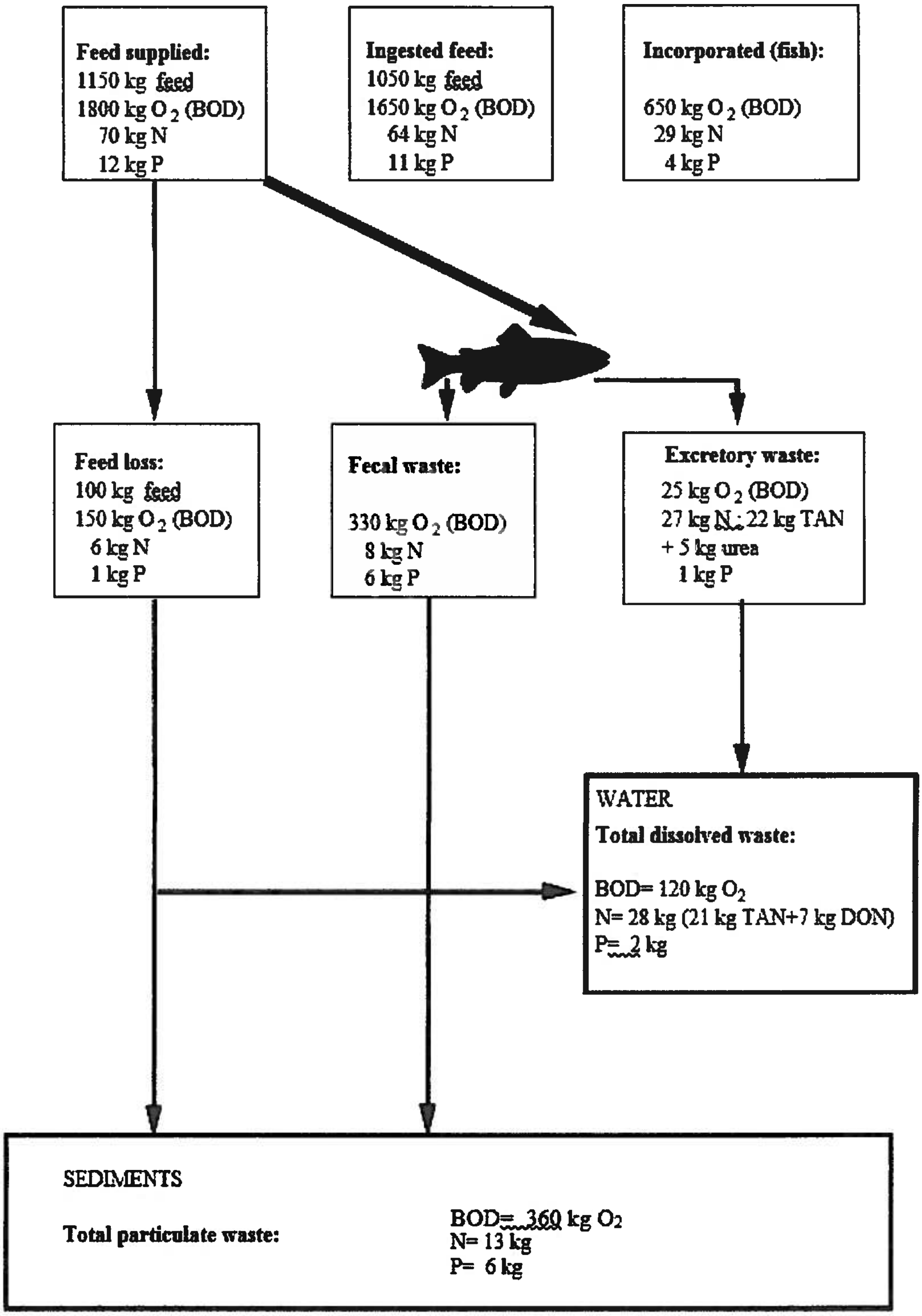

Figure 1. Mass balance of organics and nutrients in a salmonid cage farm supplied with high energy feed. Unit: kg per ton produced fish. Modified from Bergheim & Åsgård (1996).

Assumptions:

Feed conversion rate (FCR), 1.15 kg/kg, 9% feed loss. Feed composition: 34% fat, 38% protein, 12% carbohydrate, 12 g P/kg, energy: 24 MJ/kg

In order to manage fish ponds and cages in a sustainable and profitable way, and not least, maintain the welfare of the fish stock, it is vital to control the water quality. Dissolved oxygen (DO) is a key parameter in both cages and land based facilities, and frequent DO drops and/or long-lasting DO concentrations below suboptimal – critical levels will result in poor fish performance and increased waste load. The critical concentration at which sturgeons metabolically respond to DO is higher or similar to that of rainbow trout. For summertime temperatures (> 22-25 °C), this corresponds to 4.3-4.7 mg/L (Secor & Niklitschek, 2001). In a study with "great" sturgeon of 0.3 and 1.2 kg examining the effects of hypoxia (2-3 mg/L), normoxia (5-6 mg/L) and hyperoxia (9-10 mg/L) at 18 °C during 2 months, significantly lower appetite and growth rate was observed in the hypoxia group (Lakani *et al.* 2013).

In addition to DO, other selected water quality parameters should be included in a sampling program, e.g. monitoring of effluent nutrient concentrations (N, P) and of solid settling beneath cages (sediment traps). Suggested parameters and sampling frequency are presented in Ch. 4.

2 Present situation East Aegean River Basin District

Morphometric and hydrological characteristics, production of sturgeon and monitored physical-chemical parameters during two sampling periods (2011-12 & July-November 2015) of the Dam Kardzhali have been provided (Prof. Hubenova, personnel communication). In general, the water samples indicate enhanced concentrations of phosphorous in the water column (TP: 20 – 500 µg/L) and a high level of eutrophication characterized by strong DO deficit in deeper layers, high – moderate algae biomass at the surface, etc. Last year's sampling partly demonstrates effects from the two involved fish farms, e.g. increased concentrations of TP compared to at the station off the fish farms (station no. 4).

Based on the figures from 2011, the estimated total phosphorus load from the sturgeon farms was 36 tons. About 70% of the totally supplied 50 tons of feed-P per year was lost to the Dam (14 tons retained by the fish biomass). In terms of waste per ton of produced fish, the P-load corresponded to 18 kg. At least 50% of the lost TP ends up as a 'permanent' component of sediments according to the provided information.

The estimated quantity of lost TP, 18 kg/ton of produced sturgeon, is a high load level strongly influenced by the correspondingly high feed conversion rate (FCR) of 2.5. As formerly described, the lost TP is about 8 kg/ton produced fish at a FCR of 1.15 (Figure 1). It might be dubious to compare farming of sturgeon and salmonids because of quite different growth cycle and stages, feed composition, etc. Attempts to improve the feed utilization is nevertheless an obvious opportunity to reduce the phosphorus load from the sturgeon cages.

According to the Ministry of Environment and Waters (Prof. Hubenova, personnel communication), the allowed annual production of sturgeon in Dam Kardzhali is 2,750 tons. Apparently, the production limit is based on an upper acceptable concentration of 100 µg TP/L representing a serious risk of eutrophication of the Dam. However, the hydraulic retention time is influenced by the drainage for irrigation during the summer months and the enhanced flow rate probably contributes to reduced solid settling beneath the cages.

Attempts that combine reduced waste load, such as improved feed utilization due to improved feeding control, and mechanical removal of solids in the cages, could allow a higher production of sturgeon in the Dam within the constraints appointed by the environmental authorities.

3 Waste load reducing attempts

3.1 Feeding methods and monitoring

To develop safe and efficient cage management strategies it is of paramount importance to understand how the fish behave in response to the culture environment. Comprehensive studies in salmon cages (e.g. Føre, 2011) using underwater cameras have clarified the typical behaviour at feeding (swimming activity, vertical movement, etc.). Usage of underwater cameras in salmon cages has demonstrated significantly better feed conversion (reduced FCR) and lower fish mortality, and under summer conditions camera-operated cages also achieved higher growth rates (Ang & Petrell, 1997).

Underwater cameras are considered a most helpful device to assess the current appetite of the fish stock and to achieve improved feed utilization and minimize the feed loss. In intensively run on-growing systems, feed is normally the dominating cost factor. Such cameras may combine surveillance with monitoring of environmental conditions (temperature, DO, current velocity), Figure 2.

Usage of submerged perforated hoses, or diffusers, supplied air from blowers is an actual method for control of oxygen in fish cages (and ponds). The efficiency of diffuser based aeration is dependent on several factors, such as size of bubbles, injection depth, DO deficit in the water column, etc. Based on optimized, up-to-date diffuser technology, a so-called standard aeration efficiency (SAE) as high as 2.7 kg O_2 transferred from air to water per KWh of electricity consumed has been achieved (Gausen *et al.* 2015).

At a set point for injection at 4 - 5 mg DO/L, the aeration system will operate during periods with DO deficit such as in early morning and at feeding during high temperature periods. In cages exposed for low DO levels, better DO control will improve the performance and welfare of the fish stock. There is a close connection between available oxygen, feed appetite, utilization of ingested feed and fecal waste. Thus, better DO control may significantly contribute to reduced waste load.

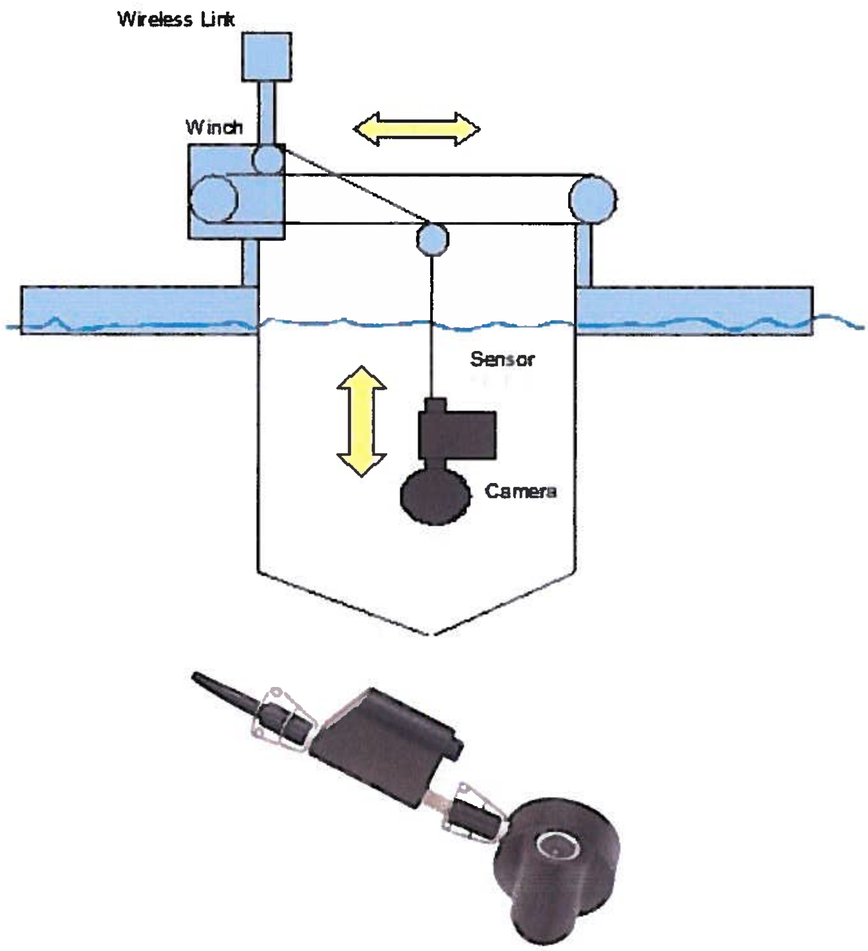

Figure 2. System for control of fish stock and environmental conditions in cages. Courtesy: Orbit AquaCam as, Norway. a) Sketch of a movable vertical – horizontal camera with sensor station, and b) Camera with Orbit-800 Sensor Station for monitoring of DO, temperature and salinity (Bergheim, 2012).

3.2 Mechanical removal of solids

There have been many attempts to collect solid wastes as they fall through the bottom of open cages towards the sediments (Beveridge, 1996), such as funnel shaped collectors completely enclosing the cage bottom where the sedimented wastes are periodically recovered by pumps. At low feed utilization/high FCR (> 2) such collectors may recover between 20 and 50% of the solids and phosphorus produced.

The expected removal of solids is higher in semi-closed cages (Figure 3) despite of little available data at present. In such designed cages with effluent screens the produced solids are continually removed from the water and pumped to the surface for further processing. According to initial tests, outlet screens applied a mesh size of 100 – 200 µm may remove 20 – 40% of the total solid load (particles > 0.45 µm).

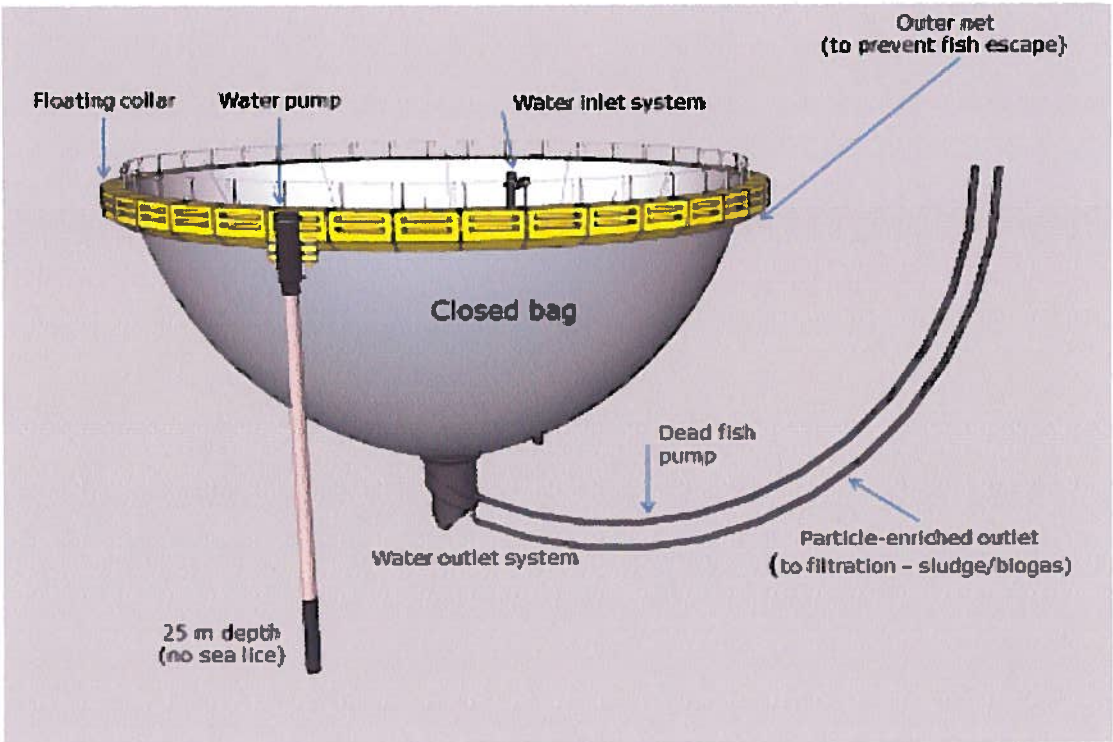

Figure 3. A semi-closed cage supplied deep water and solid removal of the outlet. System designed by Akva Design as, Brønnøysund, Norway (courtesy: Anders Næss).

3.3 Removal of dead fish from cages

The removal of dead fish from cages is a high priority. The dead fish known in the industry as "morts" that dies from bacterial disease like *furunculosis* my remain undetected in a cage for a number of days, decompose and continue to release bacteria and spread infection. Bacteria in one infected fish may therefore multiply at the rate of a hundred million every day!

Several different methods are used but none is entirely satisfactory. The system of "lifting" a net from the bottom of the cages is widely used (Figure 4.)

3.4 Anti-predatory measures (birds) and escapees

To fight predators that will feed on the fish the most used method is to use a "roof-net" on the cages (Figure 5.). This is a simple and effective way of keeping birds out of cages as well as minimizing the chances of fish to jump out of the cages. According to results from Bulgaria, birds are eating a great deal of fish every year (Marin Marinov, personal communication) and which, if not controlled, may have severe effects on the farm production. Also, escapees are a threat to the natural fish stocks as has been shown in numerous studies (e.g. Fleming *et al.* 2002).

Figure 4. A net ring with weight is at the bottom of the cage. Dead fish will sink to the bottom and can be pulled up and collected (photo: Thorleifur Agustsson).

Figure 5. An anti bird net on top of a small cage. When lager cages are used, a floating "pyramid" is used in the middle of the cage to hold the net up (photo: Thorleifur Agustsson).

3.5 Possible reduction of phosphorous load

The low feed utilization reported (FCR of 2.5) will lead to high loss of phosphorus as indicated in Ch. 2. Based on the provided Report (data of 2011, Prof. Hubenova, personnel communication), a combination of improved feed utilization and removal of fast settling particles (> 100 μm) may reduce the expected P load significantly as exemplified in the following:

Dam Kardzhali 2011:	
Estimated load (FCR: 2.5, feed: 10 g TP/kg)	22.2 g TP/kg produced fish
Total load (biomass produced: 2,000 tons/year)	44.4 tons TP/year
Simplified approach:	
Improved feed utilization, FCR reduced to 1.7	15.2 g TP/kg produced fish
Removal of 40% of particle-P (FCR: 1.7)	4.0
Load level at introduced attempts	11.2 g TP/kg produced fish

According to the brief calculation, applicable attempts reducing the P load to about 11 g/kg of produced fish may allow a doubled fish biomass production in Dam Kardzhali.

4 Carrying capacity

McKindsey *et al.* (2006) defined 4 types of *carrying capacity* in relation to aquaculture (Figure 6):
1) Physical Carrying Capacity, the total area of farms that can be accommodated in the available physical space;
2) Production Carrying Capacity, the farming density at which harvests are maximized;
3) Ecological Carrying Capacity, the farm density/size beyond which unacceptable ecological impacts at a range of spatial scales occur; and
4) Social and Regulatory Carrying Capacity, the level of farm development beyond which unacceptable social and regulatory impacts occur.

Carrying capacity for aquaculture has been defined as the maximum harvestable biomass produced within a given time period (Smaal *et al.* 1997, Bacher *et al.* 1998). This adapted the classical definition in ecology (Odum, 1969), in order to emphasize *production* carrying capacity, based largely on the physical conditions of the environment (assimilative capacity for finfish, food depletion for shellfish).

Determining ecological carrying capacity for aquaculture means answering the question ***"how much of what type(s) of aquaculture can be accommodated by the bounded system without its effects on some ecosystem component breaking an established threshold?"*** *The answer (or answers) will reflect the complex interrelationships among (i) physical environmental attributes, e.g. currents/water flows, wind, temperature); (ii) production attributes, e.g. diets, infrastructure; (iii) ecological conditions, e.g. eutrophication, Harmful Algal Blooms (HAB), critical habitats, biodiversity; and (iv) social constructs (e.g. regulations, thresholds).*

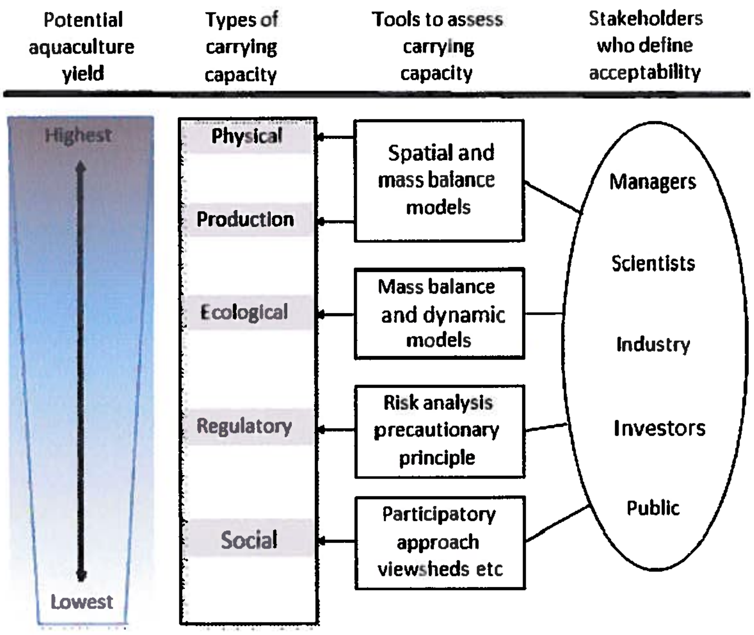

Figure 6. Carrying capacity (modified from McKindsey *et al.* 2006).
Physical + Production + Ecological = Environmental Carrying Capacity

Carrying capacity estimation is a societal requirement for maintaining good ecosystem health and diversity (IUCN, 2009). This is often managed through the application of thresholds, in ecological terms "the boundary that marks the difference between an acceptable and an unacceptable state or condition of the resource under consideration" (Macleod Institute, 2002), defined from an ecological and/or social point of view. Developing methods to estimate limits of environmental change that systems are able to absorb is essential for applying the Ecosystem Approach to Aquaculture. Tools[1] for estimation of carrying capacity are more developed in the marine sector and can be designed for low data requirements and ease of use (Borja *et al.* 2008).

Research models can account for circulation and boundary exchanges of water, dissolved, and particulate substances, together with internal processes (e.g. primary production, cycling of nutrients and organic matter) that interact with aquaculture at the system scale. Most of these models address aquaculture production, but a number extend also to ecological carrying capacity (McKindsey *et al.* 2006), e.g. system-scale models for mussel carrying capacity (Filgueira & Grant, 2009), ecosystem models for food depletion (Grant *et al.* 2008) and 3-D biogeochemical (Marinov *et al.* 2007), sediment biogeochemical (Brigolin *et al.* 2014) and ecological models (Nobre *et al.* 2010).

1 Tools = concepts, thresholds, models, systems, applications and processes which provide knowledge and/or a method that can be used to solve a problem.

5 Environmental monitoring

5.1 An introduction to the MOM Program

MOM stands for Fish farm Surveillance Modelling (in Norwegian: **M**atfiskanlegg - **O**vervåking - **M**odellering), and is a type of monitoring designed to have a standard for environmental monitoring of areas around fish farms in Norwegian fjords

From 1 January 2005, an accredited or approved company must carry out all **MOM-B** and **MOM C** surveys.

By monitoring the environment around the farms, we can assure that neither the surrounding areas nor the farmed fish cage-environment deteriorates. This is essential to exploit areas and localities optimally. MOM investigations supply important information used in connection with locating and monitoring of farms and recipient in connection with possible discharge from the farm.

By taking repeated MOM investigations at a site, it is possible to draw conclusions about the evolution of environmental conditions on the seabed under the locality.

MOM investigations are divided into two different classes: B and C.

MOM-B is the most widely used standard for environmental studies of marine fish farms and carried out by specialized personnel. It retrieves ten sediment samples from the seabed scattered throughout the territory. Samples are analyzed chemically (pH, Eh), biological and sensory (smell, color and consistency). The biological part consists of a preliminary sorting of the animals in different groups (crustaceans, polychaetes, echinoderms, snails and shells).

MOM-C investigations are primarily ordered by the county governor (monitoring) or in conjunction with research. In some cases also fish farmers initiated MOM C survey. This is a thorough examination of the diversity of species in an area. The sediment samples are collected with a **larger** grab sampler than for MOM B survey. The samples are thoroughly washed and checked before sending content to an accredited research institute for sorting and counting of animals in tests. Species composition and number are statistically rated to arrive at a state of the environment of the area.

Even though MOM is developed for seawater, fjord systems – it can be used as basis for surveillance in fresh water. Some criteria should consequently be changed and more appropriate for the Bulgarian situation used instead.

5.2 Monitoring intensity versus objective

Important inspections and monitoring can be of various types. These are either technical aspects of the farm and the equipment used (cages, feeding systems etc.) or aspects related to the production itself:

- General environmental effects
- Waste management
- Water pollution and water treatment

- General conduct and health control
- Control of safety for human consumption

The frequency of monitoring and visits should be kept at a possible minimum. This means that a fish farmer must have the responsibility of having a full control over the facility and the production.

Category	Visits pr. year	Monitoring
1	2	Every Third year
2	1	Every Fifth year
3	1	Every Tenth year
4	Every Second year	Never

Table 1. Fish farms should be categorized based on the needs for monitoring. Categories are based on outcome from environmental studies and information about the producer. A company can be moved from one category to the next based on outcome from previous monitoring/visit.

6 Recommended attempts

A. Efficient measures in order to reduce the present waste load from the farms should be initiated:
- Improve the feed utilization by better feeding control, e.g. introducing automatic feeders and submarine cameras
- Emphasize control of the oxygen concentration in cages and ponds
- Assess mechanical methods to remove solid waste

B. To initiate a monitoring program at the actual farms and recipients in order to evaluate the environmental conditions and the expected effects of the load reducing attempts

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